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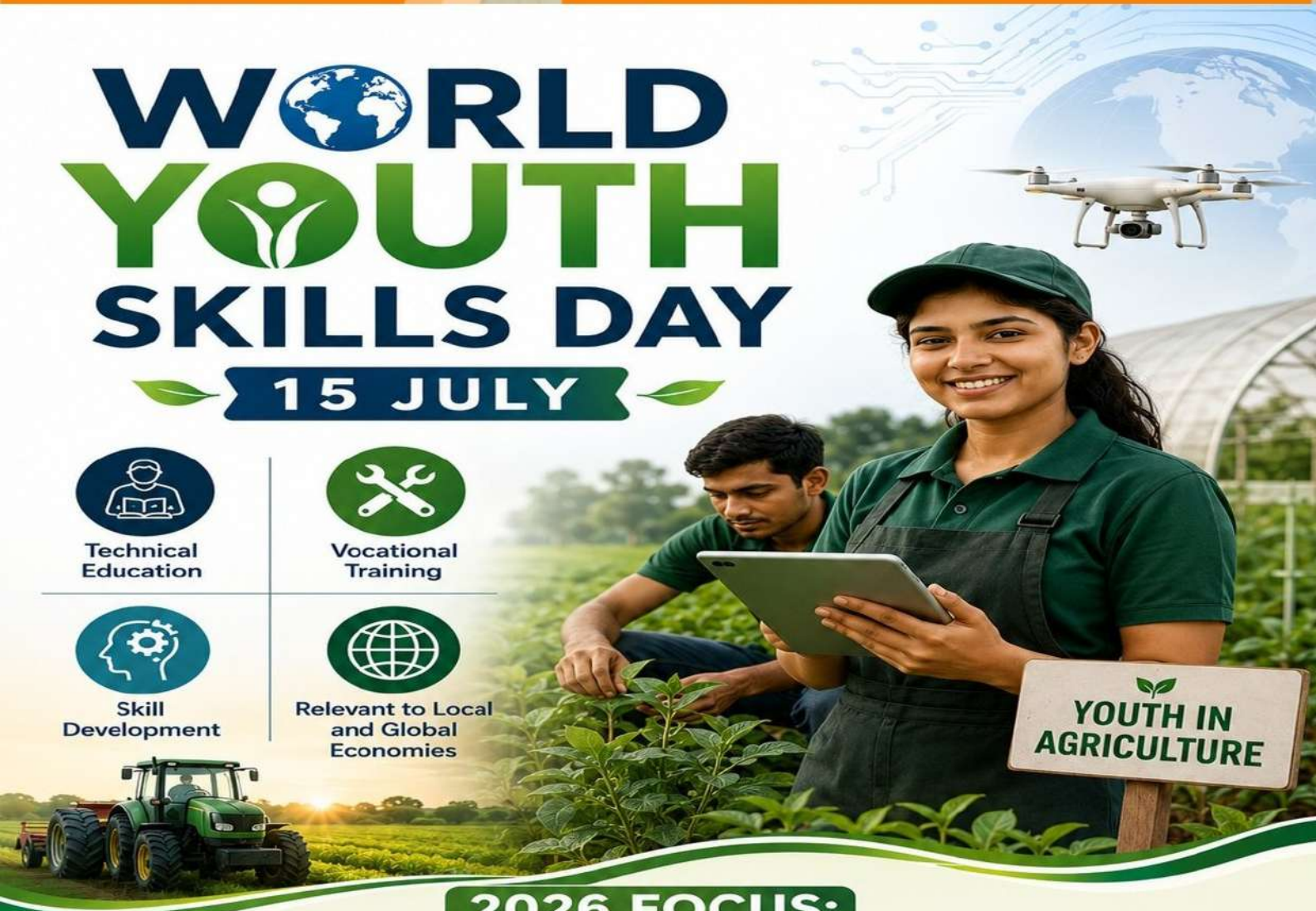
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An International Multidisciplinary Monthly e-Magazine

WORLD YOUTH SKILLS DAY

15 JULY



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"SKILLS FOR A SHARED FUTURE"

which emphasizes

- AI AND DIGITAL ADAPTATION
- GREEN TRANSITIONS
- SOCIAL-EMOTIONAL COMPETENCIES
- SKILLS FOR A SHARED FUTURE

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From the Desk of Editor-in-chief



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I would like to introduce the launch of **"AgriGate - An International Multidisciplinary Monthly e-Magazine Volume 06 Issue No. 07 – July 2026"** with immense pleasure our team is privileged to dedicate this issue to the Agricultural Youths. Every year **World Youth Skills Day** is celebrated on 15 July to raise awareness about the importance of technical, vocational education & training and the development of other skills relevant to both local and global economies. **World Nature Conservation Day** is observed on 28 July every year to recognise that a healthy environment is a foundation for a stable and productive society and for future generations. We must protect, conserve and sustainably manage our natural resources.

The main objective of the magazine is to provide a publishing platform to young researchers and scientists as well as an information hub for the enthusiast, progressive farmer and also common readers. We envisage providing an online platform that appreciates illuminating articles on various topics related to agriculture and allied sciences monthly that will appraise and update the students, farming community and the whole society at large on the updates in agriculture.

Last but not the least, I wholeheartedly thank the editorial team, authors as well as anonymous reviewers for contributing to the release of this issue.

Our team welcomes your constructive feedback and suggestions to improve delivering fruitful content to hungry minds.



Dr R Shiv Ramakrishnan
Editor-in-chief
AgriGate Magazine

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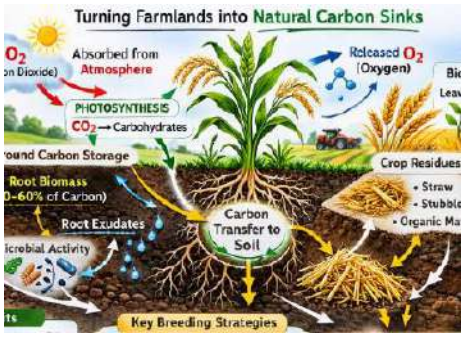
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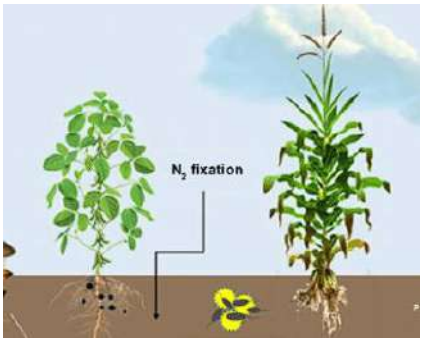
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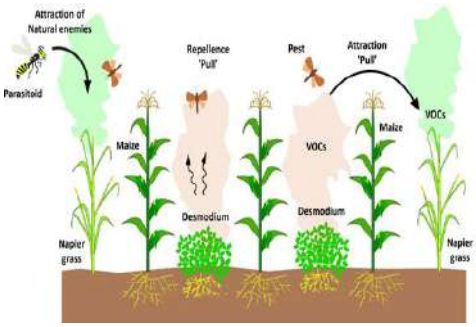
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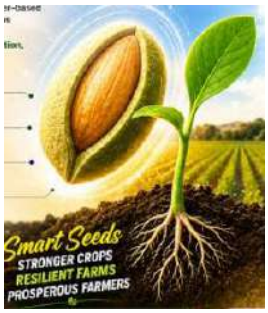
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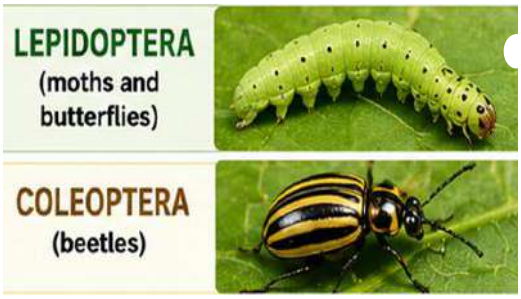
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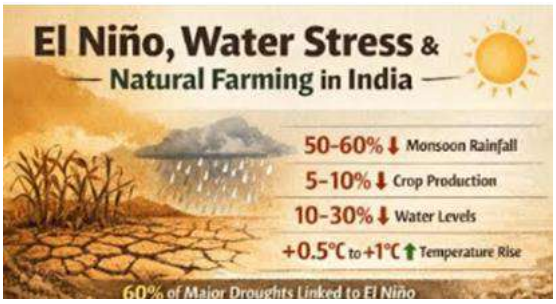
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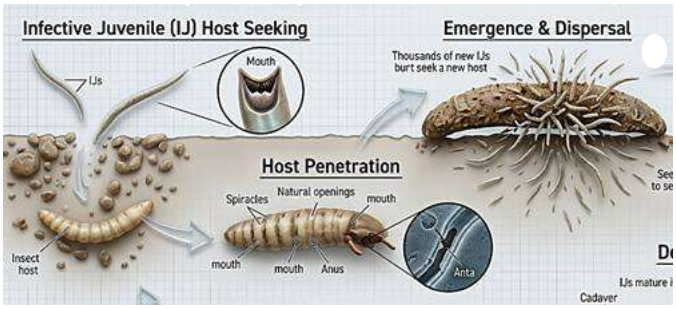
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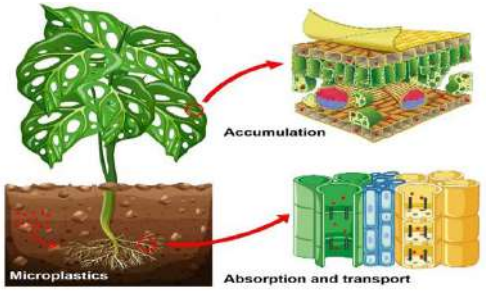
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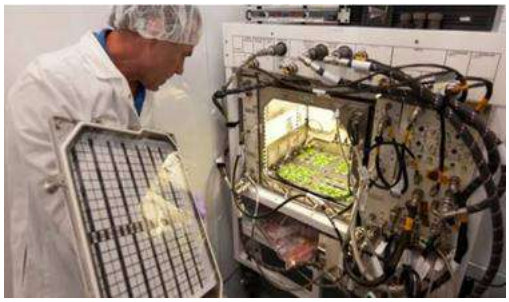
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PPV&FR REGISTRATION AND DUS GUIDELINES FOR BANANA IN INDIA

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Abstract

Banana (*Musa* spp.) is one of the most important fruit crops in India, contributing significantly to food security, nutritional security, livelihood generation, and export earnings. The development of improved banana cultivars through conventional and biotechnological approaches demands a robust regulatory framework that promotes innovation, ensures varietal protection, and upholds farmers' rights. The Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, 2001 provides a *sui generis* system for registration and protection of plant varieties as they could not be patented in India. Distinctness, Uniformity and Stability (DUS) testing forms the scientific basis for registration under the Act. In banana, DUS characterization is conducted using 41 morphological descriptors covering pseudostem, leaf, inflorescence, male bud, and fruit characteristics. This article discusses the importance of PPV&FR registration, DUS characterization, DUS test centres, and their relevance to banana improvement and germplasm conservation in India.

Introduction

Banana (*Musa* spp.) is one of the most important fruit crops cultivated in tropical and subtropical regions of the world. India is the largest producer of banana globally, contributing nearly one-fourth of the world's production. The crop serves as a staple food, dessert fruit, source of income for millions of farmers, and an important raw material for processing industries. In India, banana is cultivated on approximately 0.97 million hectares with an annual production exceeding 35 million tonnes and an average productivity of 36–38 t ha^{-1}, making it one of the

most productive fruit crops in the country. Major banana-growing states include Tamil Nadu, Maharashtra, Gujarat, Andhra Pradesh, Karnataka, Bihar and Madhya Pradesh.

The rich genetic diversity of banana and the growing demand for high-yielding, climate-resilient and disease-tolerant cultivars have led to the development and release of several improved varieties through ICAR institutes, State Agricultural Universities and other research organizations. Notable examples include BRS-1, BRS-2, Udhayam, Kaveri Kalki, Kaveri Saba, Kaveri Haritha, Kaveri Kanya, Kaveri Sugantham, Kaveri Kanchan, Kaveri Vaaman, Kaveri Poovan, CO-1, CO-2 and CO-3. The development of such varieties requires considerable investment of time, expertise and resources, often involving long-term evaluation and selection due to the perennial and clonally propagated nature of the crop.

To encourage innovation in plant breeding and safeguard the interests of breeders and farmers, India enacted the Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, 2001. The Act provides legal protection of newly developed varieties, recognizes and rewards farmers for conserving valuable genetic resources, facilitates benefit sharing and promotes the commercialization of superior cultivars. A key requirement for variety registration under the Act is the assessment of Distinctness, Uniformity and Stability (DUS). DUS characterization provides a standardized framework for identifying, describing and distinguishing varieties, thereby ensuring the authenticity, uniqueness and genetic purity of candidate varieties. In banana, DUS testing plays a crucial role in variety registration, protection of breeders' rights and documentation of the rich *Musa* diversity available in the country.

PPV&FR Act, 2001: Overview

The Protection of Plant Varieties and Farmers' Rights Act, 2001 was enacted to establish an effective system for protection of plant varieties while safeguarding farmers' rights. India enacted the Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, 2001 to comply with the WTO (World Trade Organization)-TRIPS (Trade-Related Aspects of Intellectual Property Rights) Agreement while safeguarding the interests of farming community. The Act provides a unique framework that recognizes and protects the rights of breeders, farmers and researchers, while encouraging innovation in plant breeding and ensuring the availability of quality seed and planting materials. Unlike the UPOV (International Union for the Protection of New Varieties of Plants) system, the PPV&FR Act permits farmers to save, use, sow, re-sow, exchange and share seeds of protected varieties, except the sale of branded seed. The Protection

of Plant Varieties and Farmers' Rights Authority, established in 2005, administers the Act and facilitates the registration of New Varieties, Extant Varieties, Farmers' Varieties, Varieties of Common Knowledge and Essentially Derived Varieties based on DUS testing. To support variety registration, crop-specific DUS guidelines have been developed for more than 200 crop species, and over 160 DUS testing centres are currently operating across the country. As of now, about 205 crop species had been notified for registration under the Act, the authority had received nearly 19,900 applications and granted registration certificates to more than 9,200 plant varieties, highlighting the growing role of plant variety protection in Indian agriculture.

The Seed Act, 1966 and the Protection of PPV&FR Act, 2001 are both important components of the agricultural system and they serve different purposes. The Seed Act focuses on ensuring the quality, purity, and performance of seeds and planting materials supplied to farmers, whereas the PPV&FR Act provides legal protection of newly developed plant varieties and recognizes the rights of breeders and farmers. The Seed Act ensures that farmers receive quality planting material, while the PPV&FR Act ensures that innovations in plant breeding are rewarded and protected. Together, these Acts promote agricultural development by encouraging the development and dissemination of superior crop varieties.

Categories of varieties eligible for registration

1. New Variety

Must satisfy:

- Distinctiveness
- Uniformity
- Stability (DUS criteria)

2. Extant variety

Includes:

- Notified varieties
- Farmers' varieties
- Varieties of common knowledge

3. Farmers' variety

Traditional varieties developed and conserved by farmers.

4. Essentially Derived Variety (EDV)

Predominantly derived from an initial protected variety while retaining essential characteristics.

Distinctness, Uniformity and Stability (DUS) Testing

Distinctness : A variety must be clearly distinguishable from all known varieties by one or more characteristics.

Uniformity: Plants within a variety must be sufficiently similar in relevant characteristics.

Stability : The variety should remain unchanged after repeated propagation cycles.

DUS testing procedure for banana

Test material

- Healthy suckers or tissue culture plants.
- Free from pests and diseases.

Test duration

- One plant crop and one ratoon crop or
- Two independent growing seasons.

Experimental design

- Three replications.
- Ten plants per replication.
- Total 30 plants.
- Reference variety planted alongside candidate variety.

DUS descriptors for banana (41 Characters)

The PPV&FR Authority has prescribed 41 characters (11-vegetative and 30-reproductive) for banana characterization. Among the 41 characters, 25 are qualitative. Eight are quantitative and the remaining eight are pseudo-qualitative in nature. Only four characters are observed before shooting and rest 27 are observed only at the time of shooting and thereafter.

Sl. No.	Quantitative characteristics
1	1. (*) QN Pseudostem length (m)
2	7. (+) QN Petiole length (cm)
3	9. QN Peduncle length (cm)
4	27. (*) QN Fruit length (cm)
5	33. (*) QN Pedicel surface
6	34. (*) QN Pedicel length (cm)
7	40. (*) QN No. of hands per bunch
8	41. (*) QN No. of fingers per hand

Sl. No.	Pseudo qualitative characteristics
1	**4. PQ Colour of the under surface of cigar leaf**
2	**8. (*) (+) PQ Leaf blade - shape of base**
3	**12. (*) (+) PQ Bunch Shape**
4	**14. PQ Bunch - Compactness**
5	**20. (*) (+) PQ Male bud shape**
6	**25. (*) PQ Persistence of male bracts**
7	**28. (*) (+) PQ Fruit shape**
8	**29. (*) (+) PQ Transverse section of fruit**

Sl. No	Qualitative Characteristics
1	2. QL Pseudostem colour
2	3. (+) QL Purple blotches on younger leaves
3	5. (+) QL Leaf orientation
4	6. (+) QL Petiole canal
5	10. QL Peduncle colour
6	11. (*) QL Peduncle pubescence
7	13. (*) (+) QL Bunch position
8	15. (+) QL Rachis - orientation of male phase
9	16. (*) QL Rachis appearance
10	17. (*) (+) QL Rachis - Prominence of bract scars
11	18. (*) (+) QL Male bud
12	19. (*) QL Male bud colour
13	21. (*) QL Male flower colour
14	22. QL Stigma colour
15	23. (+) QL Style shape
16	24. (*) (+) QL Bract behavior - Curling
17	26. (*) QL Fruit orientation

18	30. (*) (+) QL Fruit apex
19	31. (+) QL Persistence of floral organs
20	32. QL Fruit pedicel attachment at ripeness
21	35. QL Peel colour before ripening
22	36. QL Adherence of peel
23	37. QL Waxiness of the fruit
24	38. (*) QL Peel colour at full ripeness
25	39. (*) QL Fruit pulp colour at ripeness

Grouping characteristics in Banana DUS testing

Certain descriptors are used as grouping traits to facilitate comparison among varieties:

- Plant height
- Bunch position
- Male bud shape
- Bract colour
- Fruit curvature
- Fruit apex shape
- Peel colour
- Pulp colour

These characteristics enable efficient identification of similar varieties during DUS examination.

DUS test centres for banana in India

The PPV&FR Authority has designated the ICAR-NRCB, Trichy for conducting DUS testing in banana where the crop will be tested for two seasons.

Significance of DUS characterization in Banana

DUS characterization supports:

- Identification of unique varieties.
- Protection of breeder innovations.
- Registration of farmers' varieties.
- Germplasm documentation.
- Prevention of varietal duplication.
- Facilitation of variety release and commercialization.

- Maintenance of genetic purity.

Challenges in banana DUS testing

1. Long crop duration.
2. Environmental influence on trait expression.
3. Limited flowering in some cultivars.
4. Somaclonal variation in tissue culture-derived plants.
5. Large diversity within *Musa* germplasm.

Integration of molecular markers with morphological descriptors is increasingly being explored to improve varietal identification.

Registration fees

Type of variety	**Fees for Registration**
Essentially Derived Varieties	Individual Rs. 7000/- Educational Rs. 10000/- Commercial Rs. 50000/-
Extant variety notified under section 5 of Seeds Act, 1966	Rs. 2000/-
New Variety	Individual Rs. 7000/-Educational Rs. 10000/- Commercial Rs. 50000/-
Extant variety about which there is common knowledge	Individual Rs. 7000/- Educational Rs. 10000/- Commercial Rs. 50000/-
Farmers' Variety	No fee

DUS testing fees for Banana – Rs.20,000/-

Schematic diagram showing the process of Registration

Submission of application



Preliminary scrutiny of application by PPV&FRA



Submission of planting material to the DUS testing centre



DUS testing by ICAR-NRCB



Submission or report by ICAR-NRCB



Publication in Plant Variety Journal



Cooling period given by PPV&FRA for opposition if any



Registration and issuance of certificate.

The candidate variety undergoes DUS testing against reference varieties. Reference varieties are well characterized, officially recognized varieties used as standards for comparison during DUS testing. If the candidate demonstrates clear distinctness, sufficient uniformity, and stability across locations and seasons, it becomes eligible for registration.

Conclusion

The PPV&FR Act, 2001 has established a robust legal framework for protecting plant varieties while safeguarding farmers' rights. For banana, DUS characterization serves as the cornerstone of variety registration and intellectual property protection. The use of standardized descriptors and multilocation testing ensures reliable identification of distinct, uniform, and stable varieties. As banana breeding increasingly incorporates genomic tools, marker-assisted selection, and biotechnology, the PPV&FR system will continue to play a crucial role in encouraging innovation, protecting breeders and farmers, and conserving India's rich banana genetic resources.

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CLIMATE-SMART AGRONOMIC PRACTICES FOR ENHANCING WATER-USE EFFICIENCY

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Introduction

Agriculture is highly dependent on water availability, making it one of the most vulnerable sectors to climate change. Increasing temperatures, erratic rainfall patterns, prolonged droughts, declining groundwater resources, and rising competition for freshwater are posing serious challenges to agricultural production worldwide. According to the Food and Agriculture Organisation (FAO), agriculture accounts for nearly 70% of global freshwater withdrawals, emphasising the urgent need for efficient water management strategies (FAO, 2013).

Climate-Smart Agriculture (CSA) has emerged as an integrated approach to address the challenges of food security, climate change, and resource degradation. CSA aims to achieve three interconnected objectives: sustainably increasing agricultural productivity, enhancing resilience and adaptation to climate change, and, wherever possible, reducing greenhouse gas emissions. Within this framework, climate-smart agronomic practices are increasingly recognised as essential tools for improving water-use efficiency (WUE) and ensuring sustainable crop production under water-limited conditions.

Water-use efficiency refers to the amount of biomass or economic yield produced per unit of water utilised by the crop. Improving WUE is critical for maintaining agricultural productivity while reducing pressure on limited water resources. Climate-smart agronomic practices not only improve water conservation but also enhance soil health, nutrient-use efficiency, crop resilience, and environmental sustainability. The integration of these practices

with improved drought-tolerant crop varieties provides a promising pathway toward climate-resilient agriculture.

Conservation Agriculture

Conservation agriculture is a cornerstone of climate-smart agriculture and has gained global recognition as an effective strategy for improving water productivity. It is based on three fundamental principles: minimum soil disturbance, permanent soil cover, and crop diversification.

Minimum or zero tillage reduces soil disruption and preserves soil structure, allowing greater water infiltration and reducing runoff. Permanent soil cover through crop residues or cover crops protects the soil surface from direct solar radiation, thereby reducing evaporation losses and maintaining soil moisture. Crop diversification through rotations or intercropping enhances soil fertility and improves overall system resilience.

Several studies have shown that conservation agriculture improves soil water storage, reduces erosion, increases soil organic matter, and enhances drought resilience. In semi-arid regions, conservation agriculture has been reported to improve water-use efficiency by 15–30% compared to conventional farming systems (FAO, 2017). The long-term benefits include improved soil quality, enhanced carbon sequestration, and greater sustainability of agricultural production systems.

Soil Health Management for Water Conservation

Soil health is a critical determinant of water-use efficiency and drought resilience. Healthy soils possess better structure, increased porosity, higher infiltration rates, and greater water-holding capacity. Climate-smart soil management practices focus on improving soil organic matter through the application of farmyard manure, compost, green manures, crop residues, cover crops, and biochar.

Organic matter acts like a sponge, increasing the soil's capacity to retain water and making it available to plants during periods of moisture stress. Enhanced soil biological activity further improves nutrient cycling and root development. In addition, soils rich in organic carbon are more resistant to erosion and compaction, thereby maintaining favorable conditions for water movement and storage.

Regenerative agriculture practices that focus on soil restoration are increasingly being promoted as climate-smart solutions for improving water productivity and ecosystem

sustainability. Improving soil organic carbon not only enhances crop performance but also contributes to climate change mitigation through carbon sequestration (Lal, 2020).

Precision Nutrient Management

Efficient nutrient management is essential for maximizing crop productivity under limited water availability. Nutrient deficiencies often reduce plant growth, root development, and physiological efficiency, thereby lowering water-use efficiency. Climate-smart nutrient management involves balanced fertilization, site-specific nutrient management, and integrated nutrient management strategies.

Nitrogen is crucial for photosynthesis, chlorophyll formation, and biomass accumulation. Phosphorus promotes root growth and improves the ability of plants to extract water from deeper soil layers. Potassium regulates stomatal movement, osmotic adjustment, and cellular water balance, making it particularly important under drought conditions. Micronutrients such as zinc and boron also play important roles in stress tolerance and plant metabolism.

Precision nutrient management technologies use soil testing, crop sensors, remote sensing, and decision-support systems to optimize fertilizer application. Such approaches improve nutrient-use efficiency, reduce nutrient losses, lower production costs, and enhance water productivity (Bindraban et al., 2020).

Efficient Irrigation Management

Efficient irrigation management is one of the most effective approaches for conserving water in agriculture. Traditional surface irrigation methods often result in substantial water losses through evaporation, runoff, and deep percolation. Climate-smart irrigation strategies focus on maximizing water productivity while minimizing wastage.

Deficit Irrigation

Deficit irrigation involves applying less water than the full crop water requirement during less sensitive growth stages. This strategy encourages efficient water use and can substantially reduce irrigation demand without causing major yield reductions. Deficit irrigation has been widely adopted in water-scarce regions and has demonstrated significant improvements in water productivity (Fereres and Soriano, 2007).

Drip and Micro-Irrigation Systems

Drip irrigation delivers water directly to the root zone, minimizing evaporation and runoff losses. Compared to conventional irrigation methods, drip irrigation can improve

irrigation efficiency by up to 95%. Micro-irrigation systems also facilitate fertigation, enabling simultaneous application of water and nutrients.

Sensor-Based Irrigation Scheduling

Modern technologies such as soil moisture sensors, automated irrigation systems, and weather-based irrigation scheduling tools allow precise water application according to crop needs. These technologies improve irrigation efficiency and contribute significantly to climate-resilient water management.

Mulching and Crop Residue Management

Mulching is an effective agronomic practice for conserving soil moisture and improving water-use efficiency. Organic mulches such as crop residues, straw, compost, and green biomass create a protective layer over the soil surface, reducing evaporation losses and moderating soil temperature fluctuations.

Residue retention also improves soil organic matter content, suppresses weed growth, enhances microbial activity, and reduces erosion. In rainfed agricultural systems, mulching can significantly increase soil moisture availability and improve crop performance during dry periods. Studies have shown that mulching can reduce soil water losses by 25–50% depending on climatic conditions and mulch type (Kader et al., 2017).

Crop Diversification and Intercropping

Diversified cropping systems improve resource-use efficiency and reduce the risks associated with climate variability. Crop diversification involves the inclusion of multiple crops within a farming system through crop rotations, mixed cropping, relay cropping, or intercropping.

Intercropping systems, particularly those involving legumes, improve soil fertility through biological nitrogen fixation and promote more efficient utilization of water and nutrients. Deep-rooted and shallow-rooted crops grown together can exploit different soil moisture zones, resulting in greater overall water-use efficiency.

Crop diversification also reduces pest and disease incidence, enhances biodiversity, and improves farm resilience to drought and market fluctuations. Such systems are increasingly recognized as important components of climate-smart agriculture (Lithourgidis et al., 2011).

Climate-Resilient Crop Establishment Techniques

Proper crop establishment plays a crucial role in maximizing water-use efficiency.

Climate-smart establishment methods ensure efficient utilization of available soil moisture and promote healthy crop growth.

Laser Land Leveling

Laser land leveling improves the uniformity of water distribution across fields, reducing irrigation losses and enhancing water productivity.

Raised-Bed Planting

Raised beds improve drainage, root aeration, and irrigation efficiency. They facilitate precise water application and reduce waterlogging risks.

Ridge-and-Furrow Systems

These systems improve rainwater harvesting, increase infiltration, and enhance moisture conservation in drought-prone environments.

Optimum Sowing Time

Timely sowing allows crops to synchronize critical growth stages with favorable environmental conditions, thereby reducing exposure to drought stress and improving water-use efficiency (Jat et al., 2011).

Digital Agriculture and Smart Water Management

Recent technological advancements are revolutionizing agricultural water management. Digital agriculture integrates sensors, remote sensing, satellite imagery, drones, artificial intelligence (AI), machine learning, and Internet of Things (IoT) technologies to support informed decision-making.

These tools enable real-time monitoring of soil moisture, crop growth, evapotranspiration, and weather conditions. Precision agriculture technologies facilitate variable-rate irrigation, optimized fertilizer application, and early detection of water stress.

Artificial intelligence algorithms can analyze large datasets to predict irrigation requirements and recommend management interventions. Such technologies are increasingly important for improving resource-use efficiency and adapting agriculture to climate change (Wolfert et al., 2017).

Role of Beneficial Microorganisms in Water-Use Efficiency

Beneficial soil microorganisms contribute significantly to drought tolerance and efficient water utilization. Plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF), endophytic microbes enhance root development, nutrient uptake, and stress tolerance.

Mycorrhizal fungi extend the root absorption area through fungal hyphae, enabling plants to access water from a larger soil volume. PGPR improve hormonal balance, stimulate root growth, and enhance osmotic adjustment under drought conditions.

The integration of microbial inoculants with climate-smart agronomic practices offers a sustainable and environmentally friendly strategy for improving crop resilience under water-limited conditions (Vurukonda et al., 2016).

Water Footprint and Sustainable Water Management

The concept of water footprint has gained increasing importance in evaluating agricultural sustainability. Water footprint refers to the total volume of freshwater used to produce a commodity throughout its production cycle. Agriculture accounts for the largest share of global water footprints, highlighting the need for water-efficient production systems.

Climate-smart agronomic practices can significantly reduce the water footprint of crops by improving irrigation efficiency, reducing evaporation losses, enhancing soil moisture conservation, and increasing productivity per unit of water consumed. Water-efficient agriculture is therefore essential for sustainable management of freshwater resources under growing climatic and demographic pressures (Hoekstra et al., 2011).

Integration of Climate-Smart Practices with Water-Efficient Crop Varieties

While agronomic interventions improve water productivity, their effectiveness can be further enhanced when combined with water-efficient crop varieties. Modern breeding programs are developing crop genotypes with deep root systems, improved transpiration efficiency, stay-green characteristics, enhanced osmotic adjustment, and superior drought tolerance.

The integration of such varieties with conservation agriculture, precision nutrient management, efficient irrigation systems, and digital agriculture creates synergistic effects that maximize water-use efficiency and yield stability. This integrated approach forms the foundation of climate-resilient agricultural systems capable of sustaining productivity under increasing water scarcity.

Conclusion

Climate change, increasing water scarcity, and growing food demand pose major challenges to global agricultural sustainability. Climate-smart agronomic practices provide effective solutions for improving water-use efficiency, conserving natural resources, and enhancing resilience to drought and climatic variability. Practices such as conservation

agriculture, soil health management, precision nutrient management, efficient irrigation, mulching, crop diversification, digital agriculture, and beneficial microbial interventions contribute significantly to improved water productivity and sustainable crop production.

Future agricultural development must focus on integrating climate-smart agronomic practices with advanced breeding technologies, precision agriculture tools, and supportive policy frameworks. Such a multidisciplinary approach will enable the development of resilient farming systems capable of producing more food with less water while safeguarding environmental sustainability and ensuring global food security.

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CLIMATE-RESILIENT INTEGRATED WEED MANAGEMENT IN VEGETABLE CROPS: PRINCIPLES, EMERGING CHALLENGES AND SUSTAINABLE ADAPTATION STRATEGIES

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Abstract

Weeds are one of the major biological constraints limiting vegetable production worldwide, causing significant yield losses due to intense competition for water, nutrients, light, and space. Vegetable crops are particularly vulnerable to weed interference because of their slow initial growth, wider spacing, shallow root systems, and lower competitive ability. In addition, weeds act as reservoirs for insect pests, nematodes, and disease-causing pathogens, further aggravating crop losses. The changing climate, characterized by rising temperatures, elevated atmospheric carbon dioxide levels, erratic rainfall patterns, and frequent extreme weather events, is altering weed ecology, increasing the prevalence of invasive species, and reducing the effectiveness of conventional weed management practices.

Integrated Weed Management (IWM) offers a sustainable and climate-resilient approach by combining preventive, cultural, mechanical, biological, and judicious chemical control methods to maintain weed populations below economically damaging levels while minimizing environmental impacts. Practices such as crop rotation, stale seedbed preparation, cover cropping, intercropping, mulching, soil solarization, and precision herbicide application improve weed suppression and enhance crop competitiveness. Emerging technologies including artificial intelligence-based weed detection, drone-assisted herbicide spraying, and robotic weeders provide new opportunities for site-specific and environmentally sustainable weed control. Therefore, the adoption of climate-smart integrated weed management strategies is essential for improving vegetable productivity, conserving natural resources, reducing chemical

dependency, and ensuring the long-term sustainability of vegetable production systems under changing climatic conditions

Keywords: Climate resilience, weeds, integrated weed management, sustainable vegetable production.

Introduction

Weeds are unwanted plants that grow along with cultivated crops and interfere with their growth, development, and productivity. In vegetable production systems, weeds are considered one of the major biological constraints due to their vigorous competition for essential resources such as nutrients, moisture, sunlight, and growing space. Vegetable crops are generally poor competitors during the initial stages of growth because of their slow seedling establishment, wider plant spacing, shallow root systems, and delayed canopy development. Consequently, uncontrolled weed infestation can lead to severe reductions in yield, quality, and marketability of vegetable produce. The magnitude of yield losses caused by weeds in vegetable crops may range from 30 to more than 90 per cent depending upon crop species, weed intensity, duration of weed-crop competition, management practices, and environmental conditions. In addition to direct competition, weeds act as alternate hosts for several insect pests, nematodes, viruses, and other plant pathogens, thereby increasing the incidence of pest and disease problems in vegetable ecosystems.

Climate change has further intensified the challenge of weed management by altering weed distribution patterns, germination behaviour, growth dynamics, and competitive ability of many invasive and difficult-to-control species. Rising temperatures, changing rainfall patterns, and increased atmospheric carbon dioxide levels may favour the proliferation of certain weed species, making conventional management practices less effective. Effective weed management is therefore essential for achieving sustainable vegetable production, ensuring higher productivity, and maintaining crop quality. Vegetable fields usually contain a complex weed flora comprising broad-leaved weeds, grasses, and sedges. Since no single control measure can provide effective and long-term suppression of all weed species, the adoption of Integrated Weed Management (IWM) is widely recommended. IWM integrates preventive, cultural, mechanical, biological, and chemical approaches to maintain weed populations below economic threshold levels while minimizing environmental hazards and reducing excessive dependence on herbicides (Rana and Rana, 2019).

Climate Change and Weed Dynamics in Vegetable Cropping Systems

Climate change is increasingly influencing the distribution, abundance, and competitiveness of weed species in agricultural ecosystems. Rising atmospheric carbon dioxide (CO_2) concentrations, increasing temperatures, altered precipitation patterns, and the greater frequency of extreme weather events are significantly modifying weed biology and crop–weed interactions. Vegetable crops, owing to their relatively short growth duration, shallow root systems, and intensive cultivation practices, are particularly vulnerable to these changes. Elevated atmospheric CO_2 generally stimulates photosynthesis and biomass accumulation in many weed species, especially C_3 weeds such as *Chenopodium album*, *Parthenium hysterophorus*, and *Convolvulus arvensis*. Enhanced growth of these weeds increases their competitive ability against vegetable crops for light, nutrients, water, and space. Although crop growth may also benefit from elevated CO_2, several studies have demonstrated that weeds often exhibit a greater growth response, thereby intensifying crop yield losses. Increasing temperatures further influence weed ecology by accelerating germination, growth, flowering, and seed production. Warmer conditions may extend the growing season of many weeds and facilitate the spread of invasive species into previously unsuitable regions, including temperate and hill ecosystems. Species such as *Parthenium hysterophorus*, *Cyperus rotundus*, and *Ageratum conyzoides* have shown enhanced adaptability under changing climatic conditions, resulting in greater infestation levels and management challenges.

Changes in rainfall patterns also affect weed emergence and survival. Prolonged drought periods favour drought-tolerant weed species with deep root systems, while excessive rainfall and flooding create favourable conditions for aquatic and semi-aquatic weeds. Such shifts alter weed community composition and often reduce the effectiveness of traditional weed control practices. Climate change may also influence herbicide performance. Higher temperatures can increase herbicide volatilization and degradation, whereas irregular rainfall may affect herbicide persistence and efficacy. Furthermore, environmental stresses can modify weed physiology, potentially contributing to reduced herbicide susceptibility and the evolution of herbicide-resistant weed populations.

Consequently, climate-smart and integrated weed management strategies are becoming increasingly important. Adoption of crop diversification, conservation agriculture, precision herbicide application, mulching, cover cropping, biological weed control, and AI-

assisted weed monitoring can improve resilience and sustainability of vegetable production systems under changing climatic conditions.

Importance and Impact of Weeds in Vegetable Production Systems

Weeds are among the major biological constraints limiting vegetable production, causing significant reductions in crop yield, quality, and economic returns. Due to wider row spacing and slow initial growth, vegetable crops are highly vulnerable to weed infestation, especially during early growth stages. Weeds possess strong competitive abilities and often develop deeper and more extensive root systems, enabling them to utilize soil moisture and nutrients more efficiently than vegetable crops. Modern vegetable cultivars, although improved for yield and quality, generally exhibit reduced competitiveness against weeds due to lower vigor and limited canopy development. Weed competition for light, water, nutrients, and space adversely affects crop growth and decreases marketable yield by reducing produce size, quality, and harvest efficiency. Additionally, many weeds act as alternate hosts for insects, pathogens, viruses, and nematodes, increasing pest and disease incidence in vegetable fields (Kumar et al., 2021). .

Weed infestation also increases production costs through additional labor and management requirements while interfering with irrigation and nutrient utilization. Therefore, sustainable and integrated weed management practices are essential to minimize yield losses, improve resource-use efficiency, maintain environmental sustainability, and ensure profitable vegetable production systems (Coleman et al., 2024).

Table 1: Impact of Weed Infestation on Yield Reduction in Major Vegetable Crops

Sr. No.	Vegetable Crops	Yield Loss due to weeds (%)	References
1	Tomato	92-95	Bakht and Khan 2014
2	Okra	40-80	Patel *et al*. 2017
3	Potato	52	Singh *et al*. 2005
4	Bottle Gourd	40	Dash and Mishra 2014
5	Cabbage	45-80	Akshatha *et al*. 2018
6	Carrot	90	Singh *et al.* 2017
7	Brinjal	30-35	Syriac and Geetha 2007
8	Chilli	60-70	Khan *et al.* 2012
9	Garlic	94.8	Sanjay *et al.* 2009

10	Radish	86	Singh *et al.* 2009
11	Onion	40-80	Channapagoudar and Biradar 2007

Source: Chacko et al .2021

Critical Period of Crop–Weed Competition (CPWC)

The **Critical Period of Crop–Weed Competition (CPWC)** refers to the specific stage in a crop's growth cycle during which weed control is essential to prevent economically significant yield losses. During this period, weeds compete most aggressively with crops for vital resources such as nutrients, moisture, sunlight, and growing space, thereby exerting the greatest negative impact on crop growth, development, and productivity. Failure to manage weeds effectively during the CPWC can result in substantial reductions in yield, even if weeds are removed at a later stage. Conversely, weed infestation occurring before or after this critical interval generally has a relatively minor effect on final crop yield. The duration and timing of the CPWC vary depending on crop species, weed flora, environmental conditions, and crop management practices. Therefore, identifying and maintaining a weed-free environment during this period is crucial for maximizing crop productivity, enhancing resource-use efficiency, and reducing economic losses (Das, 2008).

Table 2: Critical Period of Crop–Weed Competition in Vegetable Crops

Sr. No.	**Crop**	**Critical Period of crop competition**
1	Tomato (transplanted)	First 6 weeks after planting
2	Tomato (seeded)	First 9 weeks after seeding
3	Okra	2-4 weeks after emergence
4	Cabbage	2-4 weeks after emergence
5	Cauliflower	0-30 days after sowing
6	Brinjal	20-60 days after sowing
7	Carrot	3-6 weeks after emergence
8	Turnip	15-20 days after sowing
9	Radish	25-30 days after sowing
10	Cucumber	Up to 4 weeks after seeding

11	Peas	30-60 days after planting
12	Onion	Entire growing season (highly sensitive to weed competition)
13	Chilli	30-45 days after transplanting
14	Potato	15-45 days after planting

Source: Chacko et al .2021

Among vegetable crops, onion is highly susceptible to weed competition and requires season-long weed management. Brinjal, pea, potato, and tomato have longer critical periods of weed competition, requiring prolonged weed control, while short-duration crops like turnip and radish need weed management for a shorter period. Effective weed control during the critical period is essential for optimum growth, yield and profitability.

Major weed flora of vegetable crops:

Weed flora in vegetable production systems is diverse and consists of broad-leaved weeds, grasses, and sedges that vary in their growth habits, life cycles, and competitive ability. The composition of weed flora changes with seasons, particularly between kharif and *Rabi* crops, due to differences in climatic conditions and cropping patterns. Accurate identification of weed species and understanding their biology and propagation methods are essential for developing effective and sustainable weed management strategies (Attri et al., 2022)

Table 3: Major Kharif season weeds

Botanical Name	Common Name	Type	Family
Trianthema portulacastrum	Patharchata, Gadhupura	Broad leaved, annual	Aizoaceae
Echinochloacolona	Barnyard Grass	Narrow leaved, annual	Graminae
Cyperus rotundus	Motha	Narrow leaved, perennial	Cyperaceae
Digeriaarvensis	Chanchali	Broad leaved, annual	Amaranthaceae
Amaranthusviridis	JangliChaulai	Broad leaved, annual	Amaranthaceae
Physalis minima	Ban Makaya	Broad leaved, annual	Solanaceae
Phyllanthusniruri	Haizardana, Jar-Amla	Broad leaved, annual	Euphorbiaceae
Commelinabenghalensis	Kanna, Kena	Broad leaved, annual	Commelinaceae
Eleusine indica	Malanpuri, Kodai	Narrow leaved, annual	Graminae

Ageratum conyzoides	Neela Phool	Broad leaved, annual	Compositae
Cynodondactylon	Bermuda, Doob Grass	Narrow leaved, perennial	Graminae
Celosia argentea	Safed Murge Ka Phool	Broad leaved, annual	Amaranthaceae
Setariaverticillata	Bristly foxtail	Grass, annual	Poaceae
Digitarissanguinalis	Crab grass	Grass, annual	Poaceae
Parthenium hsyterophorus	Congress grass	Broadleaf, annual	Asteraceae

Source: (Singh* et al.*, 2019)

Major *Rabi* season weeds in vegetable crops:

Botanical name	**Common name**	**Type**	**Family**
Chenopodium album	Bathu	Broad leaved, annual	Chenopodiaceae
Melilotus indica	Senji Methi	Broad leaved, annual	Papilionaceae
Lathyrus aphaca	Maturi, PipuraPipari	Broad leaved, annual	Papilionaceae
Vicia sativa	Anhtaankari	Broad leaved, annual	Papilionaceae
Convolvulus arvensis	Hirankhuri	Broad leaved, perennial	Convolvulaceae
Rumex maritimus	Panbheri	Broad leaved, annual	Polygonaceae
Cynodon dactylon	Bermuda grass, Doob grass	Narrow leaved, perennial	Graminae
Orobanche spp.	Broom rape	Broad leaved, annual	Orobanchaceae
Spergula arvensis	Bhandhania	Narrow leaved, annual	Caryophyllaceae
Euphorbia hirta	Bari Dudhi	Broad leaved, annual	Euphorbiaceae
Phalaris minor	Canary grass	Grass, annual	Poaceae
Avenaludo viciana	Wild oat	Grass, annual	Poaceae
Lolium temulentum	Darnel ryegrass	Grass, annual	Poaceae
Poa annua	Annual bluegrass	Grass, annual	Poaceae
Sonchus arvensis	Sowthisle	Broad leaf, perennial	Asteraceae
Stellaria media	Chickweed	Broadleaf, annual	Carophyllaceae
Cirsium arvense	Canada thistle	Broadleaf, perennial	Asteraceae
Cuscuta reflexa	Dodder	Broadleaf, annual	Cuscutaceae
The weed flora associated with vegetable crops comprises a wide range of annual and perennial			

species belonging to different botanical groups. During the ***Rabi* season**, weeds such as *Chenopodium album*, *Phalaris minor*, and *Convolvulus arvensis* are predominant, whereas ***kharif* season** vegetable crops are commonly infested by *Trianthema portulacastrum*, *Cyperus rotundus*, *Echinochloa colona*, and *Parthenium hysterophorus*. Proper identification and timely management of these weed species are essential for minimizing crop–weed competition, improving resource-use efficiency, and maximizing vegetable productivity.

Source: (Singh* et al. *2019)

			
Trifolium repen	***Polypogonmons peliensus***	***Anagallis arvensis***	***Eleusine indica***
			
Ageratum conyzoides	***Portulaca oleracea***	***Veronica persica***	***Chenopodium album***

Principles of Climate-Resilient Integrated Weed Management (CRIWM):

Climate-resilient integrated weed management (CRIWM) integrates preventive, cultural, physical, and ecological approaches to suppress weeds while conserving resources and enhancing crop resilience. It is based on three key principles: **prevention, eradication and control**. Prevention avoids the introduction and spread of weeds, eradication aims at complete removal of weed populations from a specific area, and control reduces weed growth below economically damaging levels (Rana and Rana, 2019).

Preventive Measures:

Prevention is the most economical and sustainable strategy for weed management. It includes the use of clean seeds, well-decomposed farmyard manure, and maintenance of weed-free irrigation channels and field boundaries to restrict the introduction and spread of weed seeds (Zimdahl, 2018).

Cultural Weed Management Practices

Crop Rotation and Diversification

Rotating vegetable crops with cereals, pulses, and other crops disrupts weed life cycles, reduces the dominance of specific weed species, and improves soil health and agro ecosystem resilience (Singh et al., 2019; Chacko et al., 2021)

Optimized Nutrient and Water Management

Weeds may consume 40–50% of available soil water. Efficient irrigation systems such as drip irrigation deliver water directly to crop roots, limiting resource availability for weeds and reducing their growth (Hussein et al., 2015). Subsurface drip irrigation in tomato has been shown to reduce weed density by up to 98% while increasing crop yield.

Planting Time and Crop Geometry

Timely sowing, optimum plant population, and narrow row spacing promote rapid canopy development and improve crop competitiveness against weeds by reducing light availability. In tomato, 40 cm row spacing resulted in lower weed density compared with wider spacing (Attri et al., 2022).

Intercropping and Cover Crops

Intercropping and the use of fast-growing cover crops such as clover, oilseed radish, and sunn hemp suppress weeds through competition for light, water, and nutrients (Attri et al., 2022). Intercropping faba bean with barley reduced weed cover and biomass by 92.7% and 76.6%, respectively (Fernández et al., 2024).

Mulching: A Climate-Smart Approach

Mulching is one of the most suitable technologies for hill vegetable cultivation. Organic mulches such as dry grasses, pine needles, crop residues and compost, along with biodegradable or plastic mulches, suppress weed emergence, conserve soil moisture and moderate soil temperature. Research conducted under mid-hill conditions of Himachal Pradesh demonstrated

that the use of black polythene mulch with appropriate planting methods effectively reduced weed density and improved weed control efficiency in capsicum cultivation (Tulek et al., 2025).




Biomass mulching in capsicum & Turmeric



Plastic mulch in capsicum

Soil Solarization

Soil solarization involves covering moist soil with transparent polyethylene during hot periods to increase soil temperature and destroy weeds, pathogens, and pests. Solarization for six weeks has reduced weed density and biomass by more than 90% while improving crop yields.

Physical and Mechanical Weed Control

Tillage

Tillage controls weeds by uprooting plants and burying weed seeds beyond their optimum germination depth, thereby reducing the soil weed seed bank (Labrada, 1996).

HandWeeding

Hand weeding using simple tools such as *khurpi* remains effective for controlling intra-row weeds, particularly in smallholder vegetable systems, although it requires considerable labor (Mohamed and Abdalla, 2023). Overall, CRIWM combines these complementary practices to reduce dependence on herbicides, enhance resource-use efficiency, improve soil health, and build resilient vegetable production systems under changing climatic conditions.

Table 5: Examples of Crop Rotation Systems in Vegetable Production

S.No.	Crop Rotation type	Examples
1	Leafy and root vegetable	Lettuce, spinach, cole crops and Carrots, Potatoes & Radish
2	Monocot and Dicot	Cereals and Spinach& tomato
3	Family based rotation	Brassicaceae and solanaceae vegetables
4	Bulb and fruit crop	Onion& leek and chilli & capsicum

5	Poor competitors and strong competitors	Carrot, onion and Maize & potato
6	Short and long duration crops	Radish, Lettuce and Potato, Tomato

Source: Singh et al 2019

Intercropping and cover crops:

Intercropping involves growing two or more crops simultaneously in the same field (Singh et al., 2019). Cover crops with rapid growth and dense canopy development, such as clover, oilseed radish, and sunn hemp, effectively suppress weeds by competing for light, water, and nutrients (Attri et al., 2022). Fernández et al. (2024) reported that intercropping faba bean with barley reduced weed cover by 92.7% and weed biomass by 76.6%.

Table 6: Example of intercropping system in vegetable Production

Temperate region	**Tropical region**
Lettuce + Carrot	Maize + beans + squash
Cole crops + Leek, onion, celery and tomato	Tomato + Pigeon pea
Maize+ beans & soybean	Sugarcane + onion & tomato

Source: Singh *et al.* 2019

Chemical methods of weed control (Herbicides):

Herbicides are chemical compounds used to suppress or eliminate weeds by disrupting vital physiological and biochemical processes such as photosynthesis, enzyme activity, cell division, and protein synthesis, ultimately leading to growth inhibition or plant death (Babu et al., 2024). They offer an effective and economical approach to weed management in vegetable crops, particularly under labour scarcity. Based on the time of application, herbicides are classified as **pre-emergence** and **post-emergence** herbicides.

Pre-emergence Herbicides Used in Vegetable Crops

Pre-emergence herbicides are applied after sowing or transplanting but before weed emergence. They create a chemical barrier in the soil that prevents weed seed germination and suppresses early seedling growth.

Herbicide	**Crop (Dose, kg ha^{-1})**
Pendimethalin	Garlic (0.75–1.25), Carrot & Radish (0.75–1.87), Potato (0.75–1.5), Brinjal (1.0–1.5), Cabbage (0.75–2.0), Cauliflower (0.5–1.0), Onion

	(0.75–1.5), Chilli (0.75–3.0), Tomato (0.56–1.0), Peas (1.20–1.50), Okra (0.50–0.75), Turmeric (0.975)
Oxyfluorfen	Garlic (0.125–0.240), Brinjal (0.10–0.15), Cabbage (0.09–0.234), Chilli (0.10–1.25)
Metolachlor	Garlic (1.50)
Fluchloralin fb Quizalofop-ethyl	Garlic (0.95 fb 0.05)
Trifluralin	Carrot/Radish (0.9–1.5)
Alachlor	Carrot/Radish (1.25–2.5)
Isoproturon	Potato (0.94)
Metribuzin	Potato (0.25–0.75), Tomato (0.37–0.525)
Fluchloralin	Cauliflower (0.84–1.5), Onion (1.12)
Pendimethalin fb Oxyfluorfen + Quizalofop-ethyl	Onion (0.75–1.5 fb 0.12–0.85 + 0.037–0.050)

Source: Singh et al. (2019)

Post-emergence herbicides used in vegetable crops:

Post-emergence herbicides are applied after the emergence of weeds and, in many cases, following crop establishment. These herbicides constitute an essential component of integrated weed management by effectively controlling weeds that escape pre-emergence herbicide applications and mechanical control practices. Their efficacy depends on several factors, including the weed species present, the growth stage of the weeds, prevailing environmental conditions, and the selectivity and compatibility of the herbicide with the crop.

Herbicide	Crop (Dose, kg ha^{-1})
Fenoxaprop-P-ethyl	Garlic (0.075)
Quizalofop-ethyl / Quizalofop	Garlic (0.05); Brinjal (0.040); Peas (0.050)
Sethoxydim	Carrot/Radish (0.8); Cabbage (1.5)
Fluazifop-butyl	Carrot/Radish (0.75)
Oxyfluorfen + Quizalofop-	Onion (0.12–0.85 + 0.037–0.050)

ethyl	
Imazethapyr	Peas (0.15–1.5)

Source: Singh et al. 2019

Biological methods of weed control:

Biological weed management involves the use of living organisms such as insects, pathogens, grazing animals, and competitive plants to suppress weed populations. It is an eco-friendly approach that reduces reliance on chemical herbicides and provides sustainable long-term weed control. These biological agents control weeds by feeding on them, causing diseases, or competing for essential resources like light, water, nutrients, and space (Kumar and Agrawal, 2024). A successful example in India is the use of the Mexican beetle (*Zygogramma bicolorata*) to control *Parthenium hysterophorus* (Congress grass). The beetle feeds on the leaves and flowers of Parthenium, reducing its growth and seed production, making it an effective biological weed control agent (Mishra *et al.*, 2021).

Integrated weed management in vegetable crops (IWM):

Integrated Weed Management (IWM) is a holistic, sustainable, and ecologically sound approach that combines multiple weed control strategies to maintain weed populations below economic threshold levels. It integrates preventive, cultural, mechanical, biological, and chemical methods based on weed ecology, crop requirements, and prevailing environmental conditions. By employing diverse weed management tactics, IWM reduces reliance on herbicides, delays the development of herbicide-resistant weed populations, minimizes environmental contamination, and promotes the long-term sustainability and profitability of vegetable production systems (Babu et al., 2024). In vegetable production systems, IWM involves the use of healthy and clean seeds, crop rotation, optimum planting geometry, mulching, timely irrigation and fertilizer management, manual or mechanical weeding, and the judicious application of herbicides when required. The integration of these strategies helps reduce weed competition for nutrients, water, light, and space, leading to improved crop growth, higher yields, reduced dependence on herbicides, and enhanced soil and environmental health. IWM is particularly important under changing climatic conditions, as it provides a resilient and sustainable solution for effective weed management in vegetable-based farming systems.

Future Prospects of Weed Management in Vegetable Crops

Future weed management in vegetable crops will increasingly focus on sustainable, precise, and technology-driven approaches rather than sole dependence on herbicides. Innovations in precision agriculture, including GPS, GIS, remote sensing, drones, and machine vision, will enable site-specific weed detection and targeted control, reducing herbicide use, production costs, and environmental impacts. Artificial intelligence (AI), robotics, and machine learning are expected to revolutionize weed management by enabling accurate weed identification and selective removal through mechanical, laser, or precise herbicide applications. Similarly, bioherbicides, beneficial microorganisms, allelopathic plants, and cover crops will play an important role in eco-friendly weed suppression. Climate change and the rise of herbicide-resistant weeds will necessitate climate-smart and integrated weed management strategies involving crop rotation, conservation practices, herbicide stewardship, and the combination of cultural, mechanical, biological, and chemical methods. Furthermore, digital technologies such as IOT sensors, cloud-based platforms, and decision-support systems will provide real-time recommendations for effective weed control.

Overall, the future of weed management lies in integrating advanced technologies with sustainable practices to enhance weed control efficiency, reduce reliance on synthetic herbicides, protect the environment, and ensure long-term productivity and profitability of vegetable production systems.

Emerging Technologies for Climate-Smart Weed Management

Recent advances in digital agriculture offer new opportunities for sustainable weed management. Artificial intelligence (AI) and machine learning algorithms can accurately distinguish weeds from crop plants through image analysis and computer vision techniques. Drone-based weed surveillance enables rapid monitoring of large areas and facilitates site-specific herbicide application, reducing chemical consumption and environmental contamination. Robotic weeders equipped with sensors, cameras, and precision tools can mechanically remove weeds with minimal soil disturbance. Laser-based weed control technologies are also emerging as non-chemical alternatives capable of targeting individual weeds without affecting crop plants.

The integration of Internet of Things (IoT) sensors, remote sensing technologies, Geographic Information Systems (GIS), and Decision Support Systems (DSS) can provide real-time recommendations for weed management based on weather conditions, crop stage, and weed

population dynamics. These technologies are expected to play a vital role in climate-resilient vegetable production systems in the future.



Conclusion

Weeds remain one of the most serious biological constraints affecting vegetable production worldwide. Their competition for nutrients, moisture, light, and space significantly reduces crop productivity, quality, and profitability. The challenge has become more complex under changing climatic conditions, which influence weed distribution, growth behaviour, competitiveness, and response to management practices. Integrated Weed Management (IWM) offers an effective and sustainable approach by combining preventive, cultural, mechanical, biological, and chemical methods to maintain weed populations below economic threshold levels while minimizing environmental impacts. Climate-resilient weed management practices such as crop diversification, mulching, cover cropping, efficient water management, soil solarization, and precision herbicide application contribute significantly to sustainable vegetable production.

Emerging technologies including artificial intelligence, robotics, drone-assisted weed detection, precision agriculture, and decision-support systems are expected to revolutionize future weed management. The successful integration of these innovative technologies with traditional ecological knowledge will be crucial for enhancing resource-use efficiency, reducing chemical dependence, conserving biodiversity, and ensuring long-term sustainability of vegetable production systems under climate change scenarios. Therefore, adoption of climate-resilient integrated weed management strategies is essential for improving productivity, profitability, and food security while protecting environmental health.

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Volume: 06 Issue No: 07

ADVANCING SUSTAINABLE AGRICULTURE THROUGH SUPER ABSORBENT POLYMER TECHNOLOGY

Article ID: AG-V06-I07-04

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Abstract

Agriculture faces increasing challenges from water scarcity and drought stress, which adversely affect crop growth, productivity and water-use efficiency. Superabsorbent polymers (SAPs) also known as hydrogels, are cross-linked hydrophilic materials capable of absorbing and retaining large quantities of water and gradually releasing it to plants under moisture-deficit conditions. This review highlights the classification, structure, mechanism of action and agricultural applications of SAPs. SAPs improve soil water-holding capacity, enhance soil structure, reduce nutrient leaching and promote biological activity, thereby supporting better seed germination, root development and crop growth. Their use as soil conditioners, seed-coating materials and controlled-release carriers for fertilizers contributes to improved water and nutrient-use efficiency. Despite limitations such as high production costs and environmental concerns associated with synthetic polymers, recent advances in biodegradable and bio-based SAPs offer promising solutions for sustainable agriculture. Overall, SAPs represent an effective strategy for enhancing drought resilience, conserving water resources and improving crop productivity under changing climatic conditions.

Keywords

Superabsorbent polymers (SAPs); Hydrogels; Water retention; Drought stress; Soil moisture conservation.

Introduction

Agriculture is the largest consumer of freshwater resources worldwide, accounting for nearly 70–80% of total freshwater usage. Climate change and increasing drought frequency have reduced water availability for crop production. Water stress adversely affects seed germination, root development, nutrient uptake, photosynthesis and ultimately crop yield. To overcome these challenges, various water conservation technologies have been developed, including drip irrigation, mulching, rainwater harvesting and soil conditioners. Among them, Super Absorbent Polymers (SAPs) have gained considerable attention because of their extraordinary ability to absorb and retain water.

Super Absorbent Polymers (SAPs), commonly known as hydrogels, are three-dimensional cross-linked hydrophilic polymers capable of absorbing and retaining water many times their own weight. Depending on their composition, SAPs can absorb approximately 100 to 1000 times their dry weight in water. (Oladosu *et al*., 2022). The absorbed water is stored within the polymer network and is gradually released when the surrounding soil becomes dry.

Due to their ability to improve soil water-holding capacity and reduce water losses, SAPs are widely used in agriculture as soil conditioners, seed-coating materials and carriers for fertilizers and pesticides. The use of SAPs not only improves soil moisture availability but also enhances nutrient retention, reduces fertilizer losses, improves soil structure and promotes plant growth under drought conditions. Their application has shown positive effects on germination, seedling establishment, biomass production, water productivity and crop yield.



Classification of Super Absorbent Polymer:

- ✓ Natural SAPs
- ✓ Synthetic SAPs

- ✓ Semi synthetic SAPs

Natural SAPs:

These are derived from renewable biological resources. Natural hydrogels are biodegradable, eco-friendly and safer for long-term agricultural applications. Cellulose-based hydrogels possess excellent biodegradability and high absorbency compared to many synthetic polymers (Oladosu et al., 2022). Eg: Starch, Cellulose, Chitosan, Agarose, Alginate.

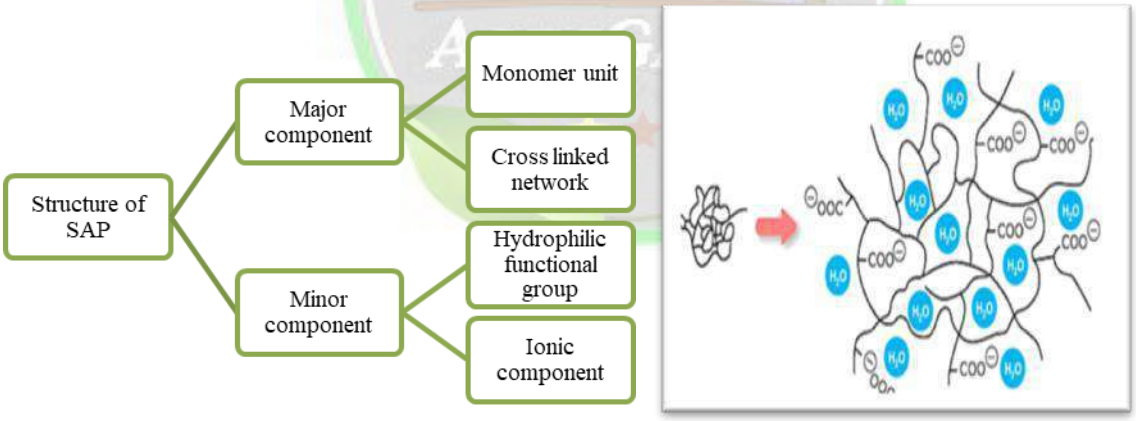
Synthetic SAPs:

Synthetic SAPs are commonly produced from Polyacrylamide, Polyacrylate and Acrylic acid derivatives. These materials exhibit superior water absorption capacity and swelling behaviour but may create environmental concerns because many acrylate-based polymers are non-biodegradable (Oladosu et al., 2022).

Semi Synthetic SAPs:

Semi-synthetic SAPs combine natural polymers with synthetic monomers to improve biodegradability, strength and water retention efficiency. Starch-polyacrylate copolymers, Cellulose-acrylamide composites.

Structure of SAPs:



Mechanism of SAP action:

The effectiveness of Super Absorbent Polymers (SAPs) in agriculture is primarily attributed to their remarkable water absorption and release characteristics. SAPs are three-dimensional cross-linked hydrophilic polymer networks containing functional groups such as carboxyl (-COOH), hydroxyl (-OH) and amide (-$CONH_2$). These functional groups possess a strong affinity for water molecules, enabling the polymers to absorb and retain large quantities of water relative to their own weight (Malik *et al.*, 2023). When exposed to rainfall or irrigation

water, SAP particles rapidly absorb moisture and swell forming a gel-like structure. Depending on their composition and degree of cross-linking, SAPs can absorb water several hundred times their dry weight.

Once absorbed, water is stored within the polymer network through hydrogen bonding and osmotic forces. The cross-linked structure prevents the polymer from dissolving while allowing it to retain water for extended periods. This stored water serves as a reservoir that can be utilized by plants during periods of limited soil moisture availability. The water-holding capacity of SAPs helps maintain a favorable moisture environment around the root zone, thereby reducing water stress and improving plant growth.

As soil moisture decreases due to plant uptake, evaporation, or drought conditions, a moisture gradient develops between the swollen polymer and the surrounding soil. In response to this gradient, SAPs gradually release the stored water into the rhizosphere (Patra *et al*., 2022) making it available for plant absorption. This controlled release mechanism ensures a continuous supply of moisture to plants and reduces the frequency of irrigation. The repeated cycle of water absorption during wet conditions and water release during dry periods enhances soil water availability, improves water use efficiency and helps crops withstand drought stress. Consequently, SAPs function as miniature water reservoirs within the soil, contributing significantly to sustainable water management and improved crop productivity under water-limited environments.

Soil water holding capacity:

SAPs absorb and store large amounts of water during rainfall or irrigation, releasing it gradually as soil moisture declines. This increases plant-available water, reduces water loss through evaporation and leaching, improves water-use efficiency and supports seed germination, root growth and crop productivity under drought conditions (AbdAllah *et al*., 2021).

Soil Structure:

SAPs improve soil aggregation, porosity, and aeration by creating a more stable soil structure when swollen with water. This enhances water infiltration, reduces erosion and compaction, and promotes deeper root growth, especially in sandy and compacted soils (AbdAllah *et al*., 2021).

Nutrition and Retention:

SAPs retain nutrient-rich water within their polymer network and release nutrients

gradually to plants. This reduces nutrient leaching, improves nutrient-use efficiency, minimizes fertilizer losses, and supports sustainable nutrient management.

Biological activity:

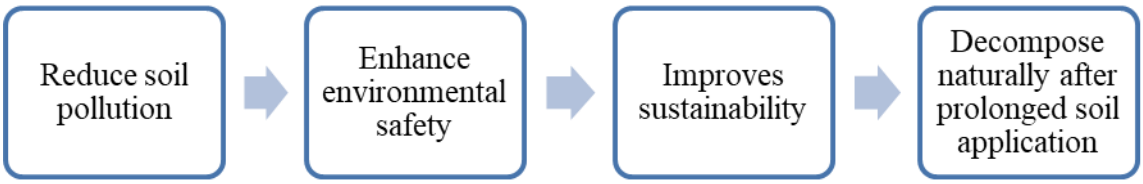
By maintaining favorable soil moisture, SAPs stimulate beneficial microbial activity and nutrient mineralization. They enhance root–microbe interactions, improve soil fertility, and contribute to overall soil health and agricultural sustainability.

Agricultural Applications of Superabsorbent Polymers:

Superabsorbent polymers (SAPs) are widely used in agriculture due to their ability to absorb, store and gradually release water, improving soil moisture retention and reducing irrigation requirements, especially in arid and semi-arid regions (Patra *et al*., 2022). They help mitigate drought stress by maintaining root-zone moisture, enhancing plant growth, yield, and water-use efficiency (Oladosu *et al*., 2022).

SAPs also improve soil physical properties such as porosity, aggregation, aeration, and infiltration, promoting better root development and nutrient uptake. Additionally, they act as nutrient-retention and controlled-release materials, reducing fertilizer leaching and improving nutrient-use efficiency (Malik *et al*., 2023). In seed coating and seedling establishment, SAPs maintain moisture around seeds and roots, enhancing germination and crop establishment under water-limited conditions. Studies in cotton have shown that SAP application improves growth, yield, and water-use efficiency under moderate water stress (Fallahi *et al*., 2015). Thus, SAPs are valuable tools for sustainable water management and climate-resilient agriculture.

Biodegradable and Eco-Friendly Hydrogels:

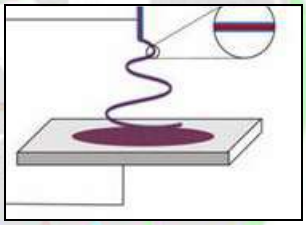
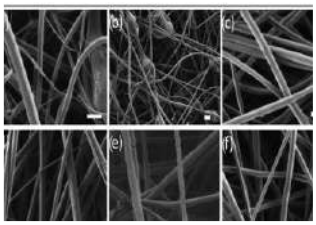


Forms of SAPs:

Form	Description	Agricultural application
Particles/Powders	Small dry particles that swell on water absorption	Soil amendment to improve water retention, reduce irrigation, and enhance drought

		tolerance
Beads	Spherical hydrogel particles with high water absorption	Seed coating, nurseries, and potting media to improve germination and seedling establishment
Fibre	Absorbent polymers incorporated into fibrous materials	Erosion control, seed mats, and landscape management for moisture conservation
Gels (Hydrogels)	Water-swollen polymer network	Root dipping, nurseries, forestry, and horticulture to protect roots and reduce transplant shock
Seed coatings	Thin polymer layer applied on seeds or fertilizers	Enhance germination, maintain seed moisture, and enable controlled nutrient release



Particles Fibre





Beads Gel

Benefits of Superabsorbent Polymers in Agriculture:

- Increased soil moisture retention
- Improved crop growth and yield
- Higher water-use efficiency
- Reduced fertilizer leaching
- Better root development and microbial activity

- Improved soil physical properties
- Enhanced nutrient availability

Limitations and challenges:

- ✓ High production cost
- ✓ Reduced efficiency under saline conditions
- ✓ Potential environmental concerns with synthetic polymers
- ✓ Limited biodegradability of acrylate-based SAPs
- ✓ Decline in water absorption capacity under high salt concentration

Future perspectives:

Superabsorbent polymers (SAPs) will focus on developing biodegradable and environmentally friendly materials with improved water-retention efficiency. The integration of SAPs with fertilizers and agrochemicals for controlled release, along with their use in seed enhancement technologies, offers significant potential for improving crop performance under drought conditions. As water scarcity and climate change intensify, SAPs are expected to play an important role in sustainable agriculture, particularly in arid and semi-arid regions. Further studies are needed to reduce production costs and assess their long-term effects on soil health and the environment.

Conclusion

Superabsorbent polymers represent an innovative and sustainable approach for improving agricultural water management under drought and moisture-stress conditions. Their exceptional water absorption and slow-release characteristics enable efficient conservation of soil moisture and enhancement of crop productivity. SAPs improve soil physical properties, nutrient-use efficiency, irrigation efficiency and drought tolerance while reducing water losses through evaporation, runoff and deep percolation. Although concerns remain regarding the environmental safety of synthetic hydrogels, recent advances in biodegradable and bio-based polymers offer promising alternatives for sustainable agriculture. Therefore, the adoption of eco-friendly superabsorbent polymers may play a critical role in ensuring food security and water conservation under changing climatic conditions.

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FRUIT BAGGING : AN ECO-FRIENDLY METHOD FOR PRODUCING EXPORT QUALITY MANGOES

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Introduction

India is the second-largest producer of fruits in the world, next only to China. Its diverse climatic and geographical conditions support the production of a wide variety of fruits. Despite this, India's export competitiveness remains low, contributing only about 1 percent to agricultural export earnings. Constraints in fruit exports are mainly related to production practices, post-harvest technologies, market access, and policy limitations.

Mango, revered as the "king of fruits," is a cornerstone of tropical horticulture in India, occupying about 2.41 million hectares with a production of over 23.26 million tonnes during 2024–25 (3rd advance estimates). Despite this dominance, India's presence in the global mango export market remains limited, contributing only a small fraction (≈1–2%) of its total production (APEDA, 2025). This paradox highlights a critical issue: while production is abundant, the proportion of fruits meeting international quality standards is relatively low.

In Tamil Nadu, which accounts for around 145 thousand hectares under mango cultivation with a production of 0.97 million tonnes, fruit quality still lags behind the national average. This emphasizes the need for improved pre-harvest management strategies.

Beyond production: Barriers to global markets

The primary reasons for poor export performance are linked to quality-related constraints rather than production limitations. Pre-harvest factors such as thrips infestation, which leads to russeting and surface scarring, significantly reduce the visual appeal of fruits. In addition, fruit fly damage, diseases, sunburn, and pesticide residues further compromise fruit quality.

These issues result in a high proportion of fruits being downgraded or rejected in export markets, where strict standards demand blemish-free, uniform, and residue-safe produce. Consequently, even high-yielding orchards often fail to translate production into profitable export returns.

Bagging for perfection: Elevating mango quality for global markets

Fruit bagging emerges as a simple yet transformative technology to enhance mango quality and export potential. By enclosing developing fruits in protective covers, bagging creates a controlled micro-environment that shields fruits from thrips, pests, and environmental damage while reducing the need for chemical sprays.

This results in cleaner, more uniform, and residue-free fruits that meet international market requirements. Wider adoption of fruit bagging, especially in regions like Tamil Nadu, can bridge the gap between production and export quality, enabling a shift from quantity-driven cultivation to value-driven mango production systems.

Bagging techniques



Mr. Kamalraj, farmer from Ayalanlam village of KV Kuppam taluk, Velur district followed bagging technique in mango, Himampasand variety in 2.5 acres. He harvested attractive, blemish free mango fruits, fetching premium price in the market.





A farmer from Pochampalli village of Krishnagiri district, Mr. K. Saravanan, used bagging for alphonso mangoes for an area of one hectare. He inferred that the fruits are premium in quality and no pesticide spray was done. Bagging helps for the production of organic mango fruits.



Mango Bagging helps in producing blemish and residue free fruits with good marketing quality. The alphonso fruits harvested from 2.2 acres fetches premium price and has good demand from consumers - Mr. M. Ravi, Morappur, Dharmapuri district.



Mango bagging done over 5 acres in Himampasand and Banaganapalli variety produced clean, uniform, chemical-free fruits with excellent appearance, fetching higher returns at farmgate itself – Mr. N. Srinivasan, Kumbakonam, Thanjavur district

Pre-harvest fruit bagging is an effective and widely adopted practice in different parts of the world. It is a physical protection technique that enhances visual quality by reducing spots, blemishes, and cracking, while improving fruit size, shape, colour, and overall appeal.

Around 35 days after fruit set, select healthy and well-shaped fruits at the lemon or small egg stage. Retain only one or two uniform fruits per panicle and remove the rest. Damaged,

deformed, or diseased fruits should also be removed. This helps the tree channel nutrients into fewer fruits, improving size and quality.

Before bagging, spray a recommended broad-spectrum fungicide and insecticide 1–2 days in advance to prevent trapping pests or pathogens inside the bag.

Use a double-layered bag and ensure it is intact with small vents for airflow. Carefully place the bag over the fruit without damaging it and secure it around the stalk. The bag should be tight enough to prevent entry of insects and rainwater, but not so tight that it damages the stalk. Once bagged, fruits should not be disturbed until harvest. During harvesting, collect fruits with a 5–10 cm stalk along with the bag. At the packhouse, remove the bags carefully and de-sap the fruits to obtain clean, export-quality mangoes.

1. Eco-friendly – Plant protection

Due to the influence of climate change, growing export quality mangoes, without use of pesticide is cumbersome. Mangoes shielded by a Double layered mango will serves as an extremely effective and environmentally friendly physical barrier. Bagging, physically prevents female fruit flies from puncturing the fruit's skin to lay their eggs by completely covering the fruit. Timely bagging ensures fruit fly-free mangoes because fruit flies pose a serious quarantine threat in international export markets. The bag also serves as an umbrella, protecting the fruit from wind and rain splashes and preventing the fungal spores that cause diseases like stem-end rot and anthracnose. Without compromising yield, this mechanical protection significantly lowers the need for frequent, hazardous chemical pesticide sprays, encouraging a more eco-friendly and sustainable method of orchard management.

2. Shielding mango fruits from environmental stress

The orchard micro environment and the unpredictable summer showers with hailstones can easily damage the developing fruits. Bagging prevents the fruit from sunburn and physical abrasions from wind-whipped branches. Additionally, the bag protects the fruit's skin from sap burn a highly corrosive issue where acidic sap drips onto the fruit during high winds, causing black blemishes leads to poor fruit quality.

3. Residue free fruits

Bagging eliminates the need of frequent chemical sprays during the critical fruit-development stage. The bagged fruits, harvested at full maturity without the use of chemicals during its growth stage satisfies the preharvest interval recommended by Central Insecticide

Board and Registration committee. This is a massive advantage in today's market, where domestic consumers and international export markets demand to Maximum Residue Limits (MRLs). Producing clean, residue-free fruit ensures consumer safety and also opens doors to premium, high value organic or export markets that would otherwise be inaccessible to conventional growers.

4. Eye catching mangoes with color and appeal

The microclimate, inside the bag enhances the cosmetic attraction of the mango, drives the consumer purchasing decisions. Bagging prevents the development of black spots, sooty mold, and lenticel spotting, ensuring a flawless, uniform smooth skin. Double layered brown paper bag can regulate light exposure to promote a uniform skin colour, whether a deep golden yellow making the fruits highly attractive and competitive on fresh-market shelves.

5. Enhanced shelf life

Mangoes that have been bagged consistently exhibit a significantly longer shelf life compared to their unbagged fruits. Bagged fruit protects the latent fungal infections and micro-abrasions in the field; it undergoes far less post-harvest decay and rotting. Additionally, the bag helps to increase the calcium content in the peel, allowing the mangoes to stay fresh, firm, and marketable for extended periods during transport and retail display.

6. Quality fruits – better shape

The physical protection offered by bagging ensures that the mango develops without external interruptions, leading to excellent morphological quality. When fruits are exposed to insect stings, fungal scarring, or tight wedging against branches, their growth becomes stunted or deformed, resulting in asymmetrical shapes. A bagged fruit, suspended safely in its own protective envelope, expands uniformly and reaches its true, genetically determined shape, which is highly preferred by commercial graders and premium retailers.

7. Bigger weight greater profit

Bagging optimizes the growing conditions around the individual fruit, which directly translates to increased fruit size and weight. By preventing the stress of pest attacks and environmental extremes, the fruit can direct all of its energy into cell expansion and pulp development. Heavier, larger, and cleaner fruits naturally fall into higher premium grading categories, allowing farmers to command significantly better prices per piece or per kilogram, thereby maximizing the overall profitability of the harvest.

8. Timely and early fruit picking

The specialized microclimate within the bag, which retains a slightly elevated and stable temperature, can accelerate the physiological maturity of the mango. This allows for a more uniform maturity process across the orchard, making harvest planning much more predictable and labour-efficient. In many cases, bagged fruits can be harvested slightly earlier than unbagged ones, giving farmers a strategic advantage to hit the early-season market when supply is low and premium prices are at their peak.

9. Value driven processing

For value-added ventures like a commercial pulping operation, starting with high-quality bagged fruit dramatically improves the efficiency and output of the processing line. Unblemished, perfectly shaped fruits are easier to wash, peel, and destone, resulting in a higher percentage of usable pulp recovery and significantly less waste. Furthermore, utilizing residue-free, premium-grade mangoes elevates the safety profile, taste, and overall quality of the final processed product, allowing processors to target higher-tier markets and command better profit margins.

Golden mangoes: The Profit Power of Fruit Bagging

Conclusion

Using double-layered bags before harvest is a game-changer for export-focused production systems, particularly in Ultra High-Density Planting (UHDP). This simple, eco-friendly method protects fruits from pests, diseases, and harsh weather while reducing heavy reliance on chemical sprays. As a result, mangoes remain clean and safe, with low chemical residues that comply with stringent international safety standards. Moreover, the potential for strong financial returns in both local and global markets can significantly enhance the economic sustainability of mango growers.

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IMPACT OF CLIMATE CHANGE ON VEGETABLE PRODUCTION AND MANAGEMENT STRATEGIES FOR SUSTAINABLE CULTIVATION

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Abstract

Vegetable crops are indispensable for ensuring food and nutritional security because they supply essential vitamins, minerals, dietary fibre, antioxidants and numerous health-promoting phytochemicals. In addition to their nutritional importance, vegetable cultivation contributes significantly to agricultural income and rural employment. However, vegetable production is increasingly threatened by climate change, which has emerged as one of the most important challenges to global agriculture. Rising temperatures, erratic rainfall, prolonged droughts, floods, soil salinity and changes in atmospheric concentrations of carbon dioxide (CO_2) and ozone (O_3) have altered the production environment of vegetable crops. Owing to their succulent tissues, shallow root systems and narrow climatic requirements, vegetables are highly susceptible to these environmental changes. Climatic stresses adversely affect seed germination, vegetative growth, flowering, pollination, fruit set, yield, produce quality and nutritional composition. They also increase the incidence of insect pests and diseases, making vegetable cultivation more difficult and economically risky. Although these challenges are becoming increasingly severe, several climate-smart management practices have shown considerable potential in minimizing production losses. The development of stress-tolerant cultivars, protected cultivation, efficient irrigation methods, mulching, grafting, seed priming, balanced nutrient management and the use of beneficial microorganisms are improving the resilience of vegetable production systems under changing climatic conditions. This article discusses the major impacts of climate change on vegetable production and highlights practical management strategies that can enhance crop

resilience, sustain productivity and support future food and nutritional security.

Introduction

Vegetables occupy a unique position in agriculture because they are not only important cash crops but also indispensable components of a healthy and balanced diet. They provide substantial quantities of vitamins, minerals, dietary fibre, antioxidants and bioactive compounds that are essential for human growth, development and disease prevention. Increasing awareness regarding nutritional security has considerably enhanced the demand for vegetables across the world, making vegetable cultivation one of the fastest-growing sectors of horticulture. Besides meeting nutritional requirements, vegetable farming generates employment, supports the livelihoods of millions of farmers and contributes significantly to national economies.

The productivity of vegetable crops, however, is closely associated with prevailing environmental conditions. Most vegetables require favourable temperature, adequate soil moisture, optimum relative humidity and balanced nutrient availability throughout their growth period. Unlike many field crops, vegetables possess succulent tissues, shallow root systems and delicate reproductive organs that make them particularly sensitive to fluctuations in weather conditions. Consequently, even short periods of environmental stress during flowering or fruit development can substantially reduce marketable yield and produce quality.

Climate change has emerged as a major threat to sustainable vegetable production worldwide. Continuous increases in global temperature, irregular rainfall patterns, prolonged droughts, floods, soil salinity and rising concentrations of atmospheric CO_2 and ozone have significantly altered crop-growing environments. These climatic changes disrupt several physiological and biochemical processes, including photosynthesis, respiration, nutrient uptake, enzyme activity, pollen development and reproductive success. As a result, vegetables frequently experience poor germination, reduced vegetative growth, flower abortion, impaired fruit set, lower yields and deterioration in nutritional quality. Furthermore, changing climatic conditions favour the multiplication and geographical spread of insect pests, pathogens and weeds, increasing production costs and reducing profitability.

Addressing these challenges requires an integrated approach that combines scientific innovations with improved crop management. Climate-resilient cultivars, protected cultivation, efficient water management, mulching, grafting, seed priming, biological inoculants and

precision nutrient management have emerged as effective strategies for reducing climate-induced production losses. The adoption of these climate-smart technologies will play a vital role in sustaining vegetable productivity while improving resource-use efficiency and environmental sustainability. This article examines the major impacts of climate change on vegetable production and discusses scientifically proven management strategies that can help build resilient vegetable production systems for the future.

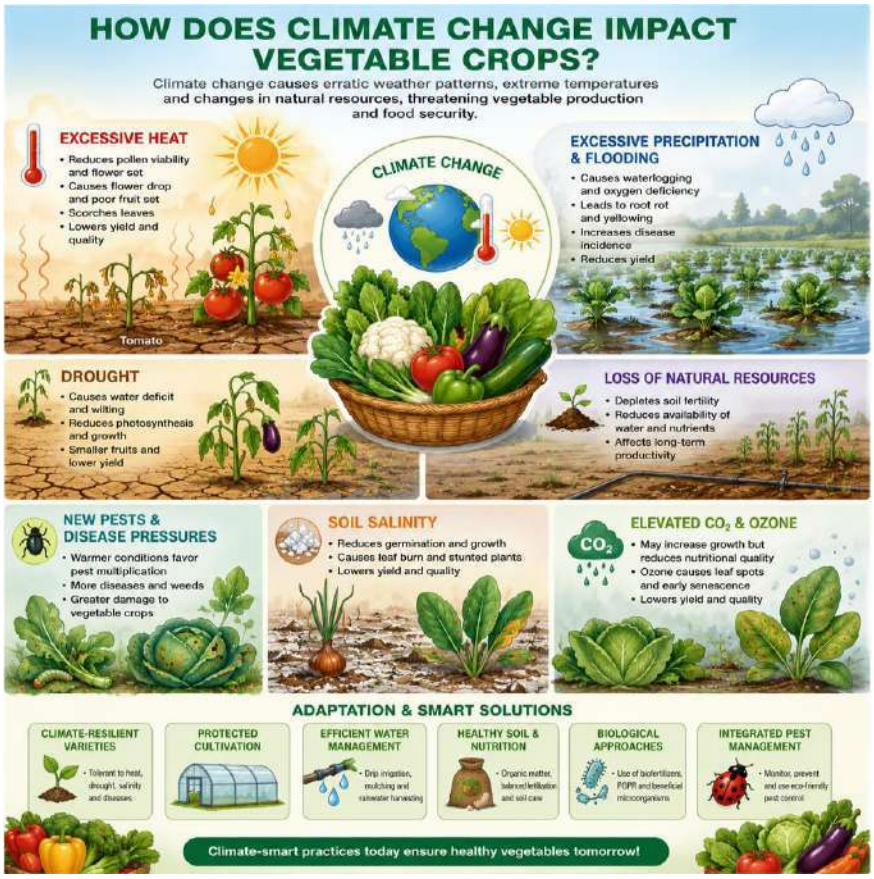


Fig.1. Impact of climate change on vegetable crops

Table 1. Major Climatic Factors Affecting Vegetable Production

Climatic factor	Major effects on vegetable crops
High temperature	Reduced pollen viability, flower drop, poor fruit set, lower yield
Low temperature	Chilling injury, delayed growth, poor seed germination
Drought	Moisture stress, reduced photosynthesis, smaller fruits
Flooding	Root oxygen deficiency, root rot, nutrient imbalance
Soil salinity	Poor germination, ion toxicity, reduced growth

Elevated CO_2	Increased photosynthesis but possible reduction in nutritional quality
Elevated ozone	Oxidative damage, reduced chlorophyll and yield

Impact of Climate Change on Vegetable Production

Climate change affects vegetable production through a combination of environmental stresses that interfere with normal plant growth, development and productivity. Unlike cereal crops, most vegetables are highly sensitive to variations in temperature, soil moisture, relative humidity and atmospheric composition because of their succulent tissues, shallow root systems and short growth duration. Even short periods of climatic stress during critical developmental stages can substantially reduce yield and market quality. The major climatic factors influencing vegetable production include elevated temperature, low temperature, drought, flooding, soil salinity, increased atmospheric carbon dioxide and ozone pollution. These factors rarely occur independently; instead, they often interact simultaneously, making crop management increasingly complex.

Heat Stress

Among the various consequences of climate change, rising temperature has become one of the most important constraints to vegetable production. Vegetable crops generally perform best within a relatively narrow temperature range and temperatures exceeding this optimum limit adversely affect several physiological and reproductive processes. The increasing frequency of heat waves and prolonged periods of high temperature has therefore become a serious concern for vegetable growers across the world.

Heat stress initially affects plant metabolism by increasing respiration while simultaneously reducing photosynthetic efficiency. Higher temperatures accelerate water loss through transpiration, disturb membrane stability and increase the production of reactive oxygen species (ROS), resulting in oxidative damage to plant cells. These physiological disturbances reduce chlorophyll content, impair enzyme activity and ultimately decrease dry matter accumulation and crop productivity.

The reproductive phase is particularly vulnerable to elevated temperatures. High temperature reduces pollen viability, delays pollen tube growth, interferes with fertilization and causes flower abortion, resulting in poor fruit set. Tomato is one of the most heat-sensitive vegetable crops, where elevated temperatures frequently induce blossom drop and significantly reduce marketable yield. Similar responses have been reported in chilli, sweet pepper, brinjal,

cucumber and other cucurbitaceous vegetables. In leafy vegetables such as spinach and lettuce, excessive heat accelerates bolting, producing fibrous leaves with inferior market quality. Root and bulb crops also experience reduced biomass accumulation because high temperatures shorten the crop duration and alter carbohydrate partitioning.

In addition to reducing yield, heat stress adversely affects vegetable quality. Fruits often become smaller, irregularly shaped and less attractive, while nutritional constituents such as vitamin C, sugars, pigments and antioxidants may decline under prolonged exposure to elevated temperatures. Consequently, both productivity and market value are adversely affected.

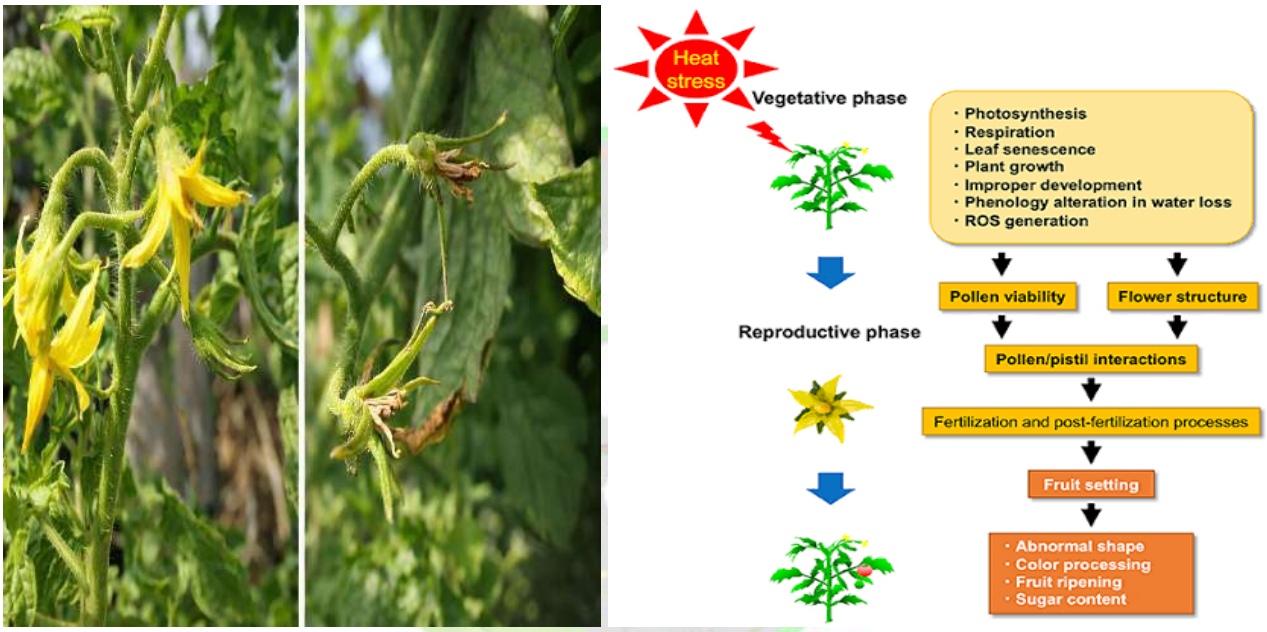


Fig.2. Effect of heat stress in tomato plant

Cold Stress

Although global warming is characterized by increasing average temperatures, low-temperature stress continues to limit vegetable production in many temperate and subtropical regions. Unexpected cold spells, frost events and chilling temperatures frequently damage sensitive vegetable crops during both field cultivation and post-harvest storage. Cold stress is generally classified into chilling injury, which occurs above the freezing point and freezing injury, where ice crystal formation causes irreversible cellular damage.

Low temperature affects several metabolic processes by reducing membrane fluidity, slowing enzyme activity and restricting photosynthesis. As a result, plant growth becomes sluggish, nutrient uptake declines and carbohydrate metabolism is disturbed. Young seedlings

are particularly susceptible because their developing tissues have limited tolerance to chilling conditions.

Vegetable crops such as tomato, chilli, cucumber, watermelon, muskmelon, brinjal, okra and sweet pepper exhibit pronounced chilling sensitivity. Exposure to low temperatures during flowering often delays reproductive development, reduces pollen viability and lowers fruit set.

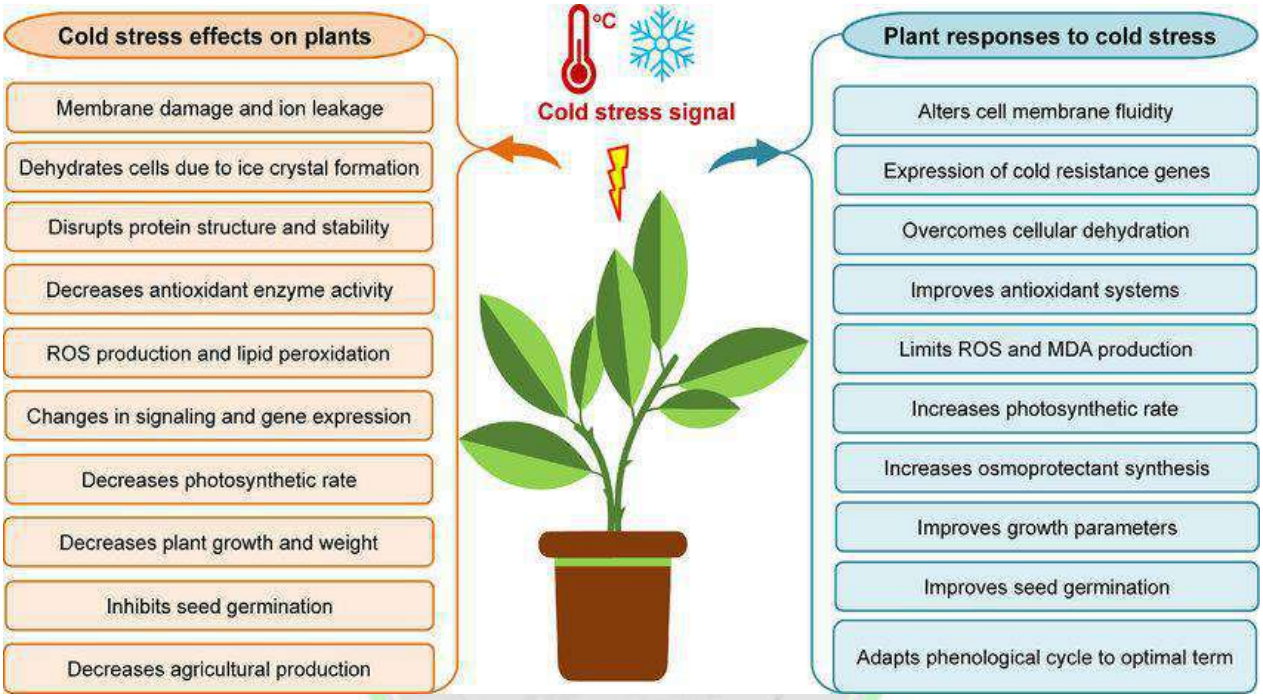


Fig.3. Effects and responses of plant to cold stress

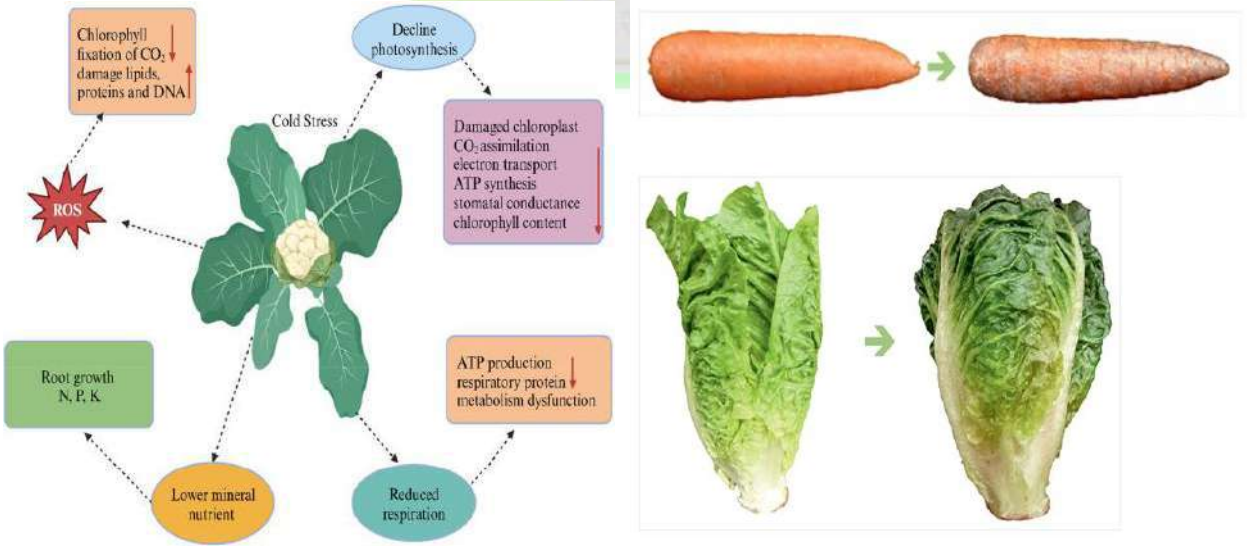


Fig.4. Effect of cold stress in in cauliflower, carrot and lettuce

In potato, chilling affects carbohydrate metabolism and photosynthetic activity, whereas cucurbits frequently exhibit water-soaked lesions, pitting and tissue collapse. Chilling injury also becomes an important post-harvest problem in vegetables such as cucumber, zucchini, eggplant and tomato when stored below their critical storage temperatures. These physiological disorders reduce shelf life, increase post-harvest losses and lower consumer acceptance.

Drought Stress

Water availability is one of the most critical factors determining vegetable productivity. Climate change has increased the frequency and severity of droughts in many vegetable-growing regions, resulting in prolonged periods of soil moisture deficit. Since vegetables possess shallow root systems and high-water requirements, they are particularly susceptible to moisture stress.

Drought primarily affects plant water relations by reducing cell turgor, limiting leaf expansion and inducing stomatal closure. Although stomatal closure helps conserve water, it simultaneously restricts carbon dioxide uptake, reducing photosynthesis and biomass production. Reduced photosynthesis limits carbohydrate synthesis, leading to slower growth and poor yield formation. Moisture deficiency also impairs nutrient uptake because nutrients become less mobile in dry soils.

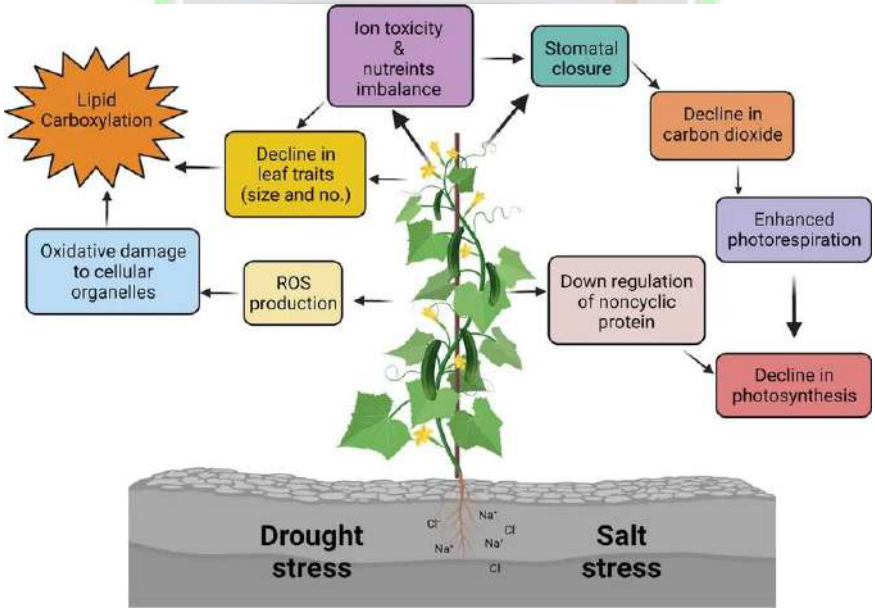


Fig.5. Effect of drought and salt stress in cucumber

The reproductive stage is especially sensitive to drought stress. Water deficit during flowering causes flower drop, poor pollination, reduced fruit set and increased fruit abortion. Tomato and sweet pepper frequently experience severe yield losses when drought coincides with flowering

and fruit development. Onion bulb enlargement, potato tuber formation and leafy vegetable growth are similarly reduced under prolonged moisture stress. Besides lowering yield, drought often decreases fruit size, fresh weight and overall market quality

Flooding and Waterlogging

In contrast to drought, excessive rainfall and flooding have become increasingly common under changing climatic conditions. Heavy precipitation and poor drainage result in waterlogging, where soil pores become saturated with water and oxygen availability around the root system declines. Oxygen deficiency inhibits root respiration, reduces nutrient absorption and restricts root growth, ultimately affecting the entire plant.

Vegetable crops exhibit characteristic symptoms of waterlogging, including chlorosis, wilting despite adequate soil moisture, reduced leaf expansion, premature senescence and root decay. Onion is highly susceptible because of its shallow root system, while tomato, chilli and brinjal also experience significant reductions in growth and fruit yield following prolonged flooding. Waterlogged conditions further favour the development of fungal and bacterial diseases, thereby increasing crop losses.

Soil Salinity

Soil salinity is emerging as a major constraint to vegetable production, particularly in arid, semi-arid and coastal regions where climate change has intensified the accumulation of soluble salts in the soil. Rising temperatures increase evaporation, while declining freshwater availability often forces farmers to use poor-quality irrigation water, accelerating the process of salinization. In coastal areas, sea-level rise further aggravates the problem by allowing seawater intrusion into agricultural lands. These changes have reduced the productivity of many vegetable-growing regions and pose a serious threat to sustainable horticulture.

Excess salts in the root zone create both osmotic and ionic stress. Osmotic stress limits the ability of plants to absorb water, even when adequate soil moisture is present, whereas ionic stress results from the accumulation of toxic sodium (Na^+) and chloride (Cl^-) ions in plant tissues. These ions interfere with the uptake of essential nutrients such as potassium, calcium and magnesium, disrupting metabolic processes and reducing plant growth. Salinity also decreases chlorophyll content, inhibits photosynthesis, alters enzyme activity and increases oxidative damage through the accumulation of reactive oxygen species.

Vegetable crops differ considerably in their tolerance to saline conditions. Onion, carrot, pea, beans and lettuce are among the most salt-sensitive vegetables, while beetroot and asparagus exhibit comparatively greater tolerance. Tomato, cabbage, cauliflower, potato and brinjal show moderate tolerance but experience significant reductions in growth and yield under prolonged exposure to saline conditions. Visible symptoms include delayed seed germination, poor seedling establishment, leaf chlorosis, marginal scorching, stunted growth, reduced flowering and poor fruit development. The severity of these symptoms depends on the crop species, growth stage, salt concentration and duration of exposure.

Elevated Atmospheric Carbon Dioxide (CO_2)

Atmospheric carbon dioxide concentration has increased steadily due to industrialization, fossil fuel combustion and land-use changes. Since carbon dioxide is the primary substrate for photosynthesis, elevated CO_2 can initially stimulate plant growth by enhancing carbon fixation and biomass accumulation. Many experimental studies have reported increased leaf area, improved photosynthetic rate and higher yields in vegetables such as tomato, cucumber, lettuce, spinach and potato when grown under elevated CO_2 concentrations. In addition, reduced stomatal opening under elevated CO_2 decreases transpiration, thereby improving water-use efficiency and partially alleviating drought stress.

However, the positive effects of elevated CO_2 are often offset by other climate-related stresses. High temperatures, nutrient deficiencies, drought and salinity can reduce the beneficial effects of enhanced carbon availability. Moreover, rapid biomass accumulation under elevated CO_2 frequently leads to a dilution of mineral nutrients, resulting in lower concentrations of iron, zinc, calcium, magnesium and certain vitamins in edible plant parts. Thus, although vegetable yield may increase under favourable conditions, improvements in productivity are not always accompanied by enhanced nutritional quality. This highlights the importance of integrated nutrient and crop management under future climatic conditions.

Ground-Level Ozone Pollution

Ground-level ozone (O_3) is an important secondary air pollutant formed through photochemical reactions involving nitrogen oxides and volatile organic compounds. Unlike the protective ozone layer present in the upper atmosphere, ozone near the Earth's surface is highly toxic to plants. It enters leaves through stomata and rapidly generates reactive oxygen species that damage cellular membranes, chloroplasts, proteins and nucleic acids.

Ozone-induced oxidative stress reduces chlorophyll concentration, inhibits photosynthesis, accelerates leaf senescence and restricts biomass accumulation. The resulting reduction in carbohydrate production adversely affects flowering, fruit development, and final yield. Vegetable crops such as tomato, potato, onion, spinach, beans and carrot are particularly sensitive to ozone injury. Typical symptoms include bronzing, chlorotic spots, necrotic lesions, premature leaf ageing and reduced market quality. Since these symptoms often resemble nutrient deficiencies or disease infections, ozone damage may remain unnoticed until considerable yield losses have occurred.

Changing Pest and Disease Dynamics

Climate change not only affects vegetable crops directly but also alters the biology, survival and distribution of insect pests and plant pathogens. Higher temperatures, increased humidity and irregular rainfall create favourable conditions for rapid multiplication of many insects, fungi, bacteria, viruses and nematodes. As a result, pest outbreaks are becoming more frequent, severe and geographically widespread.

Warmer winters improve the survival of overwintering insect populations, while extended growing seasons allow several pests to complete additional generations within a single year. Similarly, increased humidity and prolonged leaf wetness favour fungal diseases such as early blight, late blight, downy mildew and powdery mildew. Viral diseases are also becoming more prevalent because changing climatic conditions support larger populations of insect vectors such as aphids, whiteflies, thrips and leafhoppers.

The interaction between abiotic stress and biotic stress further aggravates crop losses. Plants weakened by heat, drought, salinity or flooding become more susceptible to pest attack and disease infection due to reduced vigour and impaired defence mechanisms. Consequently, climate change increases not only the incidence of pests and diseases but also the cost of crop protection, posing an additional challenge to profitable vegetable production.

Management Strategies for Climate-Resilient Vegetable Production

1. Development and Adoption of Climate-Resilient Varieties
2. Protected Cultivation
3. Efficient Water Management
4. Mulching and Conservation Practices
5. Vegetable grafting

6. Seed Priming and Beneficial Microorganisms
7. Integrated Nutrient and Pest Management



Fig.6. Strategies for Climate-Resilient Vegetable Production

Conclusion

Climate change has emerged as a major challenge to sustainable vegetable production by exposing crops to heat stress, drought, flooding, salinity, elevated CO_2, ozone pollution and increased pest and disease incidence, all of which adversely affect growth, yield and produce quality. Nevertheless, the adoption of climate-smart approaches such as stress-tolerant varieties, protected cultivation, efficient irrigation, mulching, grafting, integrated nutrient and pest management and the use of beneficial microorganisms can substantially enhance the resilience and productivity of vegetable crops. Strengthening research, technological innovation, extension services and farmer awareness, supported by appropriate policies, will be essential for promoting sustainable vegetable production and ensuring food and nutritional security under changing climatic conditions.

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MARINE FISHING REGULATION ACT: A CORNERSTONE FOR SUSTAINABLE MARINE FISHERIES IN INDIA

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Abstract

India's marine fisheries are among the most productive in the world, contributing significantly to food security, employment, livelihoods, and foreign exchange earnings. However, increasing fishing pressure, technological advancements, habitat degradation, and overexploitation of marine resources have raised serious concerns about the sustainability of fish stocks. The Marine Fishing Regulation Acts (MFRAs), enacted by all maritime states and Union Territories based on a Model Marine Fishing Regulation Bill, provide the principal legal framework for regulating fishing activities within territorial waters. Through measures such as vessel licensing, fishing zone demarcation, seasonal fishing bans, gear and mesh-size regulations, and restrictions on destructive fishing practices, the Acts aim to conserve marine biodiversity while safeguarding the livelihoods of traditional fishing communities. Although state-specific provisions vary according to local fisheries and ecological conditions, all MFRAs share the common objective of ensuring responsible and sustainable utilization of marine fishery resources. This article discusses the evolution, key provisions, state-wise implementation, challenges, and future prospects of the Marine Fishing Regulation Act in promoting sustainable marine fisheries management in India.

Keywords: Marine fisheries, Marine Fishing Regulation Act, Sustainable fisheries, Fisheries legislation, Coastal management, India

Introduction

India has a coastline of over 11,098.81 km, an Exclusive Economic Zone (EEZ) of about 2.02 million km², and rich marine biodiversity that supports one of the world's largest marine

fisheries. Marine fisheries provide employment to more than four million people and contribute substantially to nutritional security, rural livelihoods, and the national economy (FAO, 2022). Fisheries also support several ancillary sectors, including fish processing, marketing, transportation, and export industries. Over the past five decades, mechanization and technological innovations have revolutionized India's marine fishing sector. While these developments significantly increased fish production, they also intensified fishing pressure on coastal ecosystems. Excessive fishing effort, capture of juvenile fishes, habitat destruction, and conflicts between mechanized and traditional fishing sectors became increasingly common. These issues highlighted the need for effective fisheries management to ensure that marine resources remain productive for future generations (FAO, 1995). Recognizing these challenges, the Government of India recommended a comprehensive legal framework for regulating marine fisheries. Based on the recommendations of the Central Board of Fisheries, a Model Marine Fisheries Regulation Bill was circulated to maritime states in 1979. Subsequently, all coastal states and Union Territories enacted their own Marine Fishing Regulation Acts (MFRAs), which regulate fishing activities within territorial waters (up to 12 nautical miles). These Acts continue to form the backbone of marine fisheries governance in India by balancing resource conservation with the socio-economic well-being of fishing communities.

Why is the Marine Fishing Regulation Act Important?

Marine fishery resources are renewable but finite. Unregulated fishing can lead to overexploitation, depletion of fish stocks, habitat degradation, and conflicts among different fishing sectors. The Marine Fishing Regulation Act was introduced to address these challenges by regulating fishing effort, conserving breeding stocks, protecting juvenile fishes, and ensuring equitable access to marine resources. The Act also helps minimize conflicts between mechanized and traditional fishers by allocating fishing zones and regulating the operation of fishing vessels. These measures contribute to long-term ecological sustainability while supporting the livelihoods of coastal communities (Hardin, 1968).

Evolution of the Marine Fishing Regulation Act

Marine fisheries in India were initially governed under the Indian Fisheries Act, 1897, which primarily focused on inland fisheries and provided limited provisions for marine resource management. During the 1960s and 1970s, rapid mechanization increased fishing efficiency but also led to excessive exploitation of coastal fishery resources and disputes between fishing

sectors. To address these issues, the Government of India constituted a committee in 1976 to formulate a regulatory framework for marine fisheries. The committee submitted a Model Marine Fisheries Regulation Bill in 1978, which served as the basis for state-level legislation. Kerala and Goa were the first states to implement Marine Fishing Regulation Acts in 1980, followed by other maritime states according to their regional fisheries requirements.

Objectives of the Marine Fishing Regulation Act

The Marine Fishing Regulation Act seeks to promote sustainable utilization of marine fishery resources through scientific management and effective governance. Its primary objectives include conserving marine biodiversity, preventing overfishing, protecting spawning and nursery grounds, regulating fishing gears and mesh sizes, licensing fishing vessels, reserving nearshore waters for traditional fishers, reducing conflicts among fishing sectors, and ensuring long-term livelihood security for coastal communities. The Act also supports India's commitment to responsible fisheries management under international agreements such as the FAO Code of Conduct for Responsible Fisheries (FAO, 1995).

Major Provisions of the Act

The Marine Fishing Regulation Acts require all mechanized and motorized fishing vessels operating within territorial waters to obtain valid licenses from the respective State Fisheries Departments. They prescribe fishing zones to separate mechanized vessels from traditional fishing crafts, thereby minimizing conflicts and improving safety at sea. Seasonal fishing bans are implemented during the monsoon period to protect spawning stocks and facilitate stock replenishment. The Acts also regulate fishing gears by specifying minimum mesh sizes to reduce the capture of juvenile fishes and prohibit destructive fishing methods such as explosives and poisons. Enforcement officers are empowered to inspect fishing vessels, seize illegal gears, suspend licenses, and impose penalties for violations.

State-wise Implementation of Marine Fishing Regulation Acts

Although all maritime states follow the principles of the Model Marine Fisheries Regulation Bill, the provisions vary depending on local ecological conditions and fishing practices.

- The Gujarat Marine Fishing Regulation Act aims to protect traditional fishers by reserving waters up to 9 km from the coastline exclusively for non-mechanized fishing vessels, while mechanized vessels are permitted to operate beyond this limit. To reduce the capture of juvenile fishes, the Act mandates a minimum cod-end mesh size of 40 mm

for trawl nets and prohibits the operation of gill nets with mesh sizes smaller than 150 mm. These measures contribute to sustainable exploitation of commercially important fish stocks.

- Maharashtra has adopted several stringent regulations to manage its diverse fisheries. Mechanized trawling is prohibited in shallow coastal waters (up to 5–10 fathoms in specified areas), and an annual monsoon fishing ban from 15 June to 31 July is enforced to protect breeding fish populations. Night trawling (6 pm–6 am) is prohibited, and large mechanized vessels with engines exceeding six cylinders are not allowed to operate within 22 km of the coast. The state also restricts purse seine operations in selected coastal districts and prescribes minimum mesh sizes of 25–35 mm for trawl nets to minimize juvenile fish catch.
- The Goa Marine Fishing Regulation Act reserves waters up to 5 km from the shoreline exclusively for traditional fishing crafts by prohibiting mechanized fishing within this zone. The Act also specifies minimum mesh sizes of 20 mm for prawn nets and 24 mm for fish nets, thereby reducing the capture of immature fishes and supporting sustainable fisheries management.
- Karnataka reserves waters up to 6 km from the shore or up to 4 fathoms depth (whichever is farther) for traditional fishing crafts. Mechanized fishing boats shorter than 50 feet are permitted beyond 6 km, whereas larger deep-sea vessels (50 feet and above) are required to operate beyond 20 km from the coast. These spatial regulations reduce conflicts between traditional and mechanized fishing sectors.
- Kerala introduced one of the first Marine Fishing Regulation Acts in India and has one of the most comprehensive zoning systems. The Act divides the coastline into two management zones based on water depth. Mechanized fishing is prohibited in both zones, allowing only traditional and motorized country crafts to fish. Small mechanized vessels (<25 GRT) are permitted to operate only in designated offshore depth zones. Kerala also enforces an annual monsoon trawl ban, which has become an important conservation measure for protecting spawning fish stocks.
- Tamil Nadu reserves waters up to 5 km from the coast exclusively for traditional non-mechanized fishing vessels. Mechanized vessels are allowed beyond this limit. Fishing within 100 m of river mouths is prohibited to protect nursery grounds. The Act prescribes

minimum mesh sizes of 25 mm for gill nets, 37 mm for shrimp trawl cod ends, and 40 mm for fish trawl cod ends. In addition, the Fisheries Department regulates the number of mechanized fishing vessels permitted to operate in different fishing areas to control fishing effort.

- In Andhra Pradesh, waters up to 8 km from the shore are reserved for traditional fishing crafts. Mechanized vessels operate beyond 8 km, while larger vessels (25 GRT or 15 m and above) are allowed only beyond 15 km from the coastline. The Act prohibits the use of fishing nets with mesh sizes smaller than 15 mm and requires shrimp trawlers to use Turtle Excluder Devices (TEDs) to reduce sea turtle mortality. Non-compliance attracts penalties and confiscation of catches.
- Odisha reserves coastal waters up to 5 km exclusively for traditional non-mechanized fishing crafts. Mechanized fishing vessels shorter than 15 m may operate beyond 5 km, whereas larger mechanized vessels (25 GRT or more) are permitted only beyond 10 km from the shore. These regulations protect artisanal fisheries while minimizing competition with industrial fishing operations.
- West Bengal reserves waters up to 18 km from the coastline for artisanal fishing crafts and vessels fitted with engines below 30 HP. Larger mechanized vessels are allowed to operate beyond this limit. The Act specifies minimum mesh sizes for gill nets (25 mm), bag nets (37 mm), and shore seines (25 mm). It also requires trawl nets to be fitted with Turtle Excluder Devices (TEDs) to protect endangered marine turtles.
- The Marine Fishing Regulation Act of the Andaman and Nicobar Islands emphasizes conservation of the ecologically sensitive island ecosystem. Fishing vessels with engines up to 30 HP are permitted within 10 km of the coast, while larger vessels operate beyond this limit. Seasonal closures are implemented for bottom trawling, shark fishing, and shell collection. The Act prohibits fishing nets with mesh sizes below 20 mm and mandates the use of Turtle Excluder Devices in trawl fisheries. Gill nets, shore seines, and drag nets must have mesh sizes of at least 25 mm.
- The Lakshadweep Marine Fishing Regulation Act focuses on protecting fragile coral reef ecosystems and maintaining sustainable tuna fisheries. The Act prohibits the use of purse seines, ring seines, pelagic trawls, mid-water trawls, and bottom trawls with mesh sizes below 20 mm, except for live-bait fishing. It also prescribes a minimum mesh size of 50

mm for drift gill nets and 20 mm for shore seines, helping to reduce juvenile fish mortality and conserve reef-associated fish populations.

Benefits of the Marine Fishing Regulation Act

The Marine Fishing Regulation Act has significantly contributed to sustainable fisheries management by reducing fishing conflicts, conserving breeding populations, protecting juvenile fishes, and improving compliance with responsible fishing practices. Seasonal fishing bans have facilitated stock replenishment, while fishing zone regulations have safeguarded the livelihoods of traditional fishers. The Act has also strengthened fisheries governance through licensing systems, monitoring, and enforcement, contributing to long-term conservation of marine biodiversity.

Challenges

Despite its achievements, the implementation of the Marine Fishing Regulation Act faces several challenges. Illegal, unreported and unregulated (IUU) fishing, inadequate enforcement, insufficient manpower, interstate differences in regulations, climate change, habitat degradation, and increasing fishing effort continue to threaten marine resources. Improving surveillance, harmonizing state regulations, promoting community participation, and adopting ecosystem-based fisheries management are essential for addressing these challenges (FAO, 2022).

Future Perspectives

Future fisheries management should integrate scientific stock assessments, digital vessel monitoring systems, satellite-based surveillance, stakeholder participation, and climate-resilient management strategies. Strengthening cooperation among maritime states and periodically updating fisheries legislation will improve compliance and ensure the sustainable utilization of India's marine fishery resources.

Conclusion

The Marine Fishing Regulation Act has emerged as the cornerstone of marine fisheries management in India by balancing resource conservation with the livelihood needs of coastal communities. Through licensing systems, seasonal fishing bans, fishing zone regulations, gear restrictions, and conservation measures, the Act has contributed significantly to responsible fisheries management. However, evolving challenges such as climate change, illegal fishing, habitat degradation, and increasing fishing pressure require continuous strengthening of fisheries governance. Effective implementation, supported by scientific research, technological

innovations, stakeholder participation, and adaptive management, will ensure that India's marine fisheries remain productive and sustainable for future generations.

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MOST IMPORTANT EMERGING INVASIVE INSECTS IN INDIA

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Abstract

Invasive insect species are emerging as a major threat to Indian agriculture, forestry and biodiversity. The rising movement of goods, global trade and changing climatic conditions have increased the rate of introduction and spread of several invasive pests. Species like Tobacco thrips, Invasive nesting whitefly, Eucalyptus weevil, Fall armyworm, Tomato leaf miner and Rugose spiralling whitefly are inflicting major economic and ecological damage. These pests reduce crop yields and management costs and disrupt ecosystem balance. Minimizing their impact and protecting India's agricultural and natural resources requires effective surveillance, quarantine measures and integrated pest management strategies.

Keywords: Invasive insects, Agriculture, Biodiversity, Fall Armyworm, Tobacco thrips, Pest Management.

Introduction

Agriculture and biodiversity are the backbone of India's economy and ecological stability. But invasive insect species are increasingly threatening these valuable resources. An invasive insect is a non-native species that enters a new region, establishes itself successfully and causes economic, environmental or ecological damage. Global trade, increased movement of goods and people, and changing climatic conditions have accelerated the introduction and spread of invasive pests between countries. In India, several invasive insects have become serious threats to crop production, forestry and biodiversity. These pests often multiply quickly, lack natural enemies in their new environment and cause serious damage to agricultural and natural

ecosystems. Understanding these emerging invasive species is critical for developing effective management strategies and protecting the country's food security and biodiversity.

What makes invasive insects dangerous?

Unlike native pests, invasive insects often arrive without their natural enemies, parasitoids and pathogens. This enables them to rapidly increase their populations and spread over large areas. They can damage crops, reduce yields, increase production costs, disrupt ecological balance and threaten native insect diversity. Thus, early detection and prompt management are essential to minimize their impact.

Tobacco thrips (*Thrips parvispinus*)

Tobacco thrips is one of the recently emerging invasive pests in India which has become a serious threat to vegetable and horticultural crop production. First reported from Southeast Asia, the tiny insect has spread rapidly across several Indian states. The pest attacks chilli, capsicum, papaya, ornamental plants and several vegetable crops. Nymphs and adults feed causing leaf curling, silvering, flower drop and reduced fruit quality. Heavy infestations can cause substantial yield losses, making it one of the most difficult pests faced by farmers in recent years.



(A) (B) (C) (D)

Figure 1. Emerging invasive insect pests affecting Indian agriculture and biodiversity: (A) Tobacco thrips, (B) Invasive nesting whitefly, (C) Eucalyptus weevil, (D) Fall armyworm, (E) Tomato leaf miner and (F) Rugose spiralling whitefly.

Invasive nesting whitefly (*Paraleyrodes pseudonaranjae*)

Among the recently reported invasive insects in India, invasive nesting whitefly is one of the newest. This whitefly species produces waxy secretions that cover plant surfaces and forms dense colonies on leaves. Black sooty mould often develops on infested plants as a result of honeydew excretion, which reduces photosynthesis and plant vigour. Coconut, ornamental plants

and several other hosts are susceptible to infestation. Its recent detection highlights the need to strengthen pest surveillance and quarantine measures.

Eucalyptus weevil (*Gonipterus platensis*)

Invasive species can even occur in forestry ecosystems. The Eucalyptus weevil, which has been recently reported from the Nilgiri region of Tamil Nadu, poses a significant threat to eucalyptus plantations. Both larvae and adults feed on eucalyptus foliage, causing defoliation, reduced growth and decline in tree health. Since eucalyptus is widely cultivated for timber, pulp and fuelwood production, the establishment of this invasive pest could have economic implications for the forestry sector.

Fall armyworm (*Spodoptera frugiperda*)

The Fall armyworm is an invasive pest that has gained notoriety as the most destructive insect pest of Indian agriculture in the present day. Native to the Americas, it was first detected in India in 2018 and rapidly spread throughout the country. The pest attacks a wide range of crops including maize, sorghum, millets, sugarcane and many others. Larvae feed aggressively on both the leaves and growing points, causing severe crop damage. Due to its high reproductive capacity, ability to migrate long distances and wide host range, Fall Armyworm continues to challenge farmers and pest control specialists throughout India.

Tomato leaf miner (*Tuta absoluta*)

Tomato is an important vegetable crop in India and tomato leaf miner has become a major invasive pest affecting their production. The larvae mine leaves, stems, flowers, and fruits, causing significant crop losses. Infested tomato fruits become unfit for sale, reducing farmers' income. The rapid reproduction and ability to develop resistance to insecticides make management particularly difficult.



(E)



(F)

Rugose spiralling whitefly (*Aleurodicus rugioperculatus*)

The Rugose spiralling whitefly has emerged as a key pest in coconut and ornamental crops in many regions of South India. Due to heavy infestation by these insects, there is abundant production of honeydew, which results in the development of black sooty mold. The photosynthesis rate is greatly reduced in the affected plants. These pests pose a significant threat to coconut farms.

Common name	Scientific name	Major hosts	Nature of damage
Tobacco thrips	*Thrips parvispinus*	Chilli, capsicum, papaya, ornamentals	Leaf curling, flower drop, yield reduction
Invasive nesting whitefly	*Paraleyrodes pseudonaranjae*	Coconut, ornamentals	Honeydew secretion, sooty mould
Eucalyptus weevil	*Gonipterus platensis*	Eucalyptus	Defoliation and reduced tree growth
Fall armyworm	*Spodoptera frugiperda*	Maize, sorghum, millets	Severe leaf feeding and crop loss
Tomato leaf miner	*Tuta absoluta*	Tomato	Leaf mining and fruit damage
Rugose spiralling whitefly	*Aleurodicus rugioperculatus*	Coconut, banana, ornamentals	Sooty mould and reduced photosynthesis

Table 1. Major emerging invasive insect species threatening Indian agriculture

Impact on agriculture and biodiversity

The impact of invasive insects extends far beyond crop losses. For instance, farmers may have to incur considerable expenses in managing pests, thereby increasing production costs and reducing profitability. Invasive species can also displace native insects, disrupt ecological interactions and alter functioning within the ecosystem. Pollinators, natural enemies and other beneficial insects may be indirectly affected, leading to long-term biodiversity losses. Such ecological disturbances can weaken the resilience of agricultural and natural ecosystems.

Impact area	Consequences
Agriculture	Yield reduction and quality deterioration
Economy	Increased pest management costs
Food Security	Reduced crop production
Biodiversity	Displacement of native species
Environment	Ecological imbalance and habitat disruption
Trade	Quarantine restrictions and export challenges

Table 2. Economic and ecological impacts of invasive insects

Managing the invasion

Effective management of invasive insect species requires a combination of approaches. Regular surveillance, early detection, quarantine regulations, and public awareness program are essential components of successful invasive pest management. Farming communities should implement Integrated Pest Management (IPM) practices, such as field sanitation, biological control, pheromone traps and judicious use of insecticides. Research institutions, extension agencies and policymakers must work together to strengthen pest monitoring networks and develop sustainable management strategies. International cooperation is also important because invasive pests do not recognize geographical boundaries.

Role of quarantine and biosecurity

Preventing the introduction of invasive insects is often more effective and economical than managing them after establishment. Strict quarantine procedures, inspection of imported plant materials, surveillance and early detection systems play critical roles in preventing biological invasions. Strengthening national biosecurity systems can further reduce the risk of pest introductions.

Conclusion

Invasive insects have become a rising threat to India's agricultural productivity, forestry resources and biodiversity. Species such as Tobacco thrips, Invasive nesting whitefly, Eucalyptus weevil, Fall armyworm, Tomato leaf miner and Rugose spiralling whitefly illustrate the increasing vulnerability of crops and ecosystems to biological invasions. Strengthening surveillance systems, promoting sustainable pest management and raising public awareness will prove crucial in protecting India's agricultural productivity and ecological heritage. Through timely action and collective efforts, the threats posed by invasive insects can be minimized, ensuring a more resilient and sustainable future.

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ADVANCED MATERIALS AND ENVIRONMENTAL SUSTAINABILITY-REVIEW

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Abstract

This review examines recent advances in advanced materials that support environmental sustainability, focusing on carbon-based materials (biochar, graphene-derived materials), biodegradable and biobased polymers, recyclable photovoltaic materials (perovskites), and safe-by-design nanomaterials. We discuss synthesis routes, life-cycle considerations, environmental impacts, applications (soil amendment, water treatment, energy harvesting, and packaging), challenges for scale-up, and research gaps. A comparative table summarizes material properties and sustainability trade-offs. Recommendations for future research and policy are given.

1. Introduction

The accelerating demand for high-performance materials across energy, electronics, agriculture, and packaging sectors must be balanced with environmental stewardship. Advanced materials can both exacerbate environmental burdens (through resource extraction, energy-intensive synthesis, and end-of-life waste) and enable solutions (carbon sequestration, pollution remediation, energy efficiency). This paper synthesizes the current state-of-the-art and highlights pathways to align materials innovation with sustainability goals.

2. Carbon-based materials and biochar

2.1 Production and properties

Biochar is produced by pyrolysis of biomass under limited oxygen; feedstock and

pyrolysis conditions control porosity, surface chemistry, and stability. These properties determine performance in soil amendment and carbon sequestration.

2.2 Environmental roles and applications

Biochar increases soil water retention, nutrient retention, and microbial habitat while acting as a stable carbon sink when properly produced and applied. It also functions in water treatment and as a precursor for carbon-based electrodes.

3. Biodegradable and biobased polymers

Recent advances in polylactic acid (PLA), polyhydroxyalkanoates (PHA), starch-based blends, and novel microbial-sourced polymers have improved mechanical properties and broadened applications (packaging, agricultural mulch films, biomedical). However, biodegradability depends strongly on environmental conditions and feedstock sourcing influences lifecycle impacts.

4. Photovoltaics and recyclable perovskites

Perovskite solar cells (PSCs) offer high efficiency and low-cost manufacturing, yet concerns over lead content and end-of-life management necessitate recycling strategies. Layer-by-layer solvent extraction and aqueous-based recycling approaches have been demonstrated to recover valuable materials and substantially reduce waste.

5. Nanomaterials: MXenes, graphene, and safety-by-design

Two-dimensional materials such as graphene and MXenes provide exceptional electrical, mechanical, and catalytic properties. Their environmental footprint depends on synthesis methods, scalability, and potential ecotoxicity. Safe-by-design approaches and sustainability assessment frameworks are essential before large-scale deployment.

6. Life-cycle assessment (LCA) and circularity

Applying LCA early in material development identifies hotspots (energy use, toxic precursors, end-of-life). Circular design—repair, reuse, recycling, and recovery—reduces overall environmental burden and conserves critical raw materials.

7. Comparative table of materials

7a. Thematic Datasets and Graphical Summaries

Dataset 1: Biochar Properties

Feedstock	Surface Area (m^2/g)	pH	Fixed Carbon (%)	Yield (%)

Rice Husk Biochar	**210**	**8.9**	**68**	**32**
Coconut Shell Biochar	**450**	**9.4**	**78**	**28**
Sugarcane Bagasse Biochar	**320**	**8.2**	**62**	**35**
Wood Biochar	**150**	**7.5**	**55**	**40**

Dataset 2: Biodegradable Polymers Performance

Polymer Type	**Day 0 Degradation (%)**	**Day 30 Degradation (%)**	**Day 60 Degradation (%)**	**Tensile Strength (MPa)**
PLA	**0**	**12**	**28**	**55**
PHA	**0**	**35**	**70**	**42**
Starch-based Blend	**0**	**50**	**85**	**18**
Cellulose Acetate	**0**	**8**	**20**	**48**

Dataset 3: Perovskite Solar Cell Performance

Year	**Efficiency (%)**	**Stability After 1000 h (%)**	**Recycling Recovery (%)**
2018	**20.1**	**70**	**55**
2020	**22.7**	**76**	**63**
2022	**24.5**	**82**	**71**
2024	**26.1**	**88**	**79**

Dataset 4: Nanomaterials Sustainability Metrics

Material	**Conductivity (S/cm)**	**Toxicity Index (1–10)**	**Lifecycle Impact Score (1–100)**
Graphene	**1200**	**3**	**45**
MXene ($Ti_3C_2T_x$)	**800**	**4**	**50**
Carbon Nanotube	**1000**	**6**	**65**
Cellulose Nanofiber	**12**	**1**	**20**

8. Representative figures (properties & sustainability trade-offs)

Material class	Key benefits	Main environmental concerns	Typical applications	Readiness/scale
Biochar	Soil improvement, carbon sequestration, low-cost feedstocks	Variable stability; transport and quality control	Agriculture, remediation	Pilot → regional scale
Biodegradable polymers (PLA, PHA)	Reduced persistence in environment; renewable feedstocks	Incomplete degradation in natural environments; feedstock competition	Packaging, mulch films, biomedical	Commercial for select products
Perovskite PV (with recycling)	High efficiency; low-temp fabrication	Lead content; EoL waste if unrecycled	Solar modules	Lab → early commercialization
Graphene & MXenes	High conductivity, mechanical strength	Energy-intensive synthesis; potential ecotoxicity	Electronics, sensors, catalysts	Emerging → scalable methods in development
Nanocomposites (bio-based)	Improved mechanical/functional properties	Nanoparticle release risk; recyclability challenges	Lightweight components, filtration	Emerging

9. Challenges and research gaps. Challenges and research gaps

- Standardized metrics for material sustainability (e.g., consistent LCA boundaries).
- Scalable, low-energy synthesis routes for advanced materials.
- Safe-by-design frameworks and ecotoxicology data for nanomaterials.
- Robust recycling and recovery methods for emerging electronics (e.g., perovskites).
- Socioeconomic analyses of feedstock sourcing for biobased materials.

10. Recommendations

- Integrate LCA and circularity thinking at the earliest design stages.

- Prioritize development of non-toxic or easily recoverable functional materials.
- Foster interdisciplinary collaborations between materials scientists, ecotoxicologists, and policy experts.
- Promote demonstration projects that validate performance and environmental benefits at scale.

Conclusion

Advanced materials can substantially contribute to environmental sustainability if developed, assessed, and deployed with circularity and safety in mind. Continued research to close knowledge gaps, standardized assessment methods, and technology transfer pathways will accelerate the sustainable adoption of these practices.

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SEAWEED PROCESSING: TRANSFORMING MARINE RESOURCES INTO HIGH-VALUE PRODUCTS

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Abstract

Seaweeds are important marine resources widely used in food, pharmaceutical, cosmetic and agricultural industries. Due to their high moisture content, fresh seaweeds require processing to improve shelf life and quality. Common processing methods include cleaning, drying, grinding, hydrocolloid extraction and packaging. These techniques help produce value-added products such as seaweed powder, agar, alginate and carrageenan. Seaweed processing contributes to economic development, food security and environmental sustainability, making it an important sector in the blue economy.

Keywords:

Seaweed Processing, Marine Resources, Value Addition, Agar, Alginate, Carrageenan, Sustainable Development.

Introduction:

Seaweeds are marine algae that grow naturally in coastal waters and are considered one of the most valuable resources of the ocean. They are rich in proteins, vitamins, minerals, dietary fiber and bioactive compounds. Due to their nutritional and industrial importance, seaweeds are gaining worldwide attention as sustainable raw materials for food, pharmaceutical and cosmetic industries.

India possesses a long coastline with favorable environmental conditions for seaweed cultivation. Species such as *Kappaphycus alvarezii*, *Gracilaria edulis* and *Sargassum wightii* are widely utilized for commercial purposes.



Importance of Seaweed Processing

Freshly harvested seaweeds contain high moisture content and are highly perishable. Processing helps to:

- Extend shelf life
- Maintain product quality
- Improve safety and hygiene
- Facilitate transportation and storage
- Produce value-added products with higher market value

Thus, processing transforms raw seaweeds into commercially valuable products.

Major Seaweed Processing Technologies

1. Cleaning and Washing

Harvested seaweeds are washed thoroughly with clean water to remove sand, salts, shells and other impurities. Proper washing improves product quality and safety.

2. Drying

Drying is the most common preservation method used in seaweed processing. Traditional sun drying and mechanical drying methods are widely employed.

Benefits of drying include:

- Reduction of moisture content
- Prevention of microbial growth
- Easier storage and transportation
- Increased shelf life

3. Grinding and Powder Production

Dried seaweeds are ground into fine powder. Seaweed powder is used in:

- Nutritional supplements

- Functional foods
- Bakery products
- Animal feed formulations

4. Extraction of Hydrocolloids

Seaweeds are important sources of industrial hydrocolloids such as:

- Agar
- Alginate
- Carrageenan

These compounds are extensively used as gelling, thickening and stabilizing agents in food and pharmaceutical industries.

5. Packaging and Storage

Processed seaweed products are packed in moisture-proof materials to maintain quality during storage and marketing.



Value-Added Seaweed Products

Seaweed processing enables the production of numerous value-added products including:

- Seaweed powder
- Seaweed snacks
- Seaweed noodles
- Seaweed beverages
- Seaweed jelly
- Agar products
- Carrageenan products

- Alginate products
- Organic fertilizers
- Animal feed supplements

These products generate higher income compared to selling raw seaweed.



Applications of Seaweed Products

Food Industry

Seaweeds are used as ingredients in soups, salads, snacks and health foods. Hydrocolloids extracted from seaweeds improve texture and stability of many food products.

Pharmaceutical Industry

Seaweeds contain bioactive compounds with antioxidant, antimicrobial and anti-inflammatory properties. These compounds are used in medicines and health supplements.

Cosmetic Industry

Seaweed extracts are incorporated into skin care products, shampoos and beauty formulations due to their moisturizing and nourishing properties.

Agriculture

Seaweed-based fertilizers and plant growth stimulants improve crop productivity and soil health.

Economic and Environmental Benefits

Seaweed processing offers several benefits:

- Generates employment opportunities
- Supports coastal livelihoods
- Increases export earnings
- Promotes sustainable utilization of marine resources
- Reduces pressure on land-based agriculture

- Contributes to environmental sustainability

Future Prospects

The global demand for natural and sustainable products is increasing rapidly. Advances in processing technologies are creating new opportunities for developing innovative seaweed-based foods, pharmaceuticals and biodegradable packaging materials. With growing consumer awareness and government support, seaweed processing has the potential to become an important component of the blue economy.

Conclusion

Seaweed processing plays a vital role in converting marine resources into high-value products. Through drying, extraction, packaging and value addition, seaweeds can be transformed into products with applications in food, pharmaceutical, cosmetic and agricultural sectors. As a sustainable and eco-friendly resource, seaweed offers significant opportunities for economic development and environmental conservation, making it an important resource for the future.

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EVOLUTION AND ADVANCES IN NEXT-GENERATION SEQUENCING TECHNOLOGIES

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Introduction

The development of DNA sequencing technologies has fundamentally transformed biological and biomedical research by enabling the exploration of genomes, transcriptomes, and molecular regulatory mechanisms at unprecedented resolution. DNA sequencing methods have evolved considerably from early labor-intensive techniques to highly sophisticated high-throughput sequencing platforms capable of generating massive amounts of genomic information within a short period. These technological developments have revolutionized diverse research areas including genomics, transcriptomics, epigenetics, metagenomics, clinical diagnostics, and precision medicine. The ability to accurately determine nucleotide sequences is essential for understanding genetic variation, identifying disease-associated genes, studying molecular evolution, and improving livestock breeding programs. Traditional sequencing approaches initially provided valuable information for small genomic regions; however, their limited throughput and high cost restricted large-scale applications. Subsequent technological innovations led to the emergence of microarray-based approaches and eventually to Next-Generation Sequencing (NGS), which substantially enhanced sequencing efficiency and analytical capabilities.

Evolution of DNA Sequencing Technologies

Early sequencing technologies emerged during the 1970s, with the chain-termination method developed by Frederick Sanger becoming one of the most widely adopted sequencing techniques. The Sanger dideoxynucleotide sequencing method utilized chain-terminating

nucleotides for accurate determination of DNA sequences (Sanger *et al.,* 1977). Alternative approaches including partial ribosubstitution sequencing, plus and minus sequencing, and chemical cleavage sequencing also contributed significantly to the foundation of molecular genetics and genome analysis (Barnes, 1978; Sanger and Coulson, 1975; Maxam and Gilbert, 1977).

Initially, sequencing applications focused primarily on individual genes and small genomes due to technological limitations. Improvements in computational methods and sequence assembly programs later enabled efficient analysis of larger genomic regions (Staden, 1979; Staden, 1984; Staden *et al.,* 2000). During the 1990s, DNA microarrays became important tools for large-scale gene expression studies. Techniques such as Expressed Sequence Tags (ESTs) and Serial Analysis of Gene Expression (SAGE) provided initial high-throughput transcriptomic approaches (Adams *et al.,* 1992; Velculescu *et al.,* 1995). Subsequently, complementary DNA microarrays and high-density hybridization arrays enabled rapid transcript profiling (Schena *et al.,* 1995; Lockhart *et al.,* 1996). However, microarray-based systems depended on pre-designed probes and were affected by hybridization bias and reduced sensitivity for detecting low-abundance transcripts (Graveley, 2008).

Emergence of Next-Generation Sequencing

The introduction of Next-Generation Sequencing (NGS), also referred to as massively parallel sequencing, represented a major advancement in molecular biology. NGS enabled simultaneous sequencing of millions of DNA fragments in a single run, dramatically increasing sequencing throughput while reducing costs (Pettersson *et al.,* 2009; Bosch and Grody, 2008). Unlike Sanger sequencing, which generates relatively long reads from individually amplified fragments, NGS technologies produce millions of shorter reads that can be analyzed simultaneously. The high-throughput capability of NGS enabled targeted genomic studies through DNA capture methods and exome sequencing (Ng *et al.,* 2009). Furthermore, RNA sequencing (RNA-Seq) emerged as an important application of NGS for comprehensive transcriptome analysis without prior sequence information (Wang *et al.,* 2009). The application of NGS expanded rapidly beyond DNA sequencing into epigenomic and functional genomic studies. High-throughput sequencing approaches enabled genome-wide analysis of DNA methylation and histone modifications, replacing many conventional microarray-based methods (Lister and Ecker, 2009; Morozova and Marra, 2008).



Major Next-Generation Sequencing Approaches

Sequencing by Ligation (SBL)

Sequencing by ligation involves hybridization of fluorescently labeled oligonucleotide probes to complementary DNA templates followed by ligation of adjacent probes. The emitted fluorescence signals identify nucleotide positions within the sequence. The SOLiD sequencing platform represents one of the most widely recognized SBL systems. SOLiD employs a two-base encoding strategy in which each fluorescent signal corresponds to a dinucleotide rather than an individual nucleotide (Valouev *et al.*, 2008). Multiple rounds of ligation, imaging, and cleavage improve sequence accuracy by interrogating each nucleotide repeatedly.

Sequencing by Synthesis (SBS)

Sequencing by synthesis relies on DNA polymerase-mediated nucleotide incorporation into a growing DNA strand. Each incorporated nucleotide generates a detectable signal allowing real-time sequence determination.

Important SBS-based technologies include:

454 Pyrosequencing:

DNA fragments are attached to beads and amplified through emulsion PCR. Pyrophosphate released during nucleotide incorporation generates ATP, which subsequently drives luciferase-mediated light production detectable by imaging systems (Metzker, 2010).

Ion Torrent Sequencing:

Ion Torrent technology detects hydrogen ions released during nucleotide incorporation rather than fluorescence signals. These pH changes are measured using semiconductor sensors and converted into nucleotide sequence information (Metzker, 2010).

Long-Read Sequencing Technologies

Short-read sequencing platforms provide high throughput but often face challenges in repetitive regions, structural variation analysis, and genome assembly. To address these limitations, long-read technologies were developed.

Single-Molecule Real-Time Sequencing

Pacific Biosciences Single-Molecule Real-Time (SMRT) sequencing utilizes circular DNA templates and zero-mode waveguides for real-time nucleotide detection. Fluorescent signals generated during DNA synthesis allow generation of long sequencing reads useful for structural variant analysis and transcript isoform characterization.

Oxford Nanopore Sequencing

Oxford Nanopore technology determines DNA sequences by measuring electrical current disruptions generated as nucleic acid molecules pass through biological nanopores. This technology enables ultra-long reads and direct sequencing of native DNA or RNA molecules.

Synthetic Long-Read Sequencing

Synthetic long-read approaches combine the accuracy of short-read sequencing with long-range genomic information. Examples include Illumina TruSeq Synthetic Long Reads and 10X Genomics linked-read sequencing systems (McCoy *et al.*, 2014).

Improvements in NGS Accuracy

Numerous technological advancements have improved NGS accuracy and efficiency. Template tagging methods reduce PCR-induced errors (Cervantes *et al.*, 2002; Kivioja *et al.*, 2012; Schmitta *et al.*, 2012). High-fidelity polymerases improve sequence reliability (Chen *et al.*, 2014), whereas amplification-free sequencing methods reduce amplification bias (Kozarewa *et al.*, 2009). Duplex sequencing and dual-base encoding strategies further enhance sequencing precision (Valouev *et al.*, 2008; Ronchi *et al.*, 2012).

Conclusion

Next-generation sequencing technologies have transformed modern biological research through substantial improvements in sequencing speed, throughput, and analytical capabilities.

Continuous technological evolution from conventional Sanger sequencing to sophisticated long-read and spatially resolved platforms has enabled comprehensive investigation of complex biological systems. Future developments focusing on improved sequencing accuracy, computational approaches, and integrated multi-omics analyses are expected to further expand the applications of NGS in genomics research, clinical medicine, and livestock improvement programs.

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COLD PLASMA TREATMENT FOR FOOD PRESERVATION: PRINCIPLES, MECHANISMS, APPLICATIONS AND FUTURE PERSPECTIVES

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Introduction

The food industry is continuously challenged to provide products that are safe, nutritious, minimally processed, and possess an extended shelf life while meeting the increasing consumer demand for fresh-like quality. Food spoilage caused by microorganisms, enzymatic reactions, oxidation, and environmental contamination remains one of the major causes of post-harvest losses worldwide. According to the Food and Agriculture Organization (FAO), approximately one-third of all food produced globally is lost or wasted each year, amounting to nearly 1.3 billion tonnes. A significant proportion of these losses is attributed to microbial spoilage and inadequate preservation technologies. Conventional preservation methods such as thermal pasteurization, sterilization, drying, freezing, irradiation, and chemical preservatives have been widely employed to improve food safety and extend storage life. Although these techniques are highly effective in controlling microbial contamination, they frequently induce undesirable changes in food quality, including nutrient degradation, colour loss, texture softening, flavour deterioration, and destruction of heat-sensitive bioactive compounds. Consequently, there has been increasing interest in developing innovative non-thermal technologies capable of ensuring microbial safety while preserving the fresh characteristics of foods.

Among the various emerging preservation technologies, cold plasma has gained considerable attention because it offers rapid microbial inactivation without significantly increasing product temperature. Cold plasma, also referred to as non-thermal plasma, is

generated by partially ionizing a gas under the influence of an electric field, resulting in a mixture of energetic electrons, ions, radicals, excited molecules, ultraviolet photons, and neutral gas particles. Unlike thermal plasma, in which all particles are at thermal equilibrium and exhibit temperatures of several thousand degrees Celsius, cold plasma operates near ambient temperature because only the electrons possess high kinetic energy while the heavy particles remain relatively cool. This unique characteristic makes cold plasma particularly suitable for preserving heat-sensitive food materials such as fresh fruits, vegetables, meat, seafood, dairy products, spices, cereals, nuts, seeds, and ready-to-eat foods.

The effectiveness of cold plasma arises from the synergistic action of several reactive components generated during the discharge process. Reactive oxygen species (ROS), including atomic oxygen, hydroxyl radicals, ozone, singlet oxygen, and hydrogen peroxide, together with reactive nitrogen species (RNS), such as nitric oxide, nitrogen dioxide, and peroxynitrite, interact with microbial cells through multiple pathways. These species oxidize membrane lipids, denature proteins, disrupt enzyme activity, damage nucleic acids, and ultimately cause irreversible cell death. Since microbial inactivation occurs through several simultaneous mechanisms, the probability of microorganisms developing resistance is considerably lower than that associated with conventional antimicrobial agents. Furthermore, cold plasma treatment leaves minimal chemical residues, requires relatively low energy consumption, and can be generated using atmospheric air or inert gases, making it an environmentally sustainable technology.

Cold plasma has been investigated for numerous food-processing applications, including surface decontamination, shelf-life extension, enzyme inactivation, mycotoxin degradation, pesticide removal, seed treatment, food packaging sterilization, and the production of plasma-activated water (PAW). Plasma-activated water has emerged as an eco-friendly sanitizer because it contains long-lived reactive oxygen and nitrogen species capable of maintaining antimicrobial activity even after plasma generation has ceased. This technology has shown considerable promise as a substitute for chlorine-based washing solutions commonly used in the fresh produce industry. Recent advances have also demonstrated the potential of integrating cold plasma with other emerging technologies such as high-pressure processing, pulsed electric fields, ultraviolet-C irradiation, ultrasound, and edible coatings to further enhance food preservation efficiency while minimizing quality deterioration.

The increasing scientific interest in cold plasma is reflected in the rapid growth of publications over the past two decades. Initially explored for applications in semiconductor manufacturing and biomedical sterilization, plasma technology has now become an important area of research in food engineering. Numerous laboratory-scale and pilot-scale studies have demonstrated its ability to reduce populations of pathogenic microorganisms such as *Escherichia coli*, *Salmonella enterica*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Bacillus cereus*, and various spoilage fungi on different food matrices. In addition to microbial safety, researchers have reported improvements in seed germination, extraction of bioactive compounds, modification of starch and protein functionality, and enhancement of packaging material properties through plasma treatment. These findings indicate that cold plasma is not merely a preservation technology but also a versatile processing tool capable of improving several functional characteristics of foods.

The commercial adoption of cold plasma is expected to increase substantially during the coming decade due to growing consumer preference for clean-label products and sustainable processing technologies. Nevertheless, challenges remain regarding process standardization, optimization of operating parameters, regulatory approval, and scale-up for continuous industrial operations. The interaction between plasma-generated reactive species and complex food matrices also requires further investigation to ensure consistent treatment efficacy without adversely affecting nutritional and sensory quality. Therefore, comprehensive knowledge of plasma physics, plasma chemistry, microbial inactivation mechanisms, food quality changes, and engineering aspects is essential for successful industrial implementation. This chapter provides an in-depth discussion of the principles, generation techniques, antimicrobial mechanisms, applications, advantages, limitations, and future prospects of cold plasma technology for food preservation.

2. History and Development of Cold Plasma

The scientific concept of plasma dates back to the nineteenth century, when researchers began investigating the electrical behaviour of gases under reduced pressure. In 1879, the English physicist Sir William Crookes observed that gases subjected to high voltages inside partially evacuated tubes produced a luminous discharge distinct from solids, liquids, and ordinary gases. These observations led to the recognition of ionized gases as a unique state of matter. However, the term "plasma" was not introduced until 1928, when the American physicist

Irving Langmuir described ionized gases containing electrons and positive ions that collectively exhibited unique electrical behaviour. Langmuir compared the ionized gas to blood plasma because it carried charged particles in a manner analogous to the transport of blood cells. His pioneering work established the foundation of plasma physics, which subsequently evolved into an important discipline in both fundamental science and industrial engineering.

During the mid-twentieth century, plasma research expanded rapidly due to developments in nuclear fusion, aerospace engineering, semiconductor manufacturing, and materials science. Thermal plasma systems capable of generating extremely high temperatures were developed for welding, cutting, spraying, and metallurgical operations. Although these applications demonstrated the remarkable versatility of plasma technology, the extremely high operating temperatures made thermal plasma unsuitable for biological materials and food products. The development of non-equilibrium or non-thermal plasma represented a major breakthrough because it allowed the generation of highly reactive species while maintaining the bulk gas temperature close to ambient conditions. This innovation opened new opportunities for biomedical sterilization, wound healing, surface modification, and eventually food preservation.

The application of cold plasma in microbiology began during the 1990s, when researchers demonstrated its ability to inactivate bacteria and bacterial spores without causing excessive heating. Early studies primarily focused on sterilization of medical instruments, pharmaceutical packaging, and surgical equipment. The successful elimination of resistant microorganisms stimulated interest in applying plasma technology to food processing, where microbial contamination represents one of the principal causes of spoilage and foodborne illness. Initial investigations concentrated on decontamination of food contact surfaces and packaging materials, followed by direct treatment of fresh produce, meat, cereals, spices, and dairy products. The favourable outcomes of these studies encouraged researchers worldwide to explore plasma technology as an alternative to conventional preservation methods.

During the past two decades, advancements in electrical engineering have resulted in the development of several atmospheric-pressure plasma systems suitable for food applications, including dielectric barrier discharge reactors, plasma jets, corona discharge devices, radio-frequency plasma systems, and gliding arc reactors. These systems eliminate the need for expensive vacuum chambers, thereby reducing operational costs and improving industrial feasibility. Modern plasma generators are capable of producing stable discharges under

atmospheric conditions using air, oxygen, nitrogen, helium, argon, or mixtures of these gases. The flexibility of gas composition enables researchers to tailor the generation of reactive oxygen and nitrogen species according to the desired food application. As a result, cold plasma has evolved into one of the most actively investigated non-thermal preservation technologies in contemporary food science.

3. Fundamentals of Plasma Physics

Plasma is widely recognized as the fourth fundamental state of matter, complementing solids, liquids, and gases. When a gas receives sufficient external energy, either in the form of heat, electrical energy, electromagnetic radiation, or particle bombardment, the kinetic energy of electrons increases dramatically. Energetic electrons collide with neutral gas molecules, causing ionization through the removal of electrons from atoms or molecules. This process generates a complex mixture consisting of free electrons, positive ions, negative ions, neutral atoms, excited molecules, radicals, photons, and electromagnetic fields. The resulting ionized gas exhibits collective behaviour governed by long-range electromagnetic interactions rather than simple molecular collisions, distinguishing plasma from ordinary gases.

Unlike solids, liquids, and gases, plasma is electrically conductive because of the presence of mobile charged particles. Electrons possess considerably lower mass than ions and therefore respond much more rapidly to externally applied electric fields. In cold plasma systems, electrons typically attain temperatures equivalent to several thousand degrees Kelvin, whereas the heavier ions and neutral gas molecules remain close to room temperature. This non-equilibrium condition enables energetic electron-driven chemical reactions without significantly heating the treated material. Consequently, cold plasma can effectively process heat-sensitive biological materials, including fresh foods, pharmaceuticals, and living tissues.

One of the defining characteristics of plasma is quasi-neutrality, whereby the overall densities of positive and negative charges remain nearly equal, despite local fluctuations. Another important property is Debye shielding, which refers to the ability of plasma to screen electric fields over very short distances through redistribution of charged particles. These characteristics allow plasma to behave collectively rather than as individual particles. The degree of ionization, electron density, electron temperature, gas pressure, and gas composition collectively determine the physical and chemical behaviour of plasma.

In food processing, atmospheric-pressure cold plasma is preferred because it eliminates the need for vacuum systems and can be integrated into continuous processing lines. High-voltage alternating current, pulsed direct current, microwave energy, or radio-frequency power is applied between electrodes to ionize the surrounding gas. The energetic electrons subsequently generate a variety of reactive oxygen and nitrogen species through collisions with oxygen, nitrogen, and water vapour molecules present in the surrounding atmosphere. These reactive species are primarily responsible for microbial inactivation, enzyme modification, oxidation–reduction reactions, and changes in food surface chemistry. Understanding the physical principles governing plasma generation is therefore essential for

4. Classification of Plasma

Plasma can be classified in several ways depending on its thermodynamic equilibrium, operating pressure, ionization degree, energy distribution, and method of generation. Among these classifications, the distinction between thermal plasma and non-thermal plasma is the most important for food processing applications. The selection of a particular plasma type depends on the intended industrial application, the characteristics of the material being treated, and the desired physicochemical changes. In food preservation, non-thermal plasma has attracted considerable interest because it provides effective microbial decontamination while maintaining the structural, nutritional, and sensory integrity of foods.

Thermal plasma, also referred to as equilibrium plasma or hot plasma, is characterized by the thermal equilibrium between electrons, ions, and neutral gas molecules. In this type of plasma, all particles possess nearly identical temperatures, often ranging from 5,000 to 20,000 K. Because of these extremely high temperatures, thermal plasma is widely employed in industrial applications such as metal cutting, welding, plasma spraying, waste destruction, and material synthesis. The intense heat generated during thermal plasma treatment rapidly destroys microorganisms; however, it also causes extensive thermal degradation of biological materials. Consequently, thermal plasma is unsuitable for processing fresh foods, where preservation of nutrients, flavour, colour, and texture is of primary importance.

In contrast, non-thermal plasma, commonly known as cold plasma, is a non-equilibrium plasma in which electrons possess high kinetic energy while ions and neutral gas molecules remain close to room temperature. The electron temperature may reach several thousand Kelvin, whereas the gas temperature generally remains between 25 and 60°C. This non-equilibrium

energy distribution enables energetic electrons to initiate ionization, excitation, and dissociation reactions without significantly heating the food product. Cold plasma therefore combines high antimicrobial efficacy with minimal thermal damage, making it particularly suitable for preserving heat-sensitive fruits, vegetables, meat, seafood, dairy products, cereals, spices, nuts, and ready-to-eat foods. The preservation of food quality during plasma treatment has been consistently demonstrated in numerous laboratory and pilot-scale investigations.

Based on operating pressure, plasma systems are classified into low-pressure plasma and atmospheric-pressure plasma. Low-pressure plasma requires a vacuum chamber in which gas pressure is reduced before electrical discharge is initiated. Vacuum systems produce highly stable plasma and allow precise control of plasma chemistry, making them useful for laboratory studies, medical device sterilization, and surface modification of packaging materials. However, the requirement for vacuum pumps increases operational costs and limits their suitability for continuous industrial food processing.

Atmospheric-pressure plasma operates under normal atmospheric conditions and therefore eliminates the need for vacuum equipment. Atmospheric plasma systems are easier to integrate into commercial food processing lines and are currently the most widely investigated plasma systems for industrial food applications. They allow continuous treatment of fresh produce, meat products, grains, packaging materials, and conveyor-based processing operations with relatively low installation costs. Their flexibility and operational simplicity have accelerated research on commercial implementation.

Plasma may also be classified according to its degree of ionization. Fully ionized plasma contains nearly complete ionization of gas molecules and is commonly observed in stars and high-temperature fusion reactors. Partially ionized plasma contains only a small fraction of ionized particles, while the majority of gas molecules remain electrically neutral. Cold plasma used in food processing belongs to this category, with ionization levels generally below one percent. Despite the relatively low ionization degree, sufficient reactive oxygen and nitrogen species are generated to achieve effective microbial inactivation.

Another classification is based on the excitation source employed for plasma generation. Direct current (DC) plasma utilizes a constant electrical potential to generate ionization and is relatively simple to operate. Alternating current (AC) plasma employs alternating voltage and is frequently used in dielectric barrier discharge systems. Radio-frequency plasma utilizes

electromagnetic waves with frequencies typically around 13.56 MHz to generate highly uniform plasma discharges suitable for delicate materials. Microwave plasma operates at frequencies of approximately 2.45 GHz and produces dense populations of reactive species without direct electrode contact. Pulsed plasma systems employ short-duration, high-voltage electrical pulses that improve energy efficiency while minimizing thermal effects. Each excitation method produces unique plasma characteristics that influence microbial inactivation, surface modification, and chemical reactions during food processing.

The selection of plasma type depends not only on antimicrobial effectiveness but also on food composition, moisture content, surface roughness, desired treatment depth, processing capacity, and economic considerations. Fresh fruits and vegetables with delicate tissues generally require mild atmospheric cold plasma treatments, whereas packaging sterilization or dry spice decontamination may tolerate more intense plasma conditions. Consequently, optimization of plasma classification and operating parameters plays a crucial role in achieving maximum preservation efficiency while maintaining food quality.

5. Cold Plasma Generation Techniques

Cold plasma can be generated using several reactor configurations that differ in electrode design, electrical power supply, gas composition, operating pressure, and plasma discharge characteristics. The choice of reactor influences the concentration of reactive species, treatment uniformity, energy efficiency, and suitability for different food products. Among the various plasma generation techniques, dielectric barrier discharge (DBD), atmospheric pressure plasma jet (APPJ), corona discharge, radio-frequency plasma, microwave plasma, gliding arc plasma, and surface dielectric barrier discharge are the most extensively investigated in food science.

Dielectric barrier discharge is considered the most widely used cold plasma system for food preservation because of its simplicity, reliability, and ability to generate stable plasma under atmospheric conditions. A DBD reactor consists of two electrodes separated by one or more dielectric insulating materials such as glass, quartz, ceramic, or polymer sheets. When high alternating voltage is applied across the electrodes, numerous micro-discharges are produced within the gas gap, generating plasma without forming a continuous electrical arc. The dielectric barrier limits the discharge current, preventing excessive heating and ensuring non-thermal operation. DBD systems are highly effective for decontaminating fresh produce, grains, spices,

meat surfaces, food packaging materials, and processing equipment. Their large treatment area and relatively low operating costs make them attractive for industrial-scale applications.

Atmospheric pressure plasma jet technology generates plasma within a confined chamber before ejecting it through a nozzle toward the food surface. Unlike DBD reactors, plasma is generated independently of the sample, allowing treatment of irregularly shaped products without requiring direct electrode contact. Plasma jets commonly employ helium or argon as carrier gases because these gases facilitate stable plasma generation at relatively low voltages. Small quantities of oxygen or nitrogen are frequently added to increase the production of reactive oxygen and nitrogen species. Atmospheric plasma jets have demonstrated excellent antimicrobial activity on fruits, vegetables, meat, seafood, and medical devices. Their localized treatment capability makes them particularly suitable for precision applications where only selected portions of a product require plasma exposure.

Corona discharge represents one of the simplest methods for generating atmospheric cold plasma. Plasma is produced when a high electric field develops around sharp electrode tips or thin wires, resulting in localized ionization of the surrounding gas. Corona discharge reactors consume relatively little energy and are widely used for surface sterilization, polymer activation, packaging modification, and ozone generation. Although corona discharge systems generate lower plasma densities than dielectric barrier discharge reactors, they remain effective for surface decontamination of dry foods and packaging materials.

Radio-frequency plasma systems utilize alternating electromagnetic fields, commonly operating at 13.56 MHz, to sustain plasma discharges. These reactors produce highly uniform plasma with excellent control over electron density and reactive species generation. Because radio-frequency plasma can be generated at both low and atmospheric pressures, it has found applications in food packaging modification, enzyme immobilization, protein surface modification, and sterilization of sensitive food materials. The absence of direct electrode contact reduces contamination and improves treatment consistency.

Microwave plasma generation employs microwave electromagnetic radiation to ionize gases without direct electrical electrodes. Microwave plasma reactors produce high densities of energetic electrons and reactive radicals while maintaining relatively low gas temperatures. Their high energy efficiency has attracted attention for continuous food processing, although equipment costs remain relatively high compared with conventional DBD systems. Microwave

plasma is also widely investigated for degradation of pesticide residues, wastewater treatment, and environmental remediation associated with food industries.

Gliding arc plasma combines characteristics of thermal and non-thermal plasma. Electrical discharge initially forms between closely spaced electrodes and subsequently elongates due to gas flow, creating a moving plasma arc. During expansion, the plasma cools rapidly while maintaining high concentrations of chemically reactive species. Gliding arc reactors have demonstrated promising antimicrobial activity against bacterial spores and fungal contaminants on agricultural commodities. Their relatively high power output makes them suitable for industrial disinfection processes requiring rapid treatment.

Surface dielectric barrier discharge reactors represent another important plasma configuration. In these systems, plasma propagates along the surface of a dielectric material rather than within the space between electrodes. Surface DBD systems are particularly useful for treating packaging films, polymer materials, conveyor belts, and food contact surfaces because they generate highly uniform plasma over large areas. Surface activation by plasma improves wettability, adhesion, printability, and antimicrobial properties of packaging materials.

Regardless of reactor design, several operational parameters determine plasma efficiency, including applied voltage, electrical frequency, power input, gas composition, humidity, gas flow rate, electrode spacing, treatment duration, and environmental temperature. Optimization of these parameters is essential because excessive plasma exposure may induce oxidative changes in sensitive food components, whereas insufficient treatment may fail to achieve adequate microbial reduction. Recent engineering advances focus on developing compact, energy-efficient, continuous-flow plasma systems capable of processing large quantities of food under industrial conditions.

6. Reactive Oxygen Species (ROS) and Reactive Nitrogen Species (RNS)

The antimicrobial effectiveness of cold plasma is primarily attributed to the formation of reactive oxygen species (ROS) and reactive nitrogen species (RNS), which collectively create an extremely hostile chemical environment for microorganisms. These reactive species originate through electron collisions with oxygen, nitrogen, and water vapour molecules present in the surrounding gas. Because electrons possess much higher kinetic energy than heavy particles, they efficiently dissociate and ionize gas molecules, initiating a cascade of chemical reactions that generate numerous short-lived and long-lived reactive compounds.

Reactive oxygen species constitute one of the most important groups of plasma-generated antimicrobial agents. They include atomic oxygen (O), singlet oxygen (^1O_2), ozone (O_3), hydroxyl radicals (•OH), superoxide anions (O_2•$^-$), hydrogen peroxide (H_2O_2), hydroperoxyl radicals (HO_2•), and various oxygen-containing excited molecules. Among these species, hydroxyl radicals exhibit exceptionally high oxidation potential and readily attack membrane lipids, proteins, nucleic acids, and polysaccharides. Ozone acts as a powerful oxidizing agent capable of disrupting microbial cell membranes and degrading organic contaminants. Hydrogen peroxide serves as a relatively long-lived antimicrobial compound that can penetrate microbial cells and participate in secondary oxidation reactions.

Reactive nitrogen species are generated primarily from nitrogen molecules and atmospheric oxygen during plasma discharge. Important RNS include nitric oxide (NO), nitrogen dioxide (NO_2), nitrous acid (HNO_2), nitric acid (HNO_3), dinitrogen pentoxide (N_2O_5), and peroxynitrite ($ONOO^-$). Nitric oxide functions as a signalling molecule in biological systems but exhibits potent antimicrobial activity when combined with reactive oxygen species. Peroxynitrite, formed through the reaction between nitric oxide and superoxide radicals, is an extremely reactive oxidant capable of damaging proteins, DNA, and cellular membranes.

The biological activity of ROS and RNS depends on their concentration, lifetime, diffusion properties, and interactions with the food matrix. Short-lived species such as hydroxyl radicals act almost immediately at the site of plasma generation, whereas long-lived compounds such as hydrogen peroxide, ozone, nitrate, and nitrite continue to exert antimicrobial effects after plasma treatment has ceased. This distinction is particularly important in plasma-activated water, where dissolved long-lived reactive species provide prolonged antimicrobial activity during subsequent washing operations.

The simultaneous presence of multiple reactive species creates a synergistic antimicrobial effect. Lipid peroxidation compromises membrane integrity, protein oxidation inactivates essential metabolic enzymes, DNA oxidation prevents cellular replication, and oxidative stress overwhelms microbial antioxidant defence systems. Since these mechanisms occur concurrently, microorganisms find it extremely difficult to develop adaptive resistance against plasma treatment. This multi-target mode of action distinguishes cold plasma from conventional antibiotics and many chemical disinfectants, making it an attractive technology for improving food safety while reducing dependence on synthetic preservatives.

Effects of Cold Plasma Treatment on Food Quality

The successful commercialization of any food preservation technology depends not only on its ability to eliminate pathogenic and spoilage microorganisms but also on its capacity to preserve the intrinsic quality characteristics of food products. Consumer acceptance is largely influenced by the appearance, texture, flavour, aroma, and nutritional value of foods, making quality retention a primary consideration during processing. Conventional thermal preservation techniques, including pasteurization, sterilization, and blanching, often induce undesirable changes such as vitamin degradation, protein denaturation, pigment destruction, flavour loss, and texture softening. In contrast, cold plasma has emerged as a promising non-thermal preservation technology because it operates at or near ambient temperature while generating highly reactive oxygen and nitrogen species capable of inactivating microorganisms. Since the treatment involves minimal heat generation, the structural and biochemical integrity of foods is generally preserved more effectively than with traditional thermal processes. Nevertheless, the influence of cold plasma on food quality depends on several factors, including treatment duration, applied voltage, gas composition, plasma generation method, humidity, and the physicochemical characteristics of the food matrix. Therefore, understanding the effects of cold plasma on different quality attributes is essential for optimizing processing conditions and ensuring consumer acceptance.

One of the most important quality parameters affected by cold plasma treatment is colour, as colour strongly influences consumer perception of freshness and quality. Natural pigments such as chlorophylls, carotenoids, anthocyanins, and betalains are susceptible to oxidation during food processing. Under optimized cold plasma conditions, colour changes are generally minimal because the treatment temperature remains low, thereby preventing thermal degradation of pigments. Several studies have reported negligible changes in the colour of strawberries, tomatoes, apples, lettuce, spinach, blueberries, grapes, and fresh-cut vegetables following short plasma treatments. The preservation of chlorophyll in green vegetables and carotenoids in orange and yellow fruits indicates that cold plasma can maintain visual quality while improving microbial safety. However, excessive exposure time or high plasma intensity may promote oxidative degradation of pigments, resulting in slight browning or fading of colour. Such effects are particularly evident in foods rich in anthocyanins and other oxidation-sensitive compounds.

Consequently, optimization of treatment parameters is necessary to achieve microbial inactivation without compromising visual appearance.

Texture is another critical quality attribute influencing consumer preference, particularly for fresh fruits, vegetables, meat, and seafood. Texture is determined by the structural integrity of plant cell walls, muscle fibres, connective tissues, and intracellular components. Conventional heat treatments frequently soften food tissues because elevated temperatures disrupt pectin structures, collagen fibres, and cellular membranes. Cold plasma, being a non-thermal technology, generally preserves tissue firmness by avoiding excessive heating. Numerous investigations have demonstrated that plasma-treated apples, cucumbers, lettuce, tomatoes, strawberries, and leafy vegetables retain their crispness and firmness after treatment. Similar observations have been reported for poultry, beef, fish, and shellfish, where plasma exposure caused minimal alterations in muscle structure when appropriate treatment conditions were employed. Nevertheless, prolonged plasma treatment may induce oxidative modifications of cell wall polysaccharides or proteins, leading to slight softening in certain products. Therefore, treatment optimization remains essential for maintaining desirable textural characteristics.

The flavour and aroma of foods arise from a complex mixture of volatile organic compounds generated naturally during growth, ripening, and processing. These volatile compounds include aldehydes, ketones, alcohols, esters, terpenes, sulfur compounds, and phenolic substances that collectively determine the sensory identity of individual food products. Since cold plasma generates reactive oxygen species with strong oxidizing potential, concerns have been raised regarding possible alterations in flavour compounds. Most studies indicate that optimized plasma treatments produce only minor changes in volatile composition because of the relatively short exposure time and absence of thermal degradation. Fresh fruits, vegetables, herbs, and dairy products generally retain their characteristic aroma after plasma treatment. However, foods with high lipid content, such as meat, fish, nuts, and edible oils, may undergo limited lipid oxidation during prolonged exposure, producing aldehydes and ketones associated with rancid flavours. The use of inert gases such as argon or helium instead of atmospheric air has been shown to reduce oxidative changes and improve flavour preservation. Consequently, careful selection of process parameters is crucial to maintaining desirable sensory characteristics.

Nutritional quality is among the greatest advantages of cold plasma preservation. Vitamins are highly susceptible to degradation during conventional thermal processing because

elevated temperatures accelerate oxidation and decomposition reactions. Cold plasma operates at low temperatures, thereby minimizing thermal destruction of heat-sensitive nutrients. Vitamin C, one of the most oxidation-sensitive vitamins, is generally retained after mild plasma treatments applied to fresh fruits and vegetables. Similarly, B-complex vitamins and vitamin E have shown relatively high stability under optimized processing conditions. Some investigations have reported slight reductions in vitamin concentrations after prolonged exposure, primarily due to oxidation by reactive oxygen species rather than heat. Nevertheless, nutrient losses are typically much lower than those observed during pasteurization or sterilization, highlighting the nutritional advantages of cold plasma technology.

Proteins play essential roles in determining the nutritional, functional, and structural properties of foods. Plasma-generated reactive oxygen and nitrogen species may induce oxidation of amino acid side chains, formation of disulfide bonds, and limited conformational changes in protein molecules. These modifications can alter protein solubility, water-holding capacity, emulsifying properties, and digestibility. In many cases, controlled protein oxidation has been found to improve functional properties without significantly reducing nutritional value. For example, plasma treatment has been shown to enhance the emulsifying capacity of certain food proteins and improve dough characteristics in cereal products. However, excessive oxidation may decrease protein functionality and digestibility, emphasizing the need for carefully optimized treatment conditions.

Lipids are particularly susceptible to oxidation because unsaturated fatty acids readily react with reactive oxygen species generated during plasma treatment. Lipid oxidation results in the formation of hydroperoxides, aldehydes, ketones, and other secondary oxidation products that may adversely affect flavour, aroma, colour, and nutritional quality. Foods containing high concentrations of unsaturated fats, including meat, fish, nuts, edible oils, and dairy products, are therefore more vulnerable to plasma-induced oxidation. Several studies have demonstrated that mild plasma treatments produce negligible lipid oxidation, whereas prolonged exposure or high oxygen concentrations increase peroxide values and thiobarbituric acid reactive substances (TBARS). The incorporation of antioxidant treatments, modified atmosphere packaging, or inert carrier gases has proven effective in minimizing oxidative deterioration while preserving antimicrobial efficacy.

Carbohydrates generally exhibit greater stability during plasma treatment than proteins and lipids. Simple sugars remain largely unaffected because treatment temperatures are insufficient to initiate caramelization or Maillard reactions. Starch molecules may undergo limited depolymerization or surface modification due to plasma-generated radicals, resulting in altered water absorption, swelling behaviour, gelatinization properties, and digestibility. These modifications have attracted considerable attention for improving the functional characteristics of cereal flours, starch-based films, and biodegradable packaging materials. In addition, plasma treatment has been reported to modify dietary fibre structure, enhancing water-binding capacity and potentially improving functional food properties.

Bioactive compounds, including phenolic acids, flavonoids, anthocyanins, carotenoids, glucosinolates, and other phytochemicals, contribute significantly to the antioxidant activity and health-promoting properties of plant-derived foods. Interestingly, several investigations have reported increases in total phenolic content and antioxidant capacity following mild cold plasma treatment. This phenomenon is attributed to stress-induced activation of phenylpropanoid metabolism and improved extraction of intracellular phenolic compounds caused by increased membrane permeability. Enhanced antioxidant activity has been observed in fresh fruits, vegetables, sprouts, herbs, and seeds treated under optimized plasma conditions. Conversely, excessive treatment intensity may oxidize sensitive bioactive compounds, leading to reduced antioxidant capacity. Therefore, balancing microbial inactivation with phytochemical preservation remains an important aspect of process optimization.

Cold plasma may also influence enzymatic activity in foods. Enzymes such as polyphenol oxidase, peroxidase, lipoxygenase, and pectin methylesterase contribute to browning, lipid oxidation, texture degradation, and quality deterioration during storage. Plasma-generated reactive species can oxidize amino acid residues within enzyme molecules, resulting in partial or complete enzyme inactivation. Several studies have demonstrated significant reductions in polyphenol oxidase and peroxidase activity in fruits and vegetables following plasma treatment, thereby delaying enzymatic browning and extending shelf life. Similarly, inhibition of lipoxygenase activity has been associated with reduced lipid oxidation in certain food products. However, enzyme susceptibility varies considerably among food matrices and processing conditions, necessitating further research to optimize enzyme inactivation while minimizing quality losses.

Shelf-life extension is one of the most significant benefits of cold plasma technology. By simultaneously reducing microbial populations and slowing enzymatic deterioration, plasma treatment effectively delays spoilage during refrigerated and ambient storage. Numerous investigations have reported extended shelf life in fresh produce, meat, seafood, dairy products, and bakery products following plasma treatment. The combination of microbial decontamination, enzyme inactivation, and maintenance of nutritional and sensory quality makes cold plasma an attractive preservation technology for modern food industries seeking clean-label alternatives to chemical preservatives.

Applications of Cold Plasma in Different Food Commodities

Cold plasma technology has attracted significant attention across diverse sectors of the food industry because of its versatility, non-thermal nature, and ability to effectively inactivate microorganisms while preserving the physicochemical and nutritional quality of foods. Unlike conventional preservation techniques that rely on elevated temperatures or chemical additives, cold plasma operates at near-ambient temperatures and generates reactive oxygen species (ROS), reactive nitrogen species (RNS), charged particles, and ultraviolet photons that collectively contribute to microbial inactivation. The adaptability of plasma systems to different food matrices has enabled their application to fresh produce, meat, seafood, dairy products, cereals, pulses, spices, nuts, seeds, beverages, and processed foods. The effectiveness of plasma treatment varies according to food composition, surface characteristics, moisture content, and processing conditions, necessitating optimization for each commodity.

Fresh fruits and vegetables represent one of the most important application areas for cold plasma technology. These commodities are highly susceptible to contamination by pathogenic microorganisms such as *Escherichia coli*, *Salmonella enterica*, *Listeria monocytogenes*, and spoilage fungi during cultivation, harvesting, transportation, and storage. Conventional washing methods using chlorinated water reduce microbial populations but often fail to eliminate firmly attached microorganisms and may generate environmentally undesirable chlorinated by-products. Cold plasma provides an effective alternative by producing reactive species that penetrate microbial biofilms and disrupt cellular structures without substantially increasing product temperature. Numerous studies have demonstrated significant reductions in microbial populations on apples, strawberries, tomatoes, grapes, lettuce, spinach, cucumbers, blueberries, carrots, mangoes, and fresh-cut vegetables following atmospheric cold plasma treatment. In

addition to microbial decontamination, plasma treatment delays spoilage by suppressing enzymatic browning, reducing respiration rates, and maintaining firmness, thereby extending shelf life during refrigerated storage. Furthermore, plasma treatment has been reported to preserve colour, vitamin C, and antioxidant activity when appropriate treatment conditions are employed.

The meat and poultry industries have also shown considerable interest in cold plasma because fresh meat products are highly vulnerable to contamination by foodborne pathogens including *Salmonella spp.*, *Campylobacter jejuni*, *Staphylococcus aureus*, and *Listeria monocytogenes*. Surface contamination frequently occurs during slaughtering, cutting, packaging, and transportation. Since thermal processing alters the texture, colour, and flavour of fresh meat, non-thermal preservation methods are preferred for raw products. Cold plasma effectively reduces microbial populations on beef, pork, chicken, turkey, and processed meat products while preserving their sensory properties. Reactive oxygen and nitrogen species generated during plasma treatment damage bacterial membranes and genetic material without causing extensive heating of muscle tissues. However, because meat contains relatively high concentrations of unsaturated lipids, prolonged plasma exposure may accelerate lipid oxidation, leading to slight increases in peroxide values and thiobarbituric acid reactive substances. Consequently, optimization of treatment duration and gas composition is necessary to achieve microbial safety while minimizing oxidative changes. Combining cold plasma with modified atmosphere packaging or natural antioxidants has been shown to further improve storage stability.

Seafood products, including fish, shrimp, oysters, mussels, squid, and shellfish, are highly perishable because of their high moisture content, neutral pH, and abundance of readily degradable proteins. Microbial spoilage and enzymatic autolysis rapidly reduce product quality during storage. Cold plasma has emerged as an effective preservation method for seafood because it reduces spoilage microorganisms while maintaining freshness and minimizing thermal damage. Studies have demonstrated reductions in *Vibrio parahaemolyticus*, *Vibrio vulnificus*, *Aeromonas hydrophila*, and other seafood-associated pathogens following plasma treatment. Additionally, plasma has been shown to delay melanosis in shrimp and reduce unpleasant odour formation during storage. Since fish lipids are highly susceptible to oxidation, treatment parameters must be carefully optimized to avoid deterioration of flavour and nutritional quality.

Cold plasma has also demonstrated considerable potential in dairy processing. Raw milk and dairy products may harbour pathogenic bacteria including *Listeria monocytogenes*, *Bacillus cereus*, and *Escherichia coli*. Conventional pasteurization effectively eliminates these microorganisms but may affect flavour and certain heat-sensitive nutrients. Cold plasma has been investigated as an alternative or complementary treatment capable of reducing microbial populations in milk, cheese, yoghurt, and other dairy products. Plasma treatment has also been shown to improve surface sanitation of cheese without significantly affecting texture or flavour. However, because milk is a complex liquid containing proteins, lipids, minerals, and lactose, plasma treatment may induce limited oxidation under prolonged exposure. Continued research is therefore focused on optimizing reactor design for liquid foods and evaluating long-term quality changes.

Cereals, pulses, legumes, and oilseeds represent another important application area. These commodities are frequently contaminated with bacterial spores, fungal pathogens, and storage insects during harvesting and storage. Fungal contamination not only reduces product quality but also results in the production of hazardous mycotoxins such as aflatoxins, fumonisins, and ochratoxins. Cold plasma effectively reduces fungal populations on wheat, rice, maize, barley, oats, chickpeas, lentils, soybeans, peanuts, and sunflower seeds. Several studies have also reported partial degradation of mycotoxins following plasma treatment due to oxidative cleavage of toxin molecules. Importantly, plasma treatment generally preserves seed germination and may even stimulate germination by modifying seed coat permeability and activating metabolic enzymes. These findings indicate considerable potential for plasma technology in agriculture as well as food preservation.

Spices, herbs, and dried medicinal plants are often heavily contaminated with microorganisms because of drying under open environmental conditions. Conventional steam sterilization reduces microbial loads but may lead to loss of volatile essential oils responsible for aroma and flavour. Cold plasma offers an attractive alternative because it effectively decontaminates dry spices such as black pepper, turmeric, coriander, cumin, paprika, cinnamon, oregano, and basil while preserving volatile compounds. Similar benefits have been observed for nuts, including almonds, pistachios, walnuts, and peanuts, where plasma treatment significantly reduces microbial contamination with minimal changes in sensory quality. The application of plasma to beverages, fruit juices, and liquid foods is also expanding, although treatment of

liquids remains technically challenging due to limited penetration of reactive species. Recent reactor developments have improved plasma distribution within liquids, enabling enhanced microbial inactivation while preserving nutritional quality.

Plasma-Activated Water and Cold Plasma in Food Packaging

Plasma-activated water (PAW) has emerged as one of the most promising developments in cold plasma technology because it enables indirect application of plasma-generated reactive species through water rather than direct plasma exposure. Plasma-activated water is produced by exposing distilled water, deionized water, or purified water to atmospheric cold plasma for a predetermined period. During plasma generation, reactive oxygen species and reactive nitrogen species dissolve into the water, producing a complex antimicrobial solution containing hydrogen peroxide, ozone, nitrite, nitrate, hydroxyl radicals, nitric acid, and peroxynitrite. These reactive compounds remain active for varying periods depending on storage conditions, allowing plasma-generated antimicrobial activity to persist even after plasma generation has ceased.

The antimicrobial efficacy of plasma-activated water results from the combined action of oxidative stress, acidification, membrane disruption, and intracellular damage. Hydrogen peroxide penetrates microbial cells and participates in oxidation reactions, while ozone oxidizes membrane lipids and proteins. Nitric acid lowers the pH of plasma-activated water, creating conditions unfavourable for microbial survival. Peroxynitrite and hydroxyl radicals further damage nucleic acids and enzymes, leading to irreversible microbial inactivation. Unlike chlorine-based disinfectants, plasma-activated water leaves minimal harmful residues and decomposes into environmentally benign products, making it an attractive alternative for sustainable food sanitation.

In the fresh produce industry, plasma-activated water has been successfully employed for washing lettuce, spinach, tomatoes, strawberries, apples, cucumbers, carrots, and leafy vegetables. Numerous investigations have demonstrated significant reductions in *Escherichia coli*, *Salmonella*, *Listeria monocytogenes*, and spoilage fungi while maintaining the colour, firmness, and nutritional quality of produce. Similar applications have been reported for seafood, poultry, meat, and dairy equipment sanitation. Plasma-activated water has also been investigated for cleaning food-processing surfaces, conveyor belts, cutting boards, and packaging materials, thereby reducing the risk of cross-contamination during processing.

Cold plasma has also revolutionized food packaging technology by providing an environmentally friendly method for sterilizing packaging materials and modifying polymer surfaces. Food packaging serves as the primary barrier protecting products against microbial contamination, oxygen, moisture, and environmental damage. Conventional sterilization techniques frequently require high temperatures or chemical disinfectants that may damage packaging materials or leave undesirable residues. Cold plasma effectively sterilizes plastic films, glass containers, metal cans, paperboard cartons, biodegradable polymers, and composite packaging materials without causing thermal degradation.

In addition to sterilization, plasma treatment modifies the surface chemistry of packaging materials through oxidation and functionalization reactions. The introduction of oxygen-containing functional groups increases surface energy and wettability, improving adhesion of inks, coatings, adhesives, and antimicrobial compounds. Enhanced wettability also facilitates the incorporation of bioactive coatings containing natural antimicrobials, essential oils, or nanoparticles. Consequently, plasma-treated packaging materials contribute not only to microbial safety but also to the development of active and intelligent packaging systems capable of extending shelf life and monitoring food quality.

Recent advances have integrated cold plasma with modified atmosphere packaging (MAP) to create in-package plasma treatment, where plasma is generated directly inside sealed packages after filling. This innovative approach eliminates the possibility of post-processing contamination because microbial inactivation occurs after packaging has been completed. In-package plasma treatment has demonstrated significant reductions in microbial populations on strawberries, tomatoes, lettuce, poultry, and ready-to-eat foods while maintaining package integrity and product quality. The technology is particularly attractive for minimally processed foods because it combines preservation, packaging, and microbial decontamination into a single processing step.

Despite these promising developments, several challenges remain before widespread industrial adoption can be achieved. The stability of reactive species in plasma-activated water, interactions between plasma and different packaging polymers, large-scale reactor design, process standardization, and regulatory approval require further investigation. Nevertheless, plasma-activated water and plasma-assisted packaging represent rapidly expanding research

areas with considerable potential to replace conventional chemical sanitizers and improve food safety through sustainable processing technologies.

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DROPLET DIGITAL PCR (DDPCR) IN VIRUS DETECTION

Article ID: AG-VO6-I07-13

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Introduction

Research on **YMV**—referring either to **Mungbean Yellow Mosaic Virus** (a destructive Begomovirus affecting legumes) or **Yam Mosaic Virus** (a Potyvirus affecting *Dioscorea* species)—has significant knowledge gaps that must be addressed to improve crop yields and food security.

The most critical research gaps for both variations of YMV include:

Mungbean Yellow Mosaic Virus (MYMV) in Legumes

Mechanisms of Resistance: The exact physiological and molecular mechanisms governing resistance in black gram and green gram remain underexplored. While some cultivars show tolerance, the exact antiviral pathways require further investigation.

Vector Biology & Dynamics: There is a lack of deep understanding regarding how the whitefly vector (*Bemisia tabaci*) changes its population dynamics, migration, and vector competence as climates shift.

Molecular Characterization: Rapid viral evolution and the emergence of distinct new strains (e.g., MYMIV) outpace current resistance breeding. Continuous molecular tracking is needed to ensure the durability of deployed resistant genes.

Technological/Extension Gap: Significant yield gaps remain between potential (or research-demonstrated) yields and actual farmer practices. This highlights a need for better extension programs and scalable Integrated Pest Management (IPM) in pulse-growing regions.

Droplet Digital PCR (ddPCR) is a highly sensitive nucleic acid quantification technology that partitions a single sample into thousands of independent microscopic water-oil emulsion

droplets. By performing PCR inside each droplet, it enables absolute target quantification without the need for standard curves.

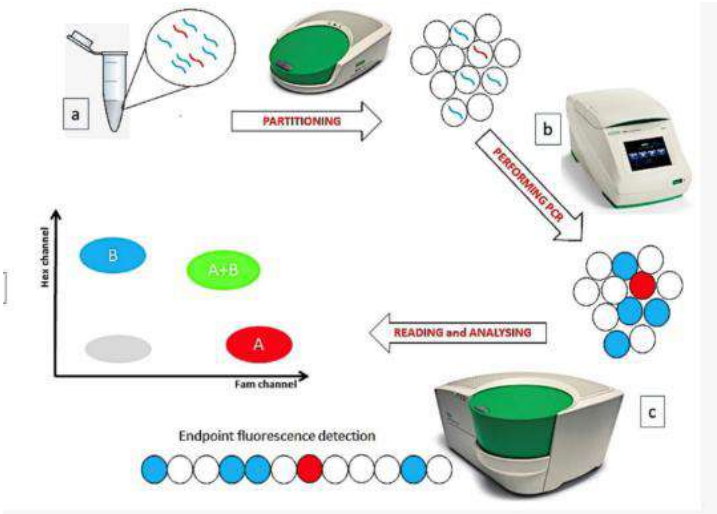


Fig1. Droplet Digital PCR (ddPCR)

Working

Partitioning: A standard PCR mixture is fractionated into approximately 20,000 submicroliter droplets, each serving as an individual reaction chamber.

Amplification: PCR is run to the endpoint within the droplets. If a target DNA sequence is present, it fluoresces; if not, it remains dark

Detection: Droplets are analyzed one by one in a flow cytometer to count the positive and negative signals.

Calculation: The concentration is determined using **Poisson statistics** based on the ratio of positive to negative droplets.

Key Advantages

Absolute Quantification: Delivers direct, copy-per-microliter counts without relying on reference standards.

Extreme Sensitivity: Can detect rare variants and low-abundance targets (down to <0.1%) that traditional qPCR misses.

High Precision: Highly resistant to PCR inhibitors, making it ideal for complex sample types like wastewater or blood.

Multiplexing: Capable of analyzing multiple targets simultaneously in the same reaction.

Common Applications

Liquid Biopsies: Tracking circulating tumor DNA (ctDNA) and minimal residual disease (MRD) in oncology.

Gene Therapy: Measuring viral vector copy numbers and editing frequencies.

Environmental Testing: Detecting low-abundance pathogens or specific genetic material in wastewater surveillance.

How Does Droplet Digital PCR Work

ddPCR technology uses a combination of microfluidics and proprietary surfactant chemistries to divide PCR samples into water-in-oil droplets (Hindson et al. 2011). The droplets support PCR amplification of the template molecules they contain and use reagents and workflows similar to those used for most standard TaqMan probe-based assays. Following PCR, each droplet is analyzed or read to determine the fraction of PCR-positive droplets in the original sample. These data are then analyzed using Poisson statistics to determine the target DNA template concentration in the original sample.

Advantages of ddPCR over Other Digital PCR Technologies

Droplet Digital PCR surpasses the performance of earlier digital PCR techniques by resolving the previous lack of scalable and practical technologies for digital PCR implementation. Serial dilution is laborious and introduces the possiblity of pipetting error; competing chip-based systems rely on complex fluidics schemes for partitioning. Droplet Digital PCR addresses these shortcomings by massively partitioning the sample in the fluid phase in one step. The creation of tens of thousands of droplets means that a single sample can generate tens of thousands of data points rather than a single result, bringing the power of statistical analysis inherent in digital PCR into practical application. Bio-Rad's Droplet Digital PCR System automates the ddPCR workflow of droplet generation, thermal cycling, droplet reading, and data analysis, making this technology accessible to the working research laboratory.

The Benefits of Droplet Digital PCR

ddPCR technology enables high-throughput digital PCR in a manner that uses lower sample and reagent volumes and reduces overall cost compared with other methods while maintaining the sensitivity and precision that are the hallmarks of digital PCR.

The benefits of ddPCR technology include:

- Absolute quantification — ddPCR technology provides an absolute count of target DNA copies per input sample without the need for running standard curves, making this

technique ideal for measurements of target DNA, viral load analysis, and microbial quantification

- Unparalleled precision — the massive sample partitioning afforded by ddPCR enables the reliable measurement of small fold differences in target DNA sequence copy numbers among sample
- Increased signal-to-noise ratio — high-copy templates and background are diluted, effectively enriching template concentration in target-positive partitions, allowing for the sensitive detection of rare targets and enabling a ±10% precision in quantification
- Removal of PCR bias — error rates are reduced by removing the amplification efficiency reliance of qPCR, enabling the detection of small (1.2-fold) differences
- Simplified quantification — neither calibration standards nor a reference (the $\Delta\Delta Cq$ method) is required for absolute quantification
- Reduced consumable costs — reaction volumes are in the pico- to nanoliter ranges, reducing reagent use and the sample quantity required for each data point
- Lower equipment costs — the emulsion-based reaction system means that the PCR reactions can be performed in a standard thermal cycler without complex chips or microfluidics
- Superior partitioning — ddPCR technology yields 20,000 droplets per 20 µl sample, nearly two million partitioned PCR reactions in a 96-well plate, whereas chip-based digital PCR systems produce only hundreds or thousands of partitions. The greater number of partitions yields higher accuracy

QX200 Droplet Digital PCR System

Bio-Rad's QX200 Droplet Digital PCR (ddPCR) System consists of two instruments, the QX200 Droplet Generator and the QX200 Droplet Reader, plus their associated software and consumables. The QX200 Droplet Generator partitions samples (20 µl into 20,000 nanoliter-sized droplets) for PCR amplification. Following amplification using a thermal cycler, droplets from each sample are analyzed individually on the QX200 Droplet Reader, where PCR-positive and PCR-negative droplets are counted to provide absolute quantification of target DNA in digital form.

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JAMUN FRUIT VALUE ADDED PRODUCTS

Article ID: AG-V06-I07-14

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Introduction

Jamun (*Syzygium cumini*) is an evergreen tropical tree in the flowering plant family Myrtaceae, native to Bangladesh, India, Pakistan and Indonesia. It is a rich source of iron (providing 1-2 mg per 100 grams) and vitamin C, and is useful in treating heart and liver ailments. The seed of the Jamun is dried and powdered and is widely used in India to control diabetes. Jamun fruits can be processed into excellent quality products such as vinegar, cider, squash and non-fermented ready to serve beverages. The colour of the Jamun pulp is attributed to the presence of anthocyanin pigment, which is responsible for providing an attractive appearance to the beverages prepared from Jamun. Jamun fruit juice had an attractive colour and excellent taste with some therapeutic value could be profitably utilized by beverage industry. For preparing of a good quality jam, fruit pulp, sugar, acid and pectin are important ingredients. Jam is a mixture of fruit and sugar cooked to a consistency firm enough to hold the fruit tissues together. The FPO (1955) specifications for nectar are minimum TSS of 15 per cent, minimum fruit content of 20 per cent. Squash and nectar preparation involves the extraction of fruit juice mixing it with sugar syrup of known strength, addition of citric acid, permitted preservative and finally packing in cans or bottles with proper seaming and processing to ensure better storage stability without spoilage

Preparation of Jamun Jam

Jamun jam was prepared by cooking 560 g of sugar with 560 g of Jamun pulp. Citric acid along with sodium benzoate was added as preservatives in order to extend the shelf life of the developed produce. After washing the Jamun fruits were boiled in water (1:1) ratio. This was responsible for softening of the pulp. The cooked Jamun were made into fine pulp by mashing

and the seed was removed manually, the pulp was made into fine soft pulp by using mixer grinder. Sugar was added to the fine pulp and cooked it to the consistency of Jam. Finally citric acid and sodium benzoate were added and filled hot in sterilized bottles. The bottles were properly labelled and stored.

Process protocol for preparation of Jamun fruit Jam

Washing of fruit

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Boiling with water (1:1) to soften the pulp

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Preparation of fine pulp

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Mixing sugar with pulp

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Cooking to consistency of the Jamun jam

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Addition of citric acid (0.5g) and sodium benzoate

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Filling hot into clean and sterilized bottles

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Sealing the bottle, Labeling and storage

Preparation of Jamun Squash

Jamun squash was made by adding 600 g of sugar syrup with 600 g of Jamun juice and adding citric acid along with sodium benzoate. Similar operations of washing and boiling in 1:1 ratio with water were performed in order to soften the pulp of fruit. The cooked Jamun were made into fine pulp by mashing and seed was removed and the pulp was made into juice by using mixer grinder. 600 g of sugar was dissolved in 1 litre water and it was boiled till it got a consistency of 40 – 45 % TSS. Sugar syrup was added to the juice and finally citric acid and sodium benzoate were added at the end point and filled hot in sterilized bottles. Pasteurization was done in order to kill the pathogens.

Washing

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Boiling in water keeping 1:1 ratio (to soften the pulp)

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Preparation of Jamun juice

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Boiling sugar for preparing sugar syrup

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Adding the sugar syrup and juice

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Addition of citric acid (0.5g) and Sodium benzoate as preservative

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Hot filling in sterilized bottles

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Sealing the bottles

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Labeling and storage

Jamun Wine

The Jamun fruits are washed and then dipped in 5% NaCl salt solution for 72 hour. The seeds are separated from the fruit and the fruit pulp is crushed with water (1:1 ratio). The pulp is pressed to extract the juice and sodium metabisulphite is added. TSS is adjusted to 17 °Brix with cane sugar and the pH to 4.5 using 1N acetic acid. The must is inoculated with wine yeast starter culture (use 28-48 hour old starter culture at 2% v/v) and kept for Fermentation (at 32 ± 20C for 6 days). Racking and decantation are done (First racking when Brix reaches 2-30. Two to three more racking at 15 days intervals if sedimentation persists). The wine is clarified by chemical method (by adding 0.04% Bentonite). Final racking is done to clear the wine. The wine is filled in bottles and corked. Then the bottles are sealed with bees wax and stored at ambient temperature.

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Volume: 06 Issue No: 07

FARMER SUCCESS STORY- IMPACT OF LBG-884 VARIETY UNDER CFLD PROGRAMME IN BLACK GRAM FOR IMPROVED FARM INCOME

Article ID: AG-V06-I07-15

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Introduction

Black gram (*Vigna mungo*) is one of the important pulse crops cultivated in Anakapalli district of Andhra Pradesh, particularly during the Rabi season under residual soil moisture conditions after rice harvest. It plays a vital role in improving soil fertility through biological nitrogen fixation and contributes significantly to nutritional security by providing a rich source of plant-based protein. Despite its importance, the productivity of black gram in the region remains considerably low compared to its potential yield. The major constraints affecting production include the cultivation of low-yielding traditional varieties, delayed and improper sowing practices, imbalance in nutrient application, inadequate weed management, and heavy incidence of insect pests and diseases such as sucking pests, yellow mosaic virus, and leaf spot diseases. These factors collectively lead to poor crop growth, reduced pod formation, and ultimately low economic returns to farmers.



In addition, limited awareness and partial adoption of improved production technologies further restrict the realization of higher yields. Farmers often rely on conventional practices with minimal use of scientific interventions, resulting in unstable productivity and reduced profitability.

To address these challenges, there is a strong need to promote improved high-yielding varieties along with scientific Integrated Crop Management (ICM) practices. Adoption of such improved technologies can significantly enhance crop productivity, reduce production risks, and improve farm income. In this context, the CFLD programme under NFSM plays a crucial role in demonstrating proven technologies at farmers' fields and accelerating their adoption in the farming community

Farmer & Location Details

Farmer Name: Mr. Dokula Appala Naidu

Village: Khandivaram

Mandal: Cheedikada

District: Anakapalli, Andhra Pradesh

Crop: Black Gram

Variety: LBG-884

Season: Rabi 2025–26

2. Intervention under CFLD Programme

Krishi Vigyan Kendra (KVK), Kondempudi, implemented **Cluster Front Line Demonstrations (CFLDs)** under the **National Food Security Mission (NFSM)** during **Rabi 2025–26** across **350 locations in 10 clusters** in Anakapalli district.

The demonstration focused on the improved black gram variety **LBG-884**, supported with a complete **Integrated Crop Management (ICM) package**, which included:

- Quality seed of LBG-884
- Seed treatment chemicals
- Herbicides for weed management
- Yellow sticky traps for pest monitoring
- Plant protection chemicals
- Multi-K and micronutrients
- Regular training and field-based technical guidance

KVK scientists conducted frequent field visits and provided continuous advisory support throughout the crop season to ensure proper adoption of the technology.

3. Farmer Adoption and Practices

Mr. Dokula Appala Naidu actively participated in the CFLD programme and adopted all recommended practices such as timely sowing, seed treatment, balanced fertilization, weed management, and integrated pest and disease management. Continuous technical guidance from KVK ensured healthy crop growth and better crop stand compared to his previous farming practices.

4. Results and Yield Performance

The adoption of LBG-884 along with improved crop management practices resulted in a significant improvement in yield and crop performance.

- **Yield under CFLD (LBG-884):** 14.95 q/ha
- **Yield under Farmers' Practice:** 9.37 q/ha
- **Yield Increase:** 59.6%

The demonstration crop showed better plant vigour, uniform growth, and higher pod formation compared to the farmer's existing practice.



5. Economic Analysis

Particulars	CFLD (LBG-884)	Farmers' Practice
Yield (q/ha)	14.95	9.37
Cost of Cultivation (₹/ha)	32,133	28,755

Particulars	CFLD (LBG-884)	Farmers' Practice
Net Returns (₹/ha)	72,493	36,486
Benefit-Cost Ratio	3.26	2.28

Additional Net Income: ₹36,007/ha.

Although the cost of cultivation was slightly higher under CFLD due to improved inputs, the net returns were significantly higher, clearly indicating the economic advantage of the improved technology.

6. Farmer's Feedback

The farmer expressed high satisfaction with the performance of the LBG-884 variety and appreciated the timely technical support provided by KVK, Kondempudi. He stated that adoption of scientific crop management practices helped him achieve higher yield, better crop health, and almost double the income compared to previous seasons. He also expressed willingness to continue the cultivation of LBG-884 and recommended it to other farmers in the village.

Conclusion

The CFLD programme conducted by **KVK, Kondempudi during Rabi 2025–26** clearly demonstrated that the adoption of the improved black gram variety **LBG-884**, along with Integrated Crop Management practices, significantly enhances productivity and profitability. The intervention resulted in higher yields and nearly doubled farm income, thereby contributing to sustainable pulse production and improved livelihoods of farmers in Anakapalli district.

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MITOCHONDRIAL DNA IN LIVESTOCK: STRUCTURE, FUNCTION AND APPLICATIONS IN MODERN ANIMAL GENOMICS

Article ID: AG-V06-I07-16

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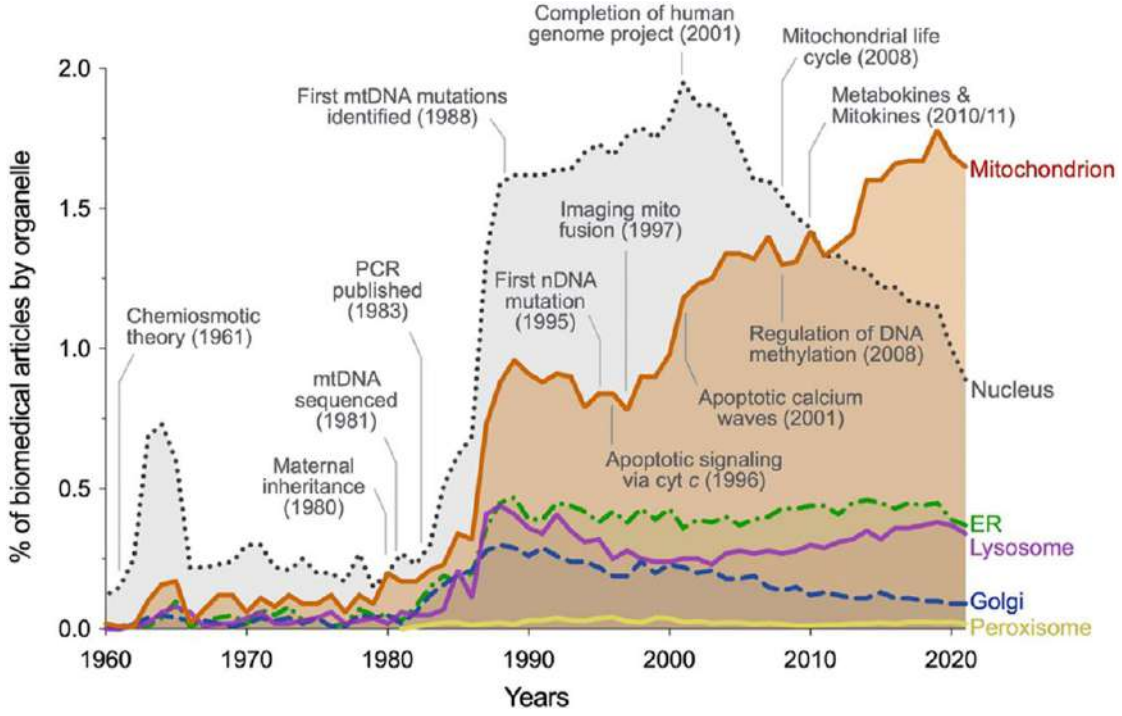
Introduction

Mitochondria are no longer considered simple energy-producing organelles. Modern biological understanding describes them as living, dynamic, maternally inherited, energy-transforming, biosynthetic and signalling organelles that influence the physiology of the entire organism (Picard and Shirihai, 2022). They integrate cellular energy metabolism, redox balance, biosynthesis and signalling pathways, thereby acting as central regulators of growth, adaptation and survival in animals. Earlier concepts referred to mitochondria as “bioblasts”, emphasizing their role in biological energy production. Later they were described as bean-shaped chemiosmotic ATP-synthesizing machines, highlighting their role in oxidative phosphorylation. However, contemporary research has expanded their function beyond ATP production to include biosynthetic regulation, cellular communication and stress response coordination (Nunnari and Suomalainen, 2012). Mitochondria are also highly dynamic structures undergoing continuous fusion and fission processes, which allow them to adapt to cellular energy demands and environmental conditions. Because of these integrated roles, mitochondria are now viewed as multifunctional organelles governing whole-organism physiology.

Functional Architecture of Mitochondria

Mitochondria function as central hubs of energy production and metabolic integration. The primary role of mitochondria is ATP synthesis through oxidative phosphorylation, which makes them the principal energy providers in animal cells and justifies their description as the “powerhouse of the cell” (Spinelli and Haigis, 2018). Beyond energy production, mitochondria

serve as biosynthetic platforms supporting the synthesis of nucleotides, fatty acids, cholesterol, amino acids, glucose intermediates and heme compounds (Spinelli and Haigis, 2018). This highlights their essential role in maintaining cellular and metabolic homeostasis. Mitochondria also regulate redox balance and oxidative stress responses, thereby controlling cellular survival pathways. They are deeply involved in programmed cell death mechanisms and act as targets in cancer therapies due to their role in apoptosis regulation. In addition, mitochondria function as signaling organelles coordinating cellular responses to metabolic and environmental changes. The concept of the mitochondrial information processing system (MIPS) describes mitochondria as integrated signalling hubs that connect metabolic states with nuclear gene expression and cellular adaptation (Picard and Shirihai, 2022).

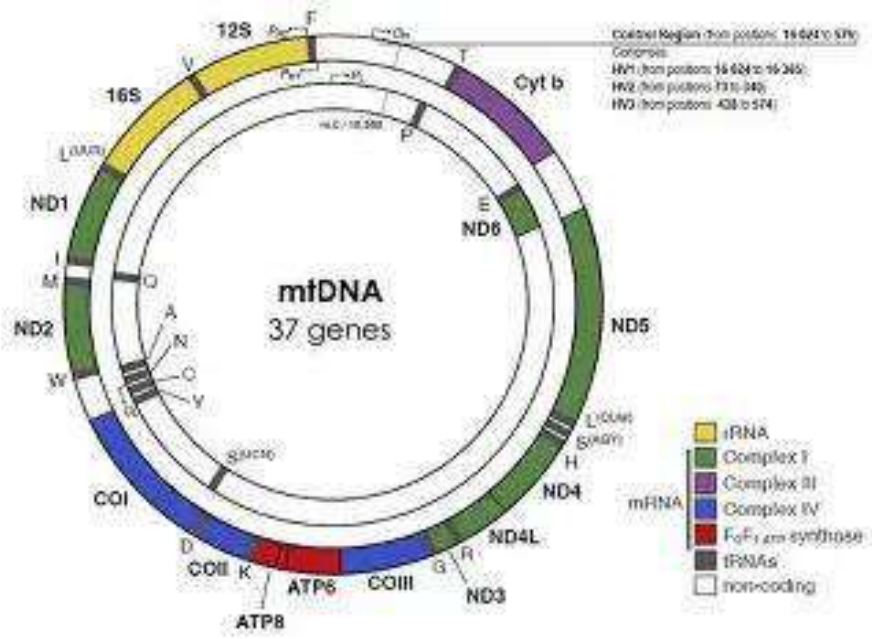


Year wise trend on mitochondrial studies (Picard *et al.*, 2016; Picard and Shirihai, 2022)

Structure and Organization of the Mitogenome

The mitochondrial genome (mitogenome) is a small, circular, double-stranded DNA molecule located within mitochondria. Despite its small size, it plays a crucial role in cellular energy metabolism. The mitogenome typically contains 37 genes, including 13 protein-coding genes involved in oxidative phosphorylation, 22 transfer RNA genes, and 2 ribosomal RNA genes. It also contains a non-coding control region known as the displacement loop (D-loop), which regulates replication and transcription (Habbane et al., 2021). In livestock species such as

goats, the mitogenome is highly conserved and consists of 13 protein-coding genes, 22 tRNA genes, 12S and 16S rRNA genes, and a D-loop region that plays a major role in maternal inheritance and genetic regulation (Mustafa et al., 2022).



Comparative Features of Nuclear and Mitochondrial Genomes

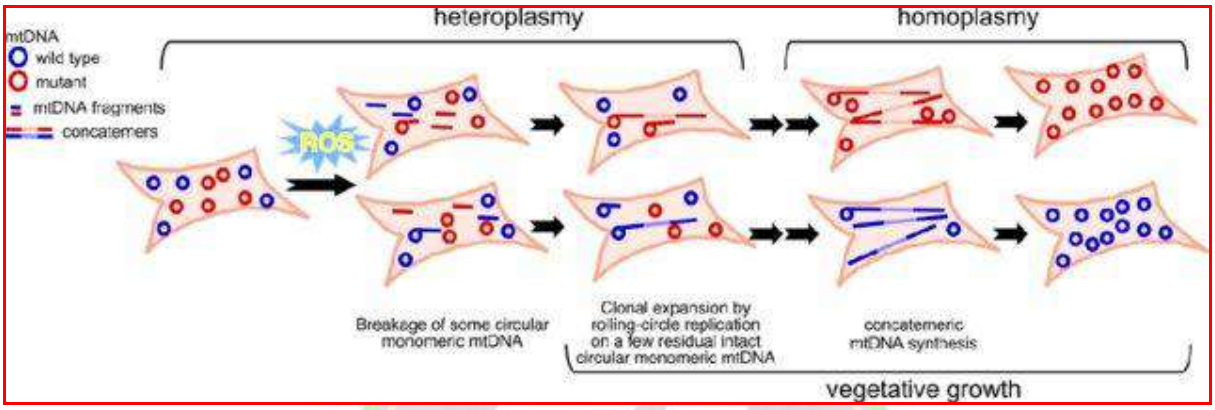
Feature	Nuclear Genome	Mitochondrial Genome
Structure	Linear chromosomes	Circular DNA
Genome size	~3.3 billion base pairs	~16 kilobases
Introns	Present	Absent
Gene organization	Mostly monocistronic	Often polycistronic
Histones	Present	Absent
Copy number	Single copy per cell	Multiple copies per cell
Replication	S-phase dependent	Independent of cell cycle
Inheritance	Biparental	Maternal inheritance

This fundamental distinction explains why mitochondrial DNA behaves differently from nuclear DNA in inheritance and evolution.

Key Characteristics of Mitochondrial Genome

Mitochondrial DNA exhibits several unique biological characteristics. It is maternally inherited in most animals, ensuring strict maternal lineage transmission. It also exists in multiple copies per cell, a condition known as polyplasmy, which enhances its functional robustness.

Another important feature is the coexistence of homoplasmy and heteroplasmy. Homoplasmy refers to a uniform mitochondrial genotype within a cell, whereas heteroplasmy refers to the presence of multiple mitochondrial DNA variants. Heteroplasmy is particularly important in disease development and evolutionary variation. The mitochondrial genome also exhibits a mutation rate that is approximately 10–20 times higher than nuclear DNA, making it highly informative for evolutionary and population genetic studies (Habbane et al., 2021).



Mitochondrial Mutations and Disease Associations

Mitochondrial mutations can be classified as somatic or inherited. Somatic mutations occur during development and contribute to ageing and tissue-specific dysfunction, whereas inherited mutations are transmitted maternally across generations. The expression of mitochondrial diseases depends on mutation type and heteroplasmy threshold. Homoplasmic mutations are often associated with severe clinical conditions such as blindness and deafness, while heteroplasmic mutations may remain silent until a threshold level is exceeded. More than 310 pathogenic mitochondrial mutations have been identified, affecting multiple biological systems. Several diseases are linked to specific mitochondrial genes. For example, Leber's Hereditary Optic Neuropathy is associated with mutations in ND1, ND3, ND4, ND5, ND6, ND4L, ATP6 and COX1 genes. Leigh disease involves ND1, ND3, ND4L, ND4 and ND6 genes, while NARP-like syndromes are linked to ATP6 mutations. Other conditions such as retinopathy and atherosclerosis risk are associated with ND4 and ND6 genes respectively.

Mitochondrial Inheritance Models and Evolutionary Interpretation

Mitochondrial variation can be interpreted through different analytical frameworks. The cytoplasmic model focuses on maternal inheritance patterns, while the haplotypic model examines mitochondrial haplotype variation across populations. The amino-acid model evaluates

functional consequences of mitochondrial protein variation, and the evolutionary model uses haplogroup classification to understand long-term divergence and adaptation.

These models collectively allow a comprehensive understanding of mitochondrial evolution, population structure and functional diversity in livestock species.

Mitochondrial Genome and Livestock Productivity

Mitochondrial variation has a measurable impact on economically important traits in livestock. Studies have shown that mitochondrial genetic variation can explain up to 10.2% variation in milk production, 8.1% variation in fat percentage, and 14.6% variation in protein content. These findings highlight the functional importance of mitochondrial genetics in dairy and meat production systems. Mitochondrial DNA copy number is also an important indicator of cellular energy efficiency and metabolic health. It is a heritable trait that responds to genetic selection and decreases with age. Therefore, mitochondrial copy number can be used as an indirect biomarker for productivity and physiological efficiency in livestock.

Applications of Mitochondrial DNA in Livestock Genetics

Mitochondrial DNA is widely used in animal genetics for studying genealogy, domestication history, phylogenetics and population structure. It is particularly valuable for tracing maternal lineages due to its strict maternal inheritance and lack of recombination. In livestock breeding programs, mitochondrial markers are increasingly being integrated into genomic selection strategies and SNP chip designs. Mitochondrial data also contribute to conservation genetics by identifying maternal lineage diversity and evaluating breed structure.

Mitochondrial Adaptation and Environmental Stress

Mitochondria play a central role in adaptation to environmental stress. Exposure to stress increases reactive oxygen species, which can damage mitochondrial DNA and accelerate mutation accumulation. However, mitochondrial genomes also undergo selective processes that maintain functional integrity. Purifying selection removes deleterious mutations, while positive selection acts on protein-coding genes, particularly in Complex I genes such as ND1 and ND4. These adaptive processes contribute to survival in extreme environments and support metabolic flexibility in livestock populations.

Conclusion

Mitochondrial DNA represents a critical component of animal genetic systems, extending far beyond its classical role in energy production. It functions as a regulator of metabolism,

cellular signaling and adaptation, while also serving as a powerful tool in evolutionary biology and livestock improvement. Its maternal inheritance, high mutation rate and functional sensitivity make it particularly valuable for studying population structure, disease associations and production traits. In modern livestock genomics, mitochondrial DNA is increasingly integrated into breeding strategies, genomic selection and conservation programs, highlighting its growing importance in animal science and biotechnology.

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MULBERRY FRUITS: TINY BERRIES WITH POWERFUL HEALTH BENEFITS

Article ID: AG-VO6-I07-17

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Abstract

Mulberry (Morus spp.), a fruit with centuries of use in traditional medicine across Asia, the Middle East, and the Mediterranean, is fast gaining recognition in the modern scientific community as a nutritional powerhouse. Rich in anthocyanins, resveratrol, flavonoids, vitamins, and dietary fiber, mulberry fruit offers a remarkable spectrum of health-promoting properties. This article reviews the current scientific evidence on the nutritional composition of mulberry fruit and its documented health benefits, including antioxidant, anti-diabetic, cardiovascular-protective, neuroprotective, anti-cancer, anti-inflammatory, and skin anti-aging effects. Key bioactive compounds and their mechanisms of action are discussed alongside practical dietary applications. The evidence strongly suggests that regular consumption of mulberry fruit may play a meaningful role in the prevention and management of several chronic diseases that define our era.

Keywords: Mulberry fruit; *Morus alba*; anthocyanins; antioxidants; functional food; chronic disease prevention; nutraceuticals; polyphenols

1. Introduction

The genus Morus belongs to the family Moraceae and comprises over a dozen recognized

species. The three most commonly encountered in food and medicine are white mulberry (*Morus alba* L.), black mulberry (*Morus nigra* L.), and red mulberry (*Morus rubra* L.). Each species presents a slightly different phytochemical profile, though all share the hallmark richness in polyphenols, vitamins, and minerals that makes the genus nutritionally exceptional (Hu *et al*., 2025).

Globally, diet-related chronic diseases including type 2 diabetes, cardiovascular disease, obesity, and certain cancers account for a staggering burden of morbidity and mortality. As consumers worldwide turn increasingly toward natural, whole-food interventions, mulberry fruit has emerged as a compelling candidate for inclusion in functional dietary strategies. Mulberry is one of the most extensively studied fruits for its diverse health benefits and economic potential, with research spanning antioxidant, hypolipidemic, hypoglycemic, hepatoprotective, antibacterial, and anticancer pharmacological effects (Hu *et al*., 2025). This article brings together the current body of peer-reviewed evidence to give a clear, accessible account of what mulberry fruit contains, what it can do for human health, and how it can realistically be incorporated into everyday life.

2. Botanical Profile and Global Distribution

Mulberry trees are deciduous, fast-growing, and remarkably adaptable. Native to China, mulberry cultivation has spread across Asia, Europe, the Americas, and Africa, both for sericulture and for food. The fruit itself is a collective drupe, botanically an aggregate of small drupelets fused together that resembles an elongated blackberry. Depending on species and ripeness, it ranges in color from white and pale pink (*Morus alba*) to deep red and near-black (*Morus nigra* and ripe *Morus rubra*).

In traditional medicine systems including Traditional Chinese Medicine (TCM), Ayurveda, and Unani, virtually every part of the mulberry plant fruit, leaf, root bark, and twig has been employed medicinally. The Chinese Ministry of Health officially classifies mulberry as a dual-purpose agricultural product serving both food and medicine, a recognition of its unique position at the intersection of nutrition and pharmacology (Hao *et al*., 2022).



Fig 1: Mulberry Fruit

Today, mulberry fruits are consumed fresh, dried, as juice, syrup, jam, vinegar, tea, and wine. They are also processed into functional food ingredients, nutraceutical supplements, natural food

colorants, and cosmetic formulations a versatility that reflects the breadth of their bioactive content.

3. Nutritional Composition

Mulberry fruit is low in calories yet dense in nutrients. A standard 100 g serving of fresh mulberries provides approximately 43 kilocalories, with moisture content ranging from 85–88%, making it a highly hydrating food. The macronutrient profile is modest but well-balanced, and its micronutrient and phytochemical content is what truly sets it apart (Singhal *et al*., 2010).

Table 1. Nutritional Composition of Fresh Mulberry Fruit (per 100 g)

Nutrient	Amount per 100 g	% Daily Value (Approx.)
Energy	43 kcal	~2%
Water	85–88 g	—
Carbohydrates	7.8–9.0 g	~3%
Dietary Fiber	1.7 g	~6%
Protein	0.5–1.4 g	~2%
Fat	0.3–0.5 g	<1%
Vitamin C	11.0–12.5 mg	~13–17%
Vitamin B1 (Thiamine)	7.9–9.0 µg	~1%
Vitamin B2 (Riboflavin)	165–179 µg	~13%
Iron	1.85 mg	~10%
Potassium	194 mg	~4%
Calcium	39 mg	~4%

Sources: Singhal et al. (2010); USDA FoodData Central; Frontiers in Plant Science (2024).

3.1 Key Bioactive Compounds

Beyond standard nutrients, mulberry fruit is distinguished by an extraordinary concentration of bioactive phytochemicals. The most significant among them include:

Anthocyanins: The dominant polyphenols responsible for the deep purple-red pigmentation of ripe mulberries. Cyanidin-3-O-glucoside (C3G) and cyanidin-3-O-rutinoside (C3R) are the most abundant. These compounds are potent antioxidants with documented anti-inflammatory, anti-cancer, anti-diabetic, and neuroprotective activities (Hu *et al*., 2025; Garrett *et al*., 2024).

Resveratrol: A stilbene polyphenol also found in grapes and red wine, but present in mulberries at notably high concentrations. Resveratrol has been associated with cardiovascular protection, anti-aging effects, and cancer-preventive properties (Zhang *et al*., 2021).

Rutin and Quercetin: Flavonoid glycosides with anti-inflammatory, antiplatelet, and vasculoprotective properties. Both compounds contribute to mulberry's beneficial effects on blood pressure and circulation (Trimarco *et al*., 2025).

Polysaccharides: Complex carbohydrates in mulberry fruit that demonstrate immunomodulatory, hepatoprotective, and hypoglycemic activities distinct from those of the phenolic compounds (*Hu et* al., 2025).

1-Deoxynojirimycin (DNJ): An alkaloid found primarily in mulberry leaves, but present in smaller amounts in the fruit. DNJ is a potent alpha-glucosidase inhibitor that slows post-meal blood sugar rises (Lim & Lee, 2024).

4. Health Benefits: Evidence from Science

4.1 Powerful Antioxidant Activity

Free radicals, unstable molecules produced through normal metabolism and amplified by pollution, UV radiation, and poor diet are central to the development of aging-related diseases. Antioxidants neutralize these molecules, preventing cellular and DNA damage. Mulberry fruit is recognized for exceptional free-radical scavenging capacity, driven primarily by its anthocyanin and resveratrol content.

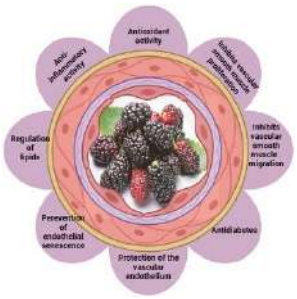


Fig 2: Health Benefits of Mulberry

Comparative studies have consistently shown that mulberry fruits possess higher resveratrol content and antioxidant activity than many common fruits, including jackfruit and jamun (Kumar *et al*., 2024). Resveratrol in mulberries has been shown to reduce reactive oxygen species (ROS) levels and suppress lipid peroxidation, thereby reducing the risk of DNA damage (Kumar *et al*., 2024). The antioxidant activity of mulberry anthocyanins has been confirmed via multiple standard assays, including DPPH radical scavenging and FRAP (Ferric Reducing Antioxidant Power) tests (Raman et al., 2016, Hu *et al*., 2025).

4.2 Blood Sugar Regulation and Anti-Diabetic Effects

Type 2 diabetes is one of the most prevalent chronic diseases worldwide, and dietary management is central to its prevention and control. Mulberry fruit has attracted significant

scientific attention for its ability to moderate blood glucose levels through multiple mechanisms.

A 2023 systematic review published in the Journal of Herbal Medicine, which evaluated 15 eligible studies on mulberry and metabolic syndrome, found that the fruit's favorable effects are predominantly attributed to its rich polyphenolic content, which interacts with diverse metabolic pathways (Howell & Martin, 2023). Key mechanisms include the inhibition of alpha-glucosidase (an intestinal enzyme that breaks down complex carbohydrates into glucose), activation of the AMPK pathway that promotes glucose uptake in muscle tissue, and inhibition of hepatic gluconeogenesis (Huang *et al*., 2017).

4.3 Cardiovascular Protection

Cardiovascular disease (CVD) remains the leading cause of death globally, and the search for dietary strategies to reduce risk is more urgent than ever. Mulberry fruit offers several converging mechanisms that collectively protect heart health.

Trimarco *et al* examined white mulberry plant extracts and cardiovascular prevention, concluding that bioactive compounds including flavonoids, phenolic acids, terpenoids, and alkaloids show great capacity in improving metabolic profile, decreasing cardiovascular risk, and supporting overall health (Trimarco *et al*., 2025).

Lipid-lowering effects: Animal studies show that mulberries and mulberry extracts can reduce excess fat and lower total cholesterol levels, while improving the ratio between LDL (bad) and HDL (good) cholesterol.

Hepatoprotective action: A study showed that mulberries reduce oxidative stress and reduce fat accumulation in the liver, potentially helping to prevent non-alcoholic fatty liver disease (NAFLD) — a condition closely linked to cardiovascular risk.

Anti-atherosclerotic activity: Resveratrol and rutin in mulberries inhibit platelet aggregation and vascular inflammation — two key processes in the formation of arterial plaques

While human clinical trials in this area are still limited, the convergence of pre-clinical evidence is compelling enough for leading nutrition researchers to recommend mulberry as a heart-friendly dietary addition.

4.4 Neuroprotective Properties

One of the more exciting emerging areas of mulberry research concerns its effects on the brain. Neurodegenerative diseases such as Alzheimer's, Parkinson's, and vascular dementia

represent a growing global health crisis, and natural dietary strategies for prevention are urgently needed.

Modern analysis of mulberry fruit shows that its polyphenols and polysaccharides have antioxidant and anti-inflammatory, anti-tumor, memory improvement, and neuroprotective properties (Hu *et al*., 2025). Phenolic substances in mulberry fruit extracts have been reported to increase the activity of antioxidant enzymes and delay memory loss during aging by promoting the clearance of amyloid-beta protein the pathological hallmark of Alzheimer's disease (Liu & Du, 2020).

Anthocyanins, particularly cyanidin-3-O-glucoside, have gained prominence for their ability to mitigate oxidative stress, enhance metabolic health, and support cognitive function. Additionally, mulberry vinegar, a fermented product of the fruit has been shown in animal studies to protect against neuroinflammation by regulating the NF-κB signaling pathway and glial cell activation (Hu *et al*., 2025).

4.5 Anti-Cancer Potential

A growing body of preclinical research suggests that mulberry fruit extracts may exert anti-proliferative effects against certain cancer cell lines. The active components of mulberries inhibit cancer progression by regulating apoptosis (programmed cell death) and matrix metalloproteinases, which are enzymes involved in tumor invasion (Hu *et al*., 2025).

Studies have shown that anthocyanins in mulberries specifically cyanidin-3-rutinoside and cyanidin-3-glucoside can dose-dependently inhibit the migration and invasion of highly metastatic A549 human lung carcinoma cells (Ding *et al*., 2013). Research has also demonstrated cytotoxic activity against human cervical cancer cells from a chemical compound isolated from *Morus alba* fruit (Singh & Sharma, 2023).

It must be emphasized that this research is almost entirely preclinical — conducted in cell cultures and animal models. Clinical trials in human cancer patients are yet to be conducted at scale, and mulberry fruit should not be presented or used as a cancer treatment. However, the mechanistic evidence does support its role in a cancer-preventive dietary pattern rich in plant polyphenols.

4.6 Anti-Inflammatory Effects

Chronic low-grade inflammation is now recognized as an underlying driver of most chronic non-communicable diseases, from heart disease to type 2 diabetes, depression, and even

Alzheimer's. Mulberry fruit's polyphenols exert broad anti-inflammatory activity through inhibition of the NF-κB signaling pathway a master regulator of inflammatory gene expression and by modulating pro-inflammatory cytokines including TNF-alpha, IL-6, and IL-1 beta.

A review published in Blackberries and Mulberries: Berries with Significant Health-Promoting Properties confirmed that all major phytochemical classes found in mulberry, including phenolics and volatile compounds, are well-known for their anti-inflammatory and antiviral properties. This systemic anti-inflammatory capacity is one of the most plausible mechanisms underlying mulberry's broad spectrum of protective health effects.

4.7 Skin Health and Anti-Aging Effects

The skin is the body's largest organ which is uniquely vulnerable to both intrinsic aging and extrinsic damage from UV radiation and environmental pollution. Mulberry fruit extracts have attracted considerable interest in dermatological science.

A recent study conducted at the Sericulture and Agri-Food Research Institute of the Guangdong Academy of Agricultural Sciences, investigated the anti-skin aging effects of mulberry fruit extracts through in vitro and in vivo evaluations of anti-glycation and antioxidant activities. The study documented that mulberry fruit extracts significantly inhibited the formation of advanced glycation end-products (AGEs) crosslinks between sugars and proteins that stiffen skin and accelerate visible aging. It also confirmed increased antioxidant enzyme activity in skin tissue.

Beyond anti-aging, mulberry's natural pigment (anthocyanins) has been shown to inhibit tyrosinase the enzyme responsible for melanin production giving mulberry extracts a legitimate place in skin-brightening and hyperpigmentation management formulations (Hu *et al*., 2025).

5. Practical Dietary Incorporation

One of mulberry's most attractive features is its versatility in the diet. Unlike many functional food ingredients that require supplementation or special preparation, mulberry fruit is genuinely enjoyable to eat and widely available in several forms:

Fresh mulberries: Best consumed immediately after harvest due to a shelf life of only 3–4 days at ambient temperature. Excellent eaten raw, added to yogurt, or blended into smoothies.

Dried mulberries: Retain most of their anthocyanin and resveratrol content and are widely available year-round. Suitable as snacks, trail mix additions, or toppings for cereals and salads.

Mulberry juice and syrup: Popular in the Middle East and South Asia; a concentrated source of polyphenols, though watch for added sugars in commercial products.

Mulberry jam and wine: Traditional preparations that preserve bioactive content to varying degrees depending on processing conditions.

Mulberry fruit powder: Increasingly available as a nutritional supplement or food ingredient to enhance the functional profile of yogurts, baked goods, and beverages.

Mulberry leaf tea: While not the fruit itself, mulberry leaf tea is the most concentrated dietary source of DNJ (1-deoxynojirimycin) for those specifically seeking blood sugar modulation.

There are no established therapeutic dose guidelines for mulberry fruit consumption in healthy individuals, and most of the intervention studies in the literature have used extracts rather than whole fruit. As a general principle, including mulberries fresh or dried as a regular part of a varied, plant-rich diet is a safe and evidence-supported approach to supporting long-term health.

6. Limitations of Current Evidence and Future Directions

The majority of mechanistic studies have been conducted in vitro (cell cultures) or in animal models, particularly rodents. Extrapolating findings from these systems to human physiology is never straightforward. Human clinical trials especially large, randomized, placebo-controlled trials are still relatively few in number and often involve small sample sizes or short durations. Most of the clinical interventions reviewed in the metabolic syndrome literature, for example, used modest oral doses of mulberry extracts ranging from 10 to 800 mg/kg of body weight per day over periods of 8–12 weeks — findings that need to be replicated in larger and more diverse populations (Howell & Martin, 2023).

Additionally, the bioactive profile of mulberry fruit varies considerably across species, cultivars, geographical origin, ripeness, and post-harvest processing methods, which makes standardization across studies challenging. Future research should prioritize well-designed human trials, standardization of extracts, investigation of synergistic effects among multiple phytochemicals, and long-term population-level epidemiological studies.

Conclusion

Mulberry fruit stands as a compelling example of nature's capacity to package multiple health-promoting compounds within a small, flavorful, and accessible food. From its rich anthocyanin and resveratrol content to its dietary fiber, vitamins, and unique alkaloids, mulberry

offers a multi-faceted nutritional identity that aligns remarkably well with the health challenges of our time.

The scientific literature, while still building its clinical foundation, consistently supports mulberry's role as a functional food with antioxidant, anti-diabetic, cardiovascular-protective, neuroprotective, anti-inflammatory, anti-cancer, and skin anti-aging properties. These benefits are not the products of a single compound acting in isolation, but rather the synergistic interplay of a rich phytochemical matrix working across multiple biological pathways.

For the everyday consumer, the message is straightforward: adding mulberries to a balanced, plant-based diet is a simple, pleasurable, and well-evidenced way to invest in long-term health. For the scientific community, the mulberry fruit remains fertile ground for clinical translation a centuries-old remedy waiting to be fully understood in the language of modern medicine.

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TOURIST INFLUX TOWARDS ECOTOURISM: A CASE STUDY OF THE PITCHAVARAM MANGROVE FOREST

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Abstract

Ecotourism refers to environmentally responsible travel to natural areas that promotes biodiversity conservation, environmental awareness, and socio-economic benefits for local communities. Mangrove ecosystems are among the most suitable destinations for ecotourism because of their unique ecological and environmental significance. The Pitchavaram Mangrove Forest, located in Cuddalore district of Tamil Nadu, is one of the largest mangrove ecosystems in India and attracts both domestic and international tourists throughout the year. The present study analysed tourist influx to Pitchavaram using secondary data collected from the Department of Tourism for the period 2015–2022. The results revealed that the number of tourists increased from 1.8 lakh in 2015 to 2.8 lakh in 2022, despite a temporary decline during 2020 and 2021 due to the COVID-19 pandemic. The findings indicate a growing interest in ecotourism and highlight the importance of conserving mangrove ecosystems while promoting sustainable tourism development.

Keywords: Ecotourism, Mangrove, Tourist influx, Pitchavaram, Sustainable tourism

Introduction

Ecotourism refers to environmentally responsible travel to natural areas that conserves biodiversity, minimizes environmental impacts, and promotes the socio-economic well-being of local communities (Joshi, 2011). It has become an important approach for conserving natural

ecosystems while generating employment and livelihood opportunities. Tourism is one of the fastest-growing sectors in India, and the World Travel and Tourism Council (WTTC, 2014) projected an annual growth rate of 6.4 per cent during 2014–2024.

Mangrove forests are ideal destinations for ecotourism because of their rich biodiversity and ecological significance. They protect coastlines from erosion and storms, serve as breeding and nursery grounds for aquatic species, sequester carbon, and support the livelihoods of coastal communities (Alongi, 2008). Sustainable ecotourism in mangrove ecosystems contributes to both environmental conservation and local economic development (Das, 2018).

Pitchavaram Mangrove Forest, located in Cuddalore district of Tamil Nadu, is one of the largest mangrove ecosystems in India, covering about 1,478.60 hectares. Situated between the Vellar and Coleroon estuaries, the ecosystem consists of numerous waterways and mangrove-covered islands. Recognizing its ecological importance, Pitchavaram was designated as a Ramsar Site (Site No. 2482) on 8 April 2022. The mangrove ecosystem functions as a natural bio-shield against coastal hazards, supports rich biodiversity, and provides livelihood opportunities for nearly 1,000 fishing families (Tamil Nadu Forest Department, 2022).







Pichavaram Mangrove Forest

The growing popularity of boating, bird watching, and nature-based tourism has increased tourist arrivals in Pitchavaram over the years. Therefore, the present study aims to analyse the trend in tourist influx and assess the development of ecotourism in the Pitchavaram Mangrove Forest.

Methodology

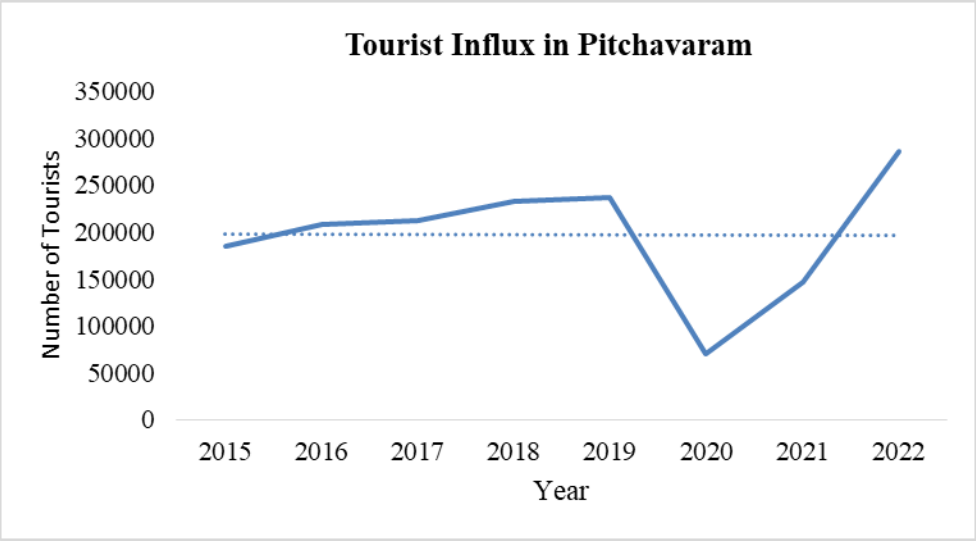
The study was conducted in the Pitchavaram Mangrove Forest located in Cuddalore district of Tamil Nadu. Secondary data on domestic and foreign tourist arrivals for the period 2015–2022 were collected from the Department of Tourism. Descriptive statistical tools such as mean, standard deviation, ranking, and graphical analysis were used to examine annual and monthly tourist trends.

Results and Discussion

Annual Tourist Influx

The annual tourist arrivals to Pitchavaram Mangrove Forest showed an overall increasing trend during the study period (2015–2022), rising from about 1.83 lakh visitors in 2015 to 2.89 lakh visitors in 2022 (Figure 1). Tourist arrivals increased steadily from 2015 to 2019, indicating the growing popularity of Pitchavaram as an ecotourism destination. A sharp decline was observed in 2020 due to travel restrictions imposed during the COVID-19 pandemic, followed by a partial recovery in 2021. In 2022, tourist arrivals increased substantially, surpassing the pre-pandemic level, reflecting renewed interest in nature-based tourism.

Figure 1. Annual Tourist Influx in Pitchavaram (2015–2022)

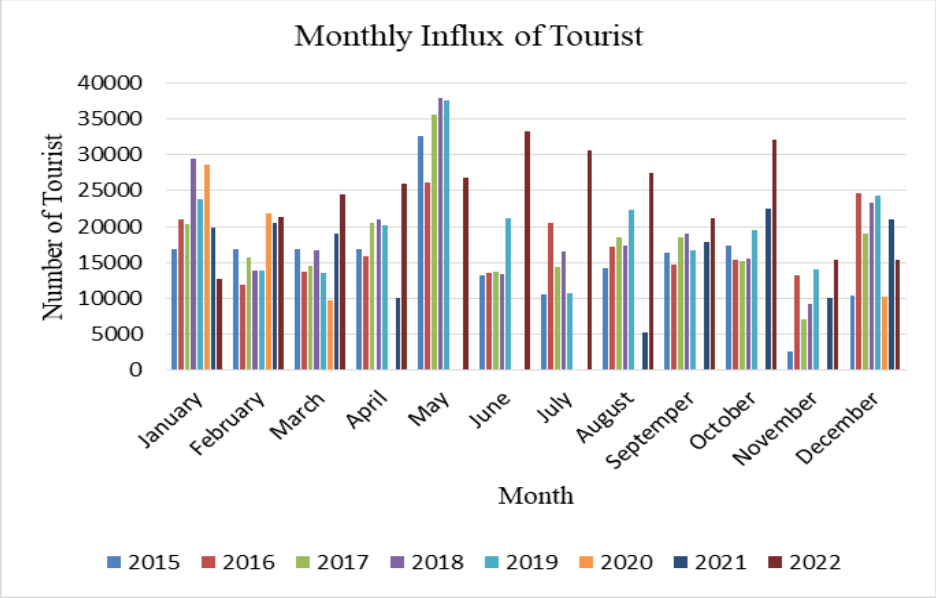


The Compound Annual Growth Rate (CAGR) of approximately 7.1 per cent over the study period indicates a healthy long-term growth in tourist arrivals despite the temporary disruption caused by the pandemic. The increasing trend suggests that improvements in tourism infrastructure, boating facilities, and the ecological significance of the Pitchavaram Mangrove Forest have contributed to the sustained growth of ecotourism in the region.

Monthly Tourist Influx

Tourists visit Pitchavaram throughout the year, although the number of visitors varies across seasons. Peak tourist arrivals occur during **May**, coinciding with the summer vacation period. A second period of relatively high visitation is observed during **December and January** because of pleasant weather and holiday vacations. In contrast, tourist arrivals are lowest during **November**, mainly due to the northeast monsoon, heavy rainfall, cyclones, and unfavourable boating conditions (Figure 2).

Figure 2. Monthly Tourist Influx in pitchavaram



Monthly Tourist Statistics of Tourist Arrivals in Pitchavaram Mangrove

The monthly tourist statistics reveal distinct seasonal variations in tourist arrivals to the Pitchavaram Mangrove Forest (Table 1). May recorded the highest average total tourist arrivals (24,585.9 visitors) and ranked first, mainly due to the summer vacation period when families and students frequently visit the destination. January ranked second with an average of 21,597.4 visitors, followed by December (18,515.6 visitors), reflecting increased tourism during the winter holidays and favourable climatic conditions.

In contrast, November recorded the lowest average tourist arrivals (8,940.1 visitors), followed by July (12,923.5 visitors) and June (13,529.9 visitors). The reduced tourist influx during these months can be attributed to the northeast monsoon, heavy rainfall, cyclones, and unfavourable boating conditions, which discourage visitors.

Table 1 Monthly Statistics of Tourist Arrivals in Pitchavaram Mangrove (2015-22)

	Domestic Tourists			Foreign Tourists			Total Tourists		
Month	**Mean**	**SD**	**Rank**	**Mean**	**SD**	**Rank**	**Mean**	**SD**	**Rank**
January	21483.1	5622.01	II	114.25	101.04	II	21597.4	5645.62	II
February	16757.9	3912.77	V	200.125	164.355	I	16958	3807.14	V
March	15950.6	4420.43	VII	106	84.7989	III	16056.6	4385.57	VII
April	16228.4	8030.96	VI	64.125	54.8932	VIII	16292.5	8054.36	VI
May	24553.8	15785.5	I	32.125	47.5978	XII	24585.9	15806.5	I
June	13483.9	10767.2	X	46	65.1767	XI	13529.9	10768.3	X
July	12858.3	10201.4	XI	65.25	59.442	VII	12923.5	10216.5	XI
August	15186.1	8853.8	IX	96.375	84.1494	IV	15282.5	8880.03	IX
September	15487.3	6550.71	VIII	52	50.7768	IX	15539.3	6567.36	VIII
October	17174.9	8980.82	IV	47.125	38.6021	X	17222	8979.31	IV
November	8868	5481.38	XII	72.125	62.231	VI	8940.13	5481.79	XII
December	18433.6	5864.26	III	82	77.8845	V	18515.6	5885.05	III

Domestic tourists constituted the overwhelming majority of visitors throughout the year, whereas foreign tourist arrivals remained comparatively low. Among foreign tourists, February recorded the highest average arrivals (200.1 visitors), followed by January (114.3 visitors) and March (106.0 visitors), indicating that international tourists prefer visiting during the pleasant winter season. Foreign tourist arrivals were lowest in May (32.1 visitors), possibly because of the high summer temperatures.

The relatively higher standard deviation observed in May (SD = 15,806.5) and June (SD = 10,768.3) indicates greater year-to-year fluctuations in tourist arrivals during these months, whereas lower standard deviations in February and March suggest comparatively stable tourist visitation patterns. Overall, the results indicate that seasonal factors, climatic conditions,

school holidays, and accessibility strongly influence tourist arrivals in Pitchavaram. Peak visitation occurs during the summer (May) and winter holiday (December–January) seasons, while the northeast monsoon period (November) experiences the lowest tourist influx.

Conclusion

The findings indicate that ecotourism in the Pitchavaram Mangrove Forest has grown steadily over the study period, as reflected by the increasing tourist arrivals from 2015 to 2022. Although the COVID-19 pandemic caused a temporary decline in visitor numbers during 2020 and 2021, tourist arrivals recovered strongly in 2022, demonstrating the resilience and growing popularity of nature-based tourism. Seasonal variations in tourist arrivals were primarily influenced by climatic conditions and vacation periods.

As one of India's largest mangrove ecosystems and a designated Ramsar Site, Pitchavaram possesses immense ecological and tourism potential. The increasing tourist influx reflects growing public awareness and appreciation of mangrove ecosystems while creating opportunities for employment generation and improving the livelihoods of local communities. To sustain this growth, emphasis should be placed on eco-friendly tourism management, enhancement of visitor facilities, environmental awareness, and conservation of mangrove biodiversity. These measures will help ensure the long-term ecological sustainability and socio-economic benefits of ecotourism in the Pitchavaram Mangrove Forest.

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MICROBIAL NECROMASS: A HIDDEN DRIVER OF SOIL CARBON DYNAMICS

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Introduction

Soil organic carbon (SOC) is a fundamental component of the soil organic matter, governing soil fertility, ecosystem productivity, and global carbon cycling. Traditionally, SOC was assumed to originate from plant derived inputs such as leaf litter and root biomass. However, contemporary research has redefined this paradigm by identifying microbial necromass (the residues of dead microorganisms) as the dominant and more persistent contributor to SOC (Liang et al., 2019). This conceptual shift has significantly enhanced our understanding of soil carbon stabilization mechanisms and the role of microbial processes in long-term carbon sequestration (Angst et al., 2021). Microbial necromass, composed of cell wall fragments, amino sugars, nucleic acids and other biomolecules. It constitutes a substantial fraction of stable soil organic matter and represents a critical link between microbial activity and carbon persistence in soils.

The formation of microbial necromass is inherently linked to microbial life cycles and soil ecological processes. Soil microorganisms utilize plant derived carbon substrates for growth and metabolism, converting labile organic matter into microbial biomass. Upon death, caused by senescence, nutrient limitation, predation, or viral lysis, microbial cells release their structural and intracellular components into the soil matrix (Camenzind et al., 2023). These residues accumulate over time, forming necromass that differs chemically and functionally from fresh organic inputs. Importantly, the biochemical composition of necromass varies depending on microbial community structure, with fungal derived necromass generally being more carbon rich

and structurally complex, thereby contributing more effectively to stable SOC pools compared to bacterial necromass.

Recent advances in analytical techniques have improved our ability to quantify and characterize microbial necromass, although significant challenges remain. Biomarker based approaches, particularly amino sugar analysis, are widely used to estimate necromass contributions in the soil. The bacterial and fungal necromass can be quantified from muramic acid and glucosamine, respectively. However, these methods have limitations in resolving temporal dynamics and capturing the full spectrum of microbial residues. Emerging tools such as isotopic labelling, NanoSIMS imaging, and molecular level analyses offer greater precision and spatial resolution, enabling a more comprehensive understanding of necromass formation, transformation, and stabilization processes (Buckeridge et al., 2022). Integrating these approaches is essential for accurately assessing necromass contributions to SOC and for refining soil carbon models.

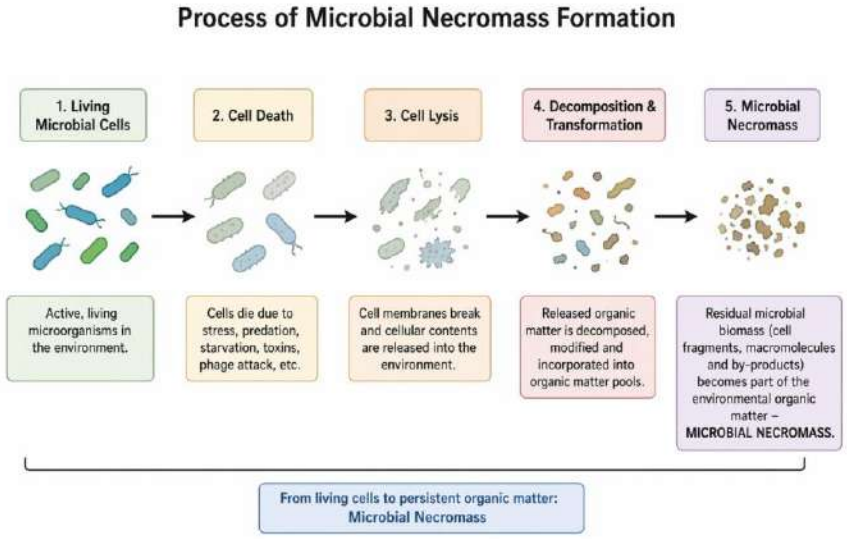


Figure 1: Process of microbial necromass formation

Unlike plant residues, which are often rapidly decomposed, microbial derived compounds exhibit a strong affinity for mineral surfaces and are frequently incorporated into mineral-associated organic matter (MAOM) (Xuan et al., 2024). This association is facilitated by various physicochemical interactions, including ligand exchange, cation bridging, hydrogen bonding, and hydrophobic interactions. Additionally, microbial necromass becomes physically protected

within soil aggregates, where it is less accessible to decomposers. These mechanisms collectively enhance the persistence of necromass, allowing it to remain in soils for extended periods ranging from decades to centuries. As a result, microbial necromass contributes more than 50% of the total SOC, underscoring its importance as a long-term carbon reservoir.

Beyond its role in carbon storage, microbial necromass significantly influences soil fertility and nutrient cycling. Due to its relatively low carbon to nitrogen ratio and biochemical similarity to living biomass, necromass serves as a readily utilizable substrate for soil microorganisms. It functions as a slow-release source of essential nutrients, particularly nitrogen and phosphorus, thereby sustaining microbial activity and supporting plant growth. The decomposition and recycling of necromass create localized nutrient rich zones, often referred to as "hotspots," which stimulate microbial diversity and enzymatic activity. This dynamic interplay between necromass decomposition and nutrient availability highlights its central role in maintaining soil productivity and ecosystem functioning.

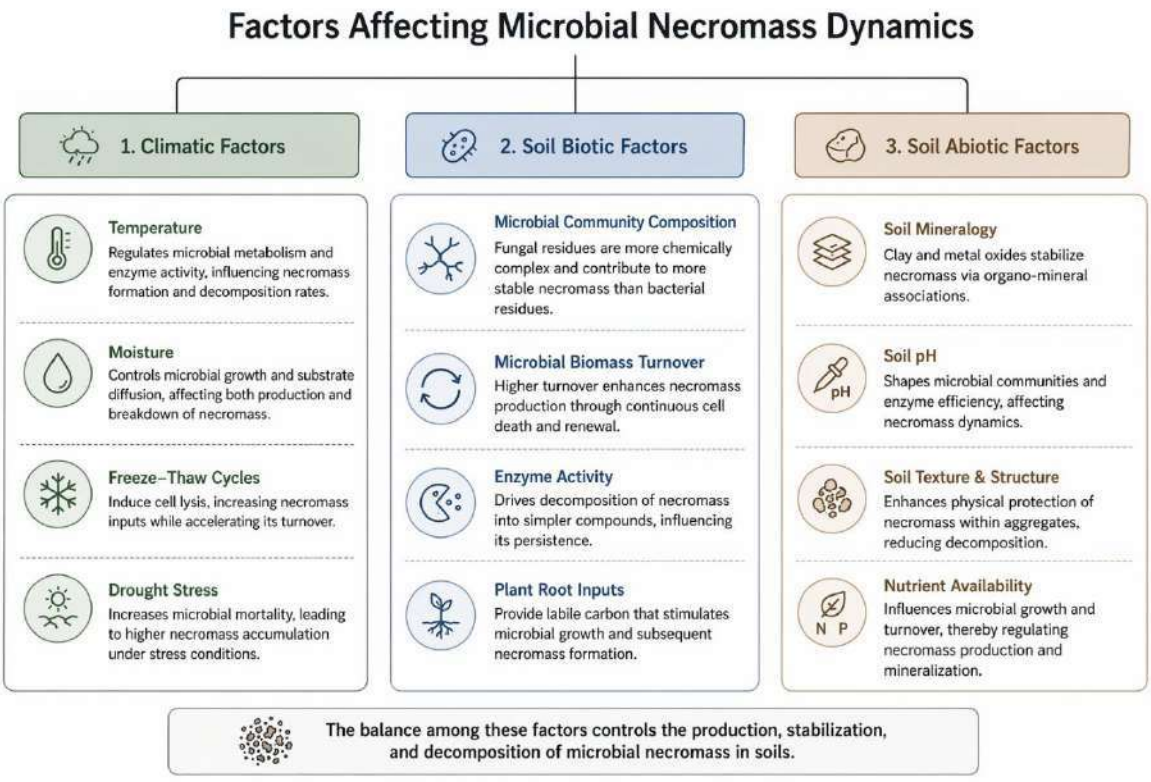


Figure 2: Different factors affecting microbial necromass dynamics

The accumulation and stabilization of microbial necromass are regulated by a complex interplay of biotic and abiotic factors. Microbial community composition, plant inputs, and root exudation patterns influence the necromass formation by affecting microbial growth and carbon use efficiency. Similarly, edaphic factors such as mineralogy, texture, and pH govern the stabilization and turnover of necromass. For instance, soils rich in clay minerals and metal oxides provide greater surface area and reactive sites for necromass adsorption, enhancing its persistence (Even & Francesca Cotrufo, 2024). Climatic conditions also play a critical role, with temperature and moisture regimes influencing both microbial activity and decomposition rates. Land use practices, including tillage, fertilization, and residue management, further modulate necromass dynamics by altering soil structure, nutrient availability, and microbial communities (Yang et al., 2022).

Despite substantial progress, several knowledge gaps remain in our understanding of microbial necromass dynamics. Current quantification methods often underestimate or oversimplify necromass contributions due to methodological constraints and the complexity of soil systems. Additionally, the roles of microbial community traits, necrobiome interactions, and mineral organic interfaces in controlling necromass stabilization are not fully elucidated. Addressing these gaps requires interdisciplinary research that integrates microbiology, soil chemistry, and ecosystem science. Furthermore, incorporating microbial necromass into Earth system models is essential for improving predictions of SOC dynamics under changing environmental conditions.

In conclusion, microbial necromass represents a fundamental yet previously underappreciated component of soil organic matter. Its formation, stabilization, and turnover are central to soil carbon dynamics, nutrient cycling, and ecosystem sustainability. By advancing our understanding of microbial necromass and its controlling factors, we can develop more effective strategies to enhance soil fertility, increase carbon sequestration, and mitigate climate change.

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INSECTS IN FORENSIC SCIENCE- SOLVING CRIMES WITH MAGGOTS

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Introduction

Forensic entomology uses the biology and ecology of arthropods to estimate the post-mortem interval (PMI). This approach provides a reliable timeline in criminal investigations when traditional physiological signs fade. This article reviews the historical background and modern methods of the field, focusing mainly on blowflies (Calliphoridae) as primary forensic indicators. It explains the six stages of blowflies' development and describes how to use the Accumulated Degree Hours (ADH) method to calculate the minimum PMI (mPMI) with specific thermal constants. Additionally, the article examines the ongoing and overlapping patterns of insect succession on decomposing remains. Finally, it discusses challenges in the field, such as geographic differences, environmental changes, and entomotoxicology, while emphasizing future directions in molecular analysis and gene expression that could improve the accuracy of entomological evidence.

Introduction to Forensic Entomology

Forensic entomology studies insects and other arthropods in relation to criminal investigations. This intriguing field has become one of the most trustworthy ways to estimate the post-mortem interval (PMI), the time since death. This is especially useful in cases of advanced decomposition, where traditional forensic methods may not work as well.

When someone dies, their body goes through a predictable series of ecological changes that attract different insects at specific times. The first insects to arrive, mainly blowflies (family Calliphoridae), can sense decomposing tissue within minutes to hours after death. By analyzing

the species, developmental stages, and succession patterns of these insects, forensic entomologists can provide key evidence regarding the timeline and circumstances of death.

The precision of traditional PMI estimation methods, such as rigor mortis, livor mortis, and algor mortis, significantly decreases after 48-72 hours following death. In contrast, entomological evidence can offer reliable estimates ranging from days to months, making it a vital resource in forensic investigations.

Historical Perspective

The Sung Tzu Case (13th Century)

The earliest known use of forensic entomology occurred in 13th-century China, recorded in "The Washing Away of Wrongs" (Xi Yuan Ji Lu) by Sung Tzu in 1247 CE. This remarkable case shows the understanding of insect behavior that existed long before forensic science was formally established.

In this historic case, a farmer was found murdered in a field. Villagers with sickles were asked to lay down their tools. Despite being cleaned, one sickle attracted blowflies to trace amounts of blood that were invisible to the naked eye. The murderer, faced with this evidence, confessed. This instance represents the first documented use of insect evidence in a criminal investigation.

Modern Development

The systematic study of forensic entomology began in the 19th and 20th centuries, with major contributions from several pioneering scientists. In 1668, Italian physician Francesco Redi disproved spontaneous generation by showing that maggots came from fly eggs rather than arising from decaying matter.

French veterinarian Jean Pierre Mégnin (1828-1905) published important studies on the succession of insects on cadavers, laying the groundwork for modern PMI estimation methods. His work showed that different insect species colonize remains in predictable waves, creating a biological clock that trained entomologists can interpret.

The Biology of Blowflies

Life Cycle Stages

Blowflies (family Calliphoridae) are the main forensic indicators used in PMI estimation. Knowing their complete metamorphosis is crucial for accurate analysis. Their life cycle has six

distinct stages, each lasting a predictable amount of time based on temperature and environmental conditions.

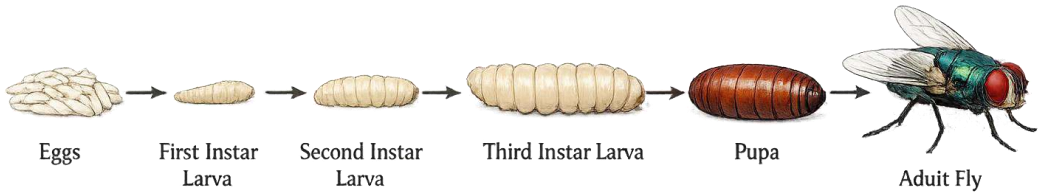


Figure 1: The complete life cycle of blowflies (Calliphoridae) showing all developmental stages from egg to adult.

Forensically Important Species

Several blowfly species hold particular forensic importance. *Lucilia sericata* (the green bottle fly) is one of the most studied due to its wide distribution and consistent developmental patterns. Other significant species include *Calliphora vicina*, *Chrysomya albiceps*, and *Phormia regina*.

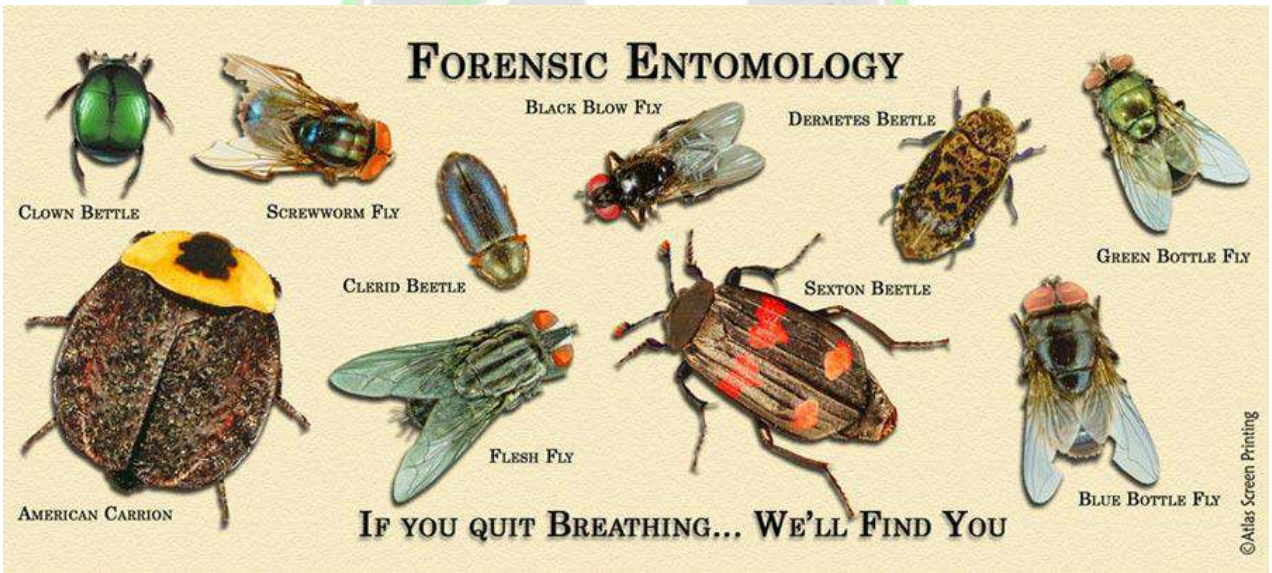


Figure 2: Insects involved in Forensic Entomology

Post-Mortem Interval Estimation

Accumulated Degree Hours (ADH) Method

The Accumulated Degree Hours (ADH) method is the most common technique for estimating the minimum post-mortem interval (mPMI). This technique relies on the idea that

insect development depends on temperature and occurs at consistent rates above a species-specific threshold temperature.

To calculate ADH, one determines the heat accumulation needed for an insect to reach a certain developmental stage. The formula is: ADH = (Temperature - Base Temperature) × Time (in hours). By comparing the ADH of larvae taken from a body with historical temperature data from the scene, entomologists can estimate when colonization started.

According to research by Shin et al. (2021), the minimum ADH values for *Lucilia sericata* are: first instar (203 ADH), second instar (525 ADH), third instar (813 ADH), post-feeding stage (1552 ADH), and pupa (2492 ADH). These serve as reference points for forensic calculations.

Insect Succession Patterns

Beyond individual species development, the order of insect colonization offers valuable time-related information. Various insect groups are attracted to remains at specific stages of decomposition, creating a dynamic and overlapping timeline that can last weeks to months. Primary colonizers like blowflies (Calliphoridae) and flesh flies (Sarcophagidae) arrive first during the early stages of decomposition. Blowflies lay eggs while flesh flies deposit live larvae, both contributing to active decay. This initial wave is later joined by house flies (Muscidae) and cheese skippers (Piophilidae), and as decomposition progresses, it transitions to beetles (like Silphidae and Dermestidae) as the remains dry. By recognizing which species are present and which have completed development, entomologists can accurately estimate the time since death.

Challenges and Future Directions

Despite its proven usefulness, forensic entomology faces challenges. Geographic differences in insect populations can greatly affect development rates, making localized baseline data necessary for accurate estimates. Changes in temperature, rainfall, and habitat can also shape insect colonization patterns. Moreover, drugs or toxins in the deceased can impact insect development, requiring careful interpretation of the evidence.

Future developments in forensic entomology include creating molecular methods for species identification, analyzing gene expression for more accurate age estimation, and compiling comprehensive databases to address geographic and seasonal variations. These advancements are expected to improve the reliability and accuracy of entomological evidence in criminal investigations.

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SEASON OF JASMINE FLOWERS

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Introduction

Jasmine flowers are among the most cherished and fragrant blossoms in the world. Known for their delicate petals and enchanting aroma, they have held cultural, medicinal, and economic importance for centuries. Widely grown in tropical and subtropical regions, jasmine is especially popular in India, where it plays a vital role in traditions, rituals and daily life.

"Fragrance that whispers purity, beauty that blooms in every heart-Jasmine, the soul of nature's elegance."

One of the most remarkable features of jasmine is its fragrance. The sweet, soothing scent has made it a key ingredient in perfumes, cosmetics, and essential oils. Jasmine oil widely used in aromatherapy to reduce stress, improve mood, and promote relaxation. Its calming nature makes it an essential part of wellness practices.

Jasmine also has important medicinal uses. In traditional systems like ayurveda, it is valued for its healing properties. Jasmine is believed to help in treating headaches, skin issues, and sleep disorders. Jasmine tea, often blended with green tea, is rich in antioxidants and helps improve digestion and immunity.

Culturally, jasmine holds deep significance, especially in India. It is associated with purity, love, devotion. The flowers are widely used in religious offerings and ceremonies.

Women commonly wear jasmine garlands in their hair as a symbol of beauty and grace. During festivals and weddings, jasmine decoration create a sacred and pleasant atmosphere.

Economically, jasmine cultivation supports many farmers and workers. Due to its high demand in the perfume and cosmetics industries, it is a valuable commercial crop. States like Tamilnadu and Karnataka are known for large-scale jasmine production. Mainly grown for decorative purposes in gardens.

VARIETIES OF JASMINE:



There are over 200 species of jasmine, each with unique characteristics. Some of the most popular varieties include:



* **common jasmine(jasminium officinale):** Also known as "poet's jasmine, it is famous for its strong fragrance and is widely used in perfumes and oils.

*__Arabian jasmine(jasminium sambac):__

One of the most popular varieties in India, known locally as *Morga* . It is used in garlands, religious rituals, and jasmine tea.



*__Spanish jasmine(jasminium gradiflorum):__

Known for its large, star shaped flowers, it is extensively used in the perfume industry.



***Winter jasmine(jasminium nudifloram):__

Unlike other varieties, it blooms in winter and has bright yellow flowers with little fragrance.

*__Star jasmine(trachelospermum jasminoides):__



Though not a "TRUE JASMINE", it is popular for its star-shaped flowers and pleasant scent, often used as an ornamental plant.

Mangaluru Mallige (*Jasminum sambac*):



It is a premium, highly fragrant jasmine native to coastal Karnataka. Its unique aroma and cultivation earned it a prestigious Geographical Indication (GI) tag.

The region features several localized varieties and closely related jasmine cousins:

Tulunad Mallige (Katpadi/Mangaluru Mallige): The flagship GI-tagged variety, famous for its intense, long-lasting fragrance and tightly woven blooms.

Shankarapura Mallige: Cultivated heavily in the Udupi district (Shankarapura, Shirva, and Innanje villages), it is one of the most commercially prominent variants of *Jasminum sambac* in the region.

Gundu Mallige: A stocky, rounder, and densely petaled bush variety of Arabian Jasmine.

Konkan Mogre (Bhatkal Mogre/Mallige): Another highly fragrant sub-variety commonly found along the coastal stretches from Bhatkal to Goa.

Known for its creamy-white buds with delicate pinkish-purple blush tips that slowly open to release a strong, sweet scent, it is an essential part of coastal culture, temples, and weddings.

JASMINE OIL:

Jasmine oil is an aromatic extraxted from the flowers of the jasmine plant. It is widely used in hair care, skincare, aromatherapy, and traditional medicine due to its pleasant fragrance and beneficial properties.

Benefits of jasmine oil:

1. Moisturizes hair and scalp- Helps reduce dryness and keeps hair soft.
2. Controls frizz- Smoothens hair and improves manageability.
3. Stregthens hair-Nourishes hair roots and may reduce breakage.
4. Promotes healthy scalp-Its antimicrobial properties can help maintain scalp hygiene.
5. Adds shine-Makes hair appear healthier and shinier.
6. Reduces stress-The calming fragrance of jasmine may help reduce stress, which can indirectly support hair health.

How to muse jasmine oil:

- Mix a few drops of jasmine essential oil with a carrier oil such as coconut oil.
- Massage gently into the scalp and hair.
- leave for 30 minutes to overnight.
- wash with a mild shampoo.

Jasmine oil is a natural hair-care product that helps moisturize the scalp, improve hair texture,add shine, and provide a relaxing fragrance. Regular use with a carrier oil like coconut oil can contribute to healthier- looking hair.

A jasmine garland is traditionally made by the criss-cross or loop-knot method. Artisans use strong sewing or tailoring thread to bind fresh jasmine buds tightly together in opposing directions, creating a continuous, fragrant strand often worn in the hair or used for religious offerings.

Essential Materials

Fresh Jasmine Buds: Picked slightly before they bloom so they hold their shape and stay secure on the thread.

String: Strong, slightly moistened tailoring or cotton thread, rolled several times over the index finger for easy access.

Step-by-Step Weaving Process

1. **Prepare the Thread:** Pull about an arm's length of thread and wrap the working end multiple times around your index finger. Leave a tail at the end to tie the garland together later.
2. **First Flower Placement:** Place the first jasmine flower on the string, holding the stem firmly between your thumb and middle finger.
3. **Second Flower Placement:** Take a second flower and place it in the *opposite* direction, facing the stem of the first flower.
4. **The Lock Knot:** Wrap the thread around the intersecting stems using a loop knot to secure both flowers firmly.
5. **Repeat:** Continue alternating the direction of the flowers (left, right, left, right) and securing them with the loop knot until you reach the desired length.
6. **Finishing:** Tie off the end securely so the buds do not slide off the thread



ENVIRONMENTAL AND AESTHETIC VALUE:

Jasmine plants enhance the beauty of gardens and surroundings. They attract pollinators like bees and butterflies, helping maintain ecological balance. Their presence adds freshness and positivity to any space.

 Biodiversity **Support:** The fragrant blooms attract essential pollinators, including bees, butterflies, and hummingbirds, supporting the health of the local ecosystem.

 Soil **Stabilization:** Many jasmine types—such as Winter Jasmine—feature extensive root systems that make them excellent functional plants for ground cover and preventing soil erosion.

 Urban **Green Infrastructure:** Research shows that jasmine species contribute significantly to the visual quality and biodiversity of urban green infrastructure.

 Natural **Hormones:** Jasmine lent its name to *jasmonates* (hormones derived from methyl jasmonate), which play a key role in a plant's ability to respond naturally to environmental cues like heat or cold stress

Conclusion

Jasmine flowers are more than just beautiful blooms. Their wide range of uses in medicine, culture, economy, and wellness highlights their immense importance. With numerous varieties offering unique qualities, jasmine continues to enrich human life with its fragrance, elegance, and timeless charm. The seasonal blooming of jasmine transforms these delicate blossoms from mere flora into cultural icons . Their cycles drive agricultural economics, traditional festivities, and stress-relief practices worldwide. Managing these flowering seasons ensures a steady supply of this timeless, fragrant treasure.

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SUSTAINABLE FISHING PRACTICES IN MARINE PROTECTED AREAS

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Abstract

Marine Protected Areas (MPAs) have emerged as one of the most effective approaches for conserving marine biodiversity and ensuring the sustainability of fisheries resources (Agardy et al., 2011). Despite legal protection, many MPAs continue to experience overfishing, habitat destruction, destructive fishing practices, and climate-related pressures (Halpern, 2003; Hilborn et al., 2023). India possesses rich marine biodiversity and a vast coastline supporting millions of people through fisheries and related activities (MoEF, 2014). However, increasing fishing pressure, use of non-selective gears, juvenile fish exploitation, habitat degradation, and governance challenges threaten the ecological integrity of marine ecosystems (Sivakumar et al., 2012). Sustainable fisheries management within MPAs requires an integrated approach combining ecosystem-based fisheries management, participatory governance, responsible fishing practices, and technological innovations in fishing gear (FAO, 1995; Sala et al., 2023).

Introduction

India is recognized as one of the world's megadiverse countries, harbouring approximately 7.8% of global biodiversity (MoEF, 2014). The country possesses an extensive coastline of more than 7,500 km and supports highly productive ecosystems including coral reefs, mangroves, estuaries, seagrass beds and coastal wetlands. Rapid urbanization, industrialization, habitat conversion, pollution, destructive fishing methods and climate change have resulted in significant degradation of marine ecosystems (Lotze et al., 2006). Climate-induced impacts such as sea-level rise, ocean warming, ocean acidification and extreme weather events further threaten marine biodiversity and coastal communities (IPCC, 2014). Marine

Protected Areas have therefore become essential tools for conserving marine biodiversity and restoring ecosystem health. Numerous studies have demonstrated that MPAs increase fish abundance, biomass and biodiversity while improving ecosystem resilience (Halpern, 2003; Halpern and Warner, 2002; Selig and Bruno, 2010). In India, marine conservation is supported by several legislative frameworks including the Wildlife (Protection) Act, 1972, Environment Protection Act, 1986, Coastal Regulation Zone Notification and the Biological Diversity Act, 2002 (Sivakumar et al., 2012).

Marine Protected Areas in India

India currently possesses 31 Marine Protected Areas covering approximately 6,271 km² of marine habitats (Patterson et al., 2016). These include four Marine National Parks and twenty-seven Marine Wildlife Sanctuaries distributed across mainland India and island territories. Important MPAs include the Gulf of Kachchh Marine National Park, Gulf of Mannar Marine National Park, Sundarbans National Park and Mahatma Gandhi Marine National Park. These protected areas conserve ecologically important habitats including coral reefs, seagrass meadows, mangroves and breeding grounds of commercially important fish species (Agardy et al., 2011). MPAs also serve as refuges for endangered species such as dugongs, sea turtles, dolphins and sharks (CBD, 2004).

Need for Sustainable Fishing in Marine Protected Areas

Despite the establishment of MPAs, several fisheries-related issues continue to threaten their effectiveness (Hilborn et al., 2023). Open-access fisheries, excessive fishing effort and competition among fishing sectors have contributed to resource depletion and habitat degradation (Sivakumar et al., 2012). Many commercially important fisheries have already reached or exceeded their Maximum Sustainable Yield levels, emphasizing the urgent need for science-based management interventions (FAO, 1995).

Sustainable Fisheries Management Approaches

Participatory Fisheries Management

Participatory fisheries management involves the active involvement of fishers, local communities, scientists and policymakers in resource management decisions. Community participation improves compliance, promotes stewardship and incorporates traditional ecological knowledge into management strategies (FAO, 1995).

Ecosystem-Based Fisheries Management

Traditional fisheries management focused primarily on individual target species without considering ecosystem interactions. Ecosystem-Based Fisheries Management (EBFM) adopts a holistic approach by considering predator-prey relationships, habitat requirements, environmental variability and socio-economic factors (Salm et al., 2000). India has initiated EBFM programmes in regions including the Gulf of Mannar, Karnataka coast and north-west coast through research institutions such as CMFRI (Sivakumar et al., 2012).

Code of Conduct for Responsible Fisheries

The Food and Agriculture Organization introduced the Code of Conduct for Responsible Fisheries in 1995 to promote sustainable exploitation of aquatic resources (FAO, 1995). The code emphasizes responsible fishing operations, effective governance, ecosystem conservation and support for small-scale fisheries.

Eco-Labelling and Sustainable Seafood

Eco-labelling programmes promote responsible fishing practices by certifying seafood products harvested with minimal environmental impact. Third-party certification systems provide independent verification of sustainability standards and improve market access for certified products (FAO, 1995). The Marine Stewardship Council remains one of the most recognized eco-labelling organizations globally. Certification standards focus on stock sustainability, ecosystem impacts and governance effectiveness.

Technological Innovations in Sustainable Fisheries

Improving Gear Selectivity

Modern fisheries increasingly emphasize selective fishing gears that reduce the capture of juveniles and non-target species (Madsen et al., 2012; Lucchetti et al., 2021). Modifications in codend mesh size, square mesh panels and exclusion grids have improved size selectivity in many fisheries (Sala et al., 2016). Turtle Excluder Devices and Bycatch Reduction Devices have proven highly effective in reducing incidental mortality of endangered species while maintaining target catches (Valdemarsen and Suuronen, 2003).

Reducing Bycatch of Protected Species

Bycatch remains one of the major conservation concerns in global fisheries (Lewison et al., 2014). Innovations such as illuminated gillnets, circle hooks and acoustic deterrent devices

have significantly reduced interactions with sea turtles, marine mammals and seabirds (Ortiz et al., 2016; Virgili et al., 2018).

Improving Fishing Efficiency

Recent technological developments aim to reduce fuel consumption and environmental impacts while improving catch quality (Sala et al., 2023). Hydrodynamic trawl designs, improved otter boards and optimized net configurations reduce seabed contact and operational costs (Farran et al., 2008; Sala et al., 2009).

Adapting to Climate Change

Climate change is altering species distributions, migration patterns and ecosystem productivity (IPCC, 2014; Rogers et al., 2019). Fisheries management must therefore become adaptive and flexible to changing environmental conditions.

Artificial Intelligence and Fisheries

Artificial Intelligence has emerged as a powerful tool for fisheries research and management. Machine learning and image analysis techniques can automate fish behaviour studies, improve stock assessments and enhance gear selectivity research (Abangan et al., 2023; Méhault et al., 2022).

Selective and Environment-Friendly Fishing Methods

Several fishing methods have lower ecological impacts and are considered sustainable alternatives to destructive gears, including pole and line fishing (Harrell, 2019), handline fishing (Spiridonov, 2005), troll fishing (Preston et al., 1987), trap and pot fisheries (Scanu et al., 2021), harpoon fishing (Pinart, 2018), longline fisheries (Løkkeborg et al., 2010) and modified trawl gears equipped with Turtle Excluder Devices (Valdemarsen and Suuronen, 2003).

Conclusion

Marine Protected Areas alone cannot ensure marine conservation without sustainable fisheries management. Overfishing, habitat degradation and climate change continue to threaten marine biodiversity and fisheries productivity across India (Lotze et al., 2006; Hilborn et al., 2023). Sustainable fisheries within MPAs require ecosystem-based management, participatory governance, responsible fishing practices and adoption of selective technologies (Agardy et al., 2011; Sala et al., 2023). The integration of scientific knowledge, stakeholder participation and adaptive management can transform MPAs into effective tools for biodiversity conservation while safeguarding coastal livelihoods (Kelleher et al., 1995; Salm et al., 2000).

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INDIAN MARKET DEMAND AND INDUSTRIAL APPLICATIONS OF SUSTAINABLE CELLULOSE

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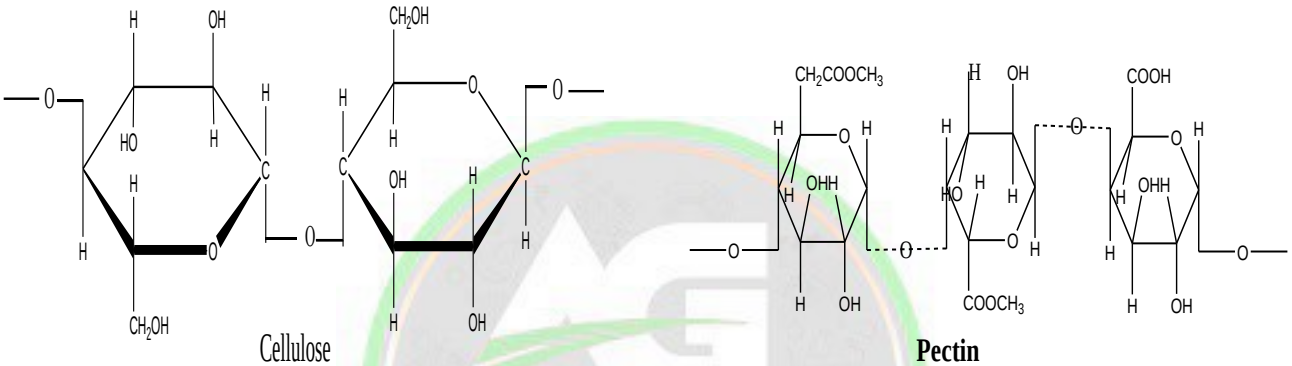
Abstract

India is emerging as a significant market for sustainable cellulose due to increasing demand for biodegradable materials, rapid industrialization, and growing environmental awareness. The market is driven by the expansion of the paper, textile, pharmaceutical, food, and packaging sectors, along with government initiatives promoting bio-based and circular economy solutions. Industry reports project steady growth in the Indian cellulose market over the coming years, supported by rising adoption of sustainable materials and increasing investments in biomass utilization. Agricultural residues such as banana pseudo stem, sugarcane bagasse, rice straw, and wheat straw are gaining attention as economical and renewable sources of cellulose. Their utilization reduces agricultural waste while creating value-added products that support rural livelihoods and sustainable manufacturing.

Introduction

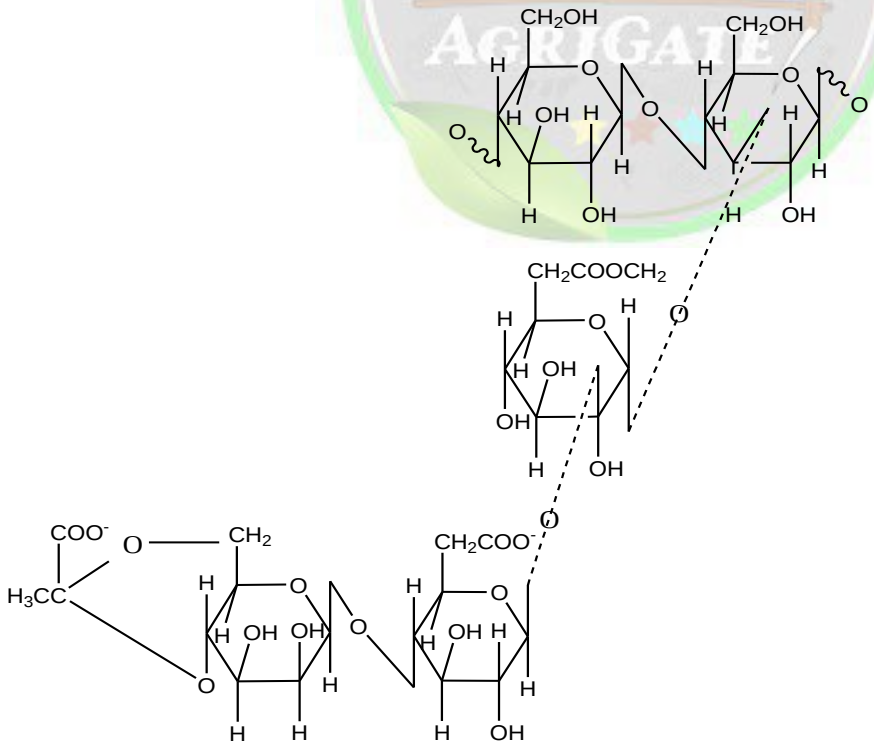
India is one of the fastest-growing markets for sustainable cellulose, driven by increasing environmental awareness, rapid industrialization, and the growing demand for biodegradable and bio-based materials. Cellulose, a renewable and biodegradable biopolymer, plays a vital role in industries such as paper and packaging, textiles, pharmaceuticals, food, construction, and personal care. The shift toward sustainable manufacturing and the reduction of plastic waste have further accelerated its industrial adoption. India generates large quantities of agricultural

residues, including banana pseudo stem, sugarcane bagasse, rice straw, and wheat straw, which serve as abundant and low-cost sources of cellulose. Converting these agricultural wastes into value-added cellulose products not only reduces environmental pollution but also enhances resource utilization and provides additional income opportunities for farmers. With supportive government policies, technological advancements, and increasing industrial investments, the demand for sustainable cellulose is expected to grow significantly. This section highlights the current market demand, major industrial applications, and future opportunities for sustainable cellulose in India.



Cellulose

Pectin



Hemicellulose



Industrial Applications of Sustainable Cellulose

Cellulose is a renewable and biodegradable biopolymer that is widely used across multiple industries. The growing demand for sustainable materials has accelerated its adoption in packaging, textiles, pharmaceuticals, food, construction, and advanced materials (Table 1).

Table.1. Major Indian Industrial Applications

Industry	Indian Company	Cellulose Application
Paper & Packaging	JK Paper Ltd.	Writing and printing paper, packaging board, specialty paper
Paper & Packaging	Tamil Nadu Newsprint and Papers Limited (TNPL)	Paper production from bagasse and sustainable raw materials
Paper & Packaging	West Coast Paper Mills Ltd.	Printing paper, tissue paper, packaging paper
Paper & Packaging	Andhra Paper Limited	Office paper, packaging paper, specialty paper
Textile	Grasim Industries Limited	Viscose rayon, modal, and lyocell fibres
Textile	Century Textiles and Industries Limited	Cellulosic fibres for textile manufacturing
Pharmaceutical	Sun Pharmaceutical Industries Ltd	Microcrystalline cellulose (MCC) used in tablet formulations
Pharmaceutical	Dr. Reddy's Laboratories	Tablet binders, fillers, and controlled-release

		formulations
Pharmaceutical	Cipla Limited	Pharmaceutical excipients and oral dosage formulations
Pharmaceutical	Lupin Limited	Cellulose-based tablet manufacturing
Food Industry	ITC Limited	Food additives, packaging materials, sustainable paperboard
Food Industry	Nestlé India Limited	Cellulose as a food stabilizer and sustainable packaging component
Personal Care	Hindustan Unilever Limited	Hindustan Unilever Limited
Personal Care	Dabur India Limited	Herbal cosmetics, oral care, personal care products
Personal Care	Patanjali Ayurved Limited	Cosmetic and personal care formulations
Paints & Construction	Asian Paints Limited	Cellulose ethers in paints and coatings
Paints & Construction	UltraTech Cement Limited	Cement additives and construction chemicals
Adhesives	Pidilite Industries Limited	Tile adhesives, wall putty, construction chemicals
Packaging	UFlex Limited	Sustainable and biodegradable packaging materials

Conclusion

Sustainable cellulose is a renewable, biodegradable, and eco-friendly biomaterial with wide applications in the paper, packaging, textile, pharmaceutical, food, and biomedical industries. The growing demand for bio-based materials has increased the global market potential of cellulose. In India, agricultural residues such as banana pseudo stem offer an abundant and sustainable source of cellulose, supporting waste valorisation and the circular bioeconomic. Despite challenges in large-scale production and commercialization, advancements in technology and increasing industrial adoption are expected to drive future market growth. Sustainable cellulose therefore represents a promising material for promoting environmental sustainability and economic development.

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BALANCED FERTILIZER USE FOR BETTER CROP YIELD AND SOIL HEALTH

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Introduction

Balanced fertilizer use is a fundamental component of sustainable crop production. Modern agriculture relies on fertilizers to replenish nutrients removed by crops; however, indiscriminate and excessive application of chemical fertilizers has resulted in nutrient imbalances, declining soil fertility, reduced fertilizer use efficiency, and environmental degradation. Maintaining an appropriate balance between inorganic fertilizers, organic manures, and biofertilizers is therefore essential for improving crop productivity while conserving soil health. Integrated nutrient management not only ensures optimum nutrient availability but also supports long-term agricultural sustainability.

Concept of Balanced Fertilizer Use

Balanced fertilizer use refers to the application of the right source of nutrients in the right quantity, at the right time, and through the right method according to crop requirements and soil fertility status. Crops require primary nutrients such as nitrogen, phosphorus, and potassium, along with secondary nutrients including calcium, magnesium, and sulphur. Micronutrients such as zinc, iron, boron, manganese, copper, and molybdenum are also indispensable for normal physiological processes. Supplying these nutrients in balanced proportions helps maximize crop growth, nutrient use efficiency, and yield while minimizing nutrient losses.

Importance of Balanced Fertilization

Balanced nutrient management promotes vigorous plant growth, healthy root development, improved flowering, fruit setting, and grain filling, ultimately resulting in higher productivity and better quality produce. Efficient nutrient utilization also reduces fertilizer

wastage and lowers cultivation costs. Equally important, balanced fertilization prevents nutrient mining from soils and minimizes groundwater contamination, nutrient runoff, and greenhouse gas emissions associated with excessive fertilizer use. Thus, balanced fertilization contributes simultaneously to farm profitability and environmental sustainability.

Role of Organic Manures in Soil Health

Organic manures form an indispensable component of balanced nutrient management. Farmyard manure, compost, vermicompost, green manures, and recycled crop residues improve soil organic carbon content, enhance soil aggregation, increase water-holding capacity, and create favorable conditions for beneficial soil microorganisms. Continuous addition of organic matter improves nutrient retention, reduces soil compaction, and enhances the resilience of agricultural soils under varying climatic conditions.

Importance of Biofertilizers in Integrated Nutrient Management

Biofertilizers contain beneficial microorganisms that improve nutrient availability through biological processes. They complement chemical fertilizers by increasing nutrient use efficiency rather than replacing mineral fertilizers completely. Their application improves soil microbial diversity, stimulates root growth, enhances nutrient uptake, and contributes to sustainable crop production.

Among the commonly used biofertilizers, **Azospirillum** is extensively recommended for cereals such as rice, maize, sorghum, pearl millet, and sugarcane. It fixes atmospheric nitrogen in association with plant roots and promotes root proliferation, thereby improving nutrient absorption and crop growth.

Azotobacter is mainly recommended for non-leguminous crops including vegetables, cotton, wheat, potato, and several horticultural crops. Besides fixing atmospheric nitrogen, it produces plant growth-promoting substances such as auxins, gibberellins, and cytokinins, which stimulate plant development.

For pulse crops such as black gram, green gram, red gram, chickpea, soybean, and groundnut, **Rhizobium** plays a crucial role by forming nodules on plant roots and fixing atmospheric nitrogen symbiotically. This significantly reduces the requirement for nitrogenous fertilizers while improving soil fertility.

Phosphate Solubilizing Bacteria (PSB) enhance phosphorus availability by converting insoluble forms of phosphorus into plant-available forms. Their application improves root

development, flowering, and crop productivity across cereals, pulses, oilseeds, vegetables, fruit crops, and plantation crops.

Potassium Solubilizing Bacteria (KSB) release potassium locked within soil minerals, thereby increasing potassium availability to crops such as coconut, banana, sugarcane, vegetables, and fruit crops. Adequate potassium nutrition enhances crop quality, disease resistance, and drought tolerance.

Zinc Solubilizing Bacteria (ZSB) increase the availability of zinc to crops including rice, maize, wheat, vegetables, and fruit crops, thereby preventing zinc deficiency and improving plant metabolism. **Silicate Solubilizing Bacteria (SSB)** are especially useful in rice and sugarcane cultivation by increasing silicon availability, which strengthens plant tissues and enhances resistance to pests, diseases, and drought stress.

Importance of Soil Testing

Soil testing serves as the scientific basis for balanced fertilizer recommendations. It provides valuable information on soil pH, organic carbon status, macro- and micronutrient availability, enabling farmers to apply fertilizers according to actual crop requirements. Soil test-based nutrient management prevents both nutrient deficiency and excessive fertilizer application, thereby improving fertilizer use efficiency and maintaining long-term soil fertility.

Balanced Fertilizer Use in Coconut-Based Cropping Systems

Coconut is a perennial crop that continuously extracts nutrients from the soil throughout its productive life. Sustaining productivity therefore requires balanced nutrient management through the combined application of recommended doses of NPK fertilizers, farmyard manure, compost, neem cake, and suitable biofertilizers such as Azospirillum, PSB, KSB, and AMF. Adoption of integrated nutrient management practices, along with mulching and proper irrigation, enhances nutrient availability, improves soil biological activity, increases nut yield, and maintains the long-term productivity of coconut-based farming systems.

Conclusion

Balanced fertilizer use is essential for ensuring sustainable agricultural production and maintaining soil health. Judicious integration of chemical fertilizers, organic manures, and biofertilizers improves nutrient availability, enhances fertilizer use efficiency, supports beneficial soil microorganisms, and sustains crop productivity over the long term. Soil test-based nutrient recommendations further enable farmers to optimize fertilizer inputs while reducing production

costs and minimizing environmental impacts. Adoption of integrated nutrient management practices will not only improve crop yields and soil fertility but also strengthen the resilience of farming systems, ensuring food security and sustainable agricultural development for future generations.

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CARBON FARMING IN MODERN AGRICULTURE: STRATEGIES FOR SOIL HEALTH AND CLIMATE CHANGE MITIGATION

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Abstract

Carbon farming has emerged as an important climate smart agricultural approach for mitigating climate change while improving soil health, crop productivity and environmental sustainability. Agriculture is a major contributor to greenhouse gas emissions through the release of carbon dioxide, methane and nitrous oxide resulting from intensive tillage, residue burning, excessive fertilizer application and flooded rice cultivation. Carbon farming focuses on capturing atmospheric carbon dioxide and storing it in soil and plant biomass through sustainable land management practices. Major carbon farming practices include conservation agriculture, cover cropping, agroforestry, organic farming, biochar application, integrated nutrient management, precision nutrient and water management, drip irrigation, direct seeded rice, and integrated crop livestock systems. These practices improve soil organic carbon, nutrient cycling, biodiversity, water-use efficiency and long-term soil fertility while reducing greenhouse gas emissions. Water saving technologies and direct seeded rice systems significantly reduce methane emissions, whereas biochar application and improved nitrogen management help mitigate nitrous oxide emissions. Carbon sequestration through residue retention, reduced tillage and agroforestry contributes to climate change mitigation and ecological sustainability. Carbon credit and carbon market mechanisms also provide economic opportunities for farmers through sustainable agricultural practices. However, challenges such as measurement difficulties, policy limitations, verification issues and limited farmer awareness restrict large scale adoption. Integration of

artificial intelligence, remote sensing, climate-smart technologies, and supportive policy frameworks can further strengthen carbon farming systems. Overall, carbon farming offers a sustainable pathway for enhancing agricultural resilience, environmental protection, and long-term food security under changing climatic conditions.

Keywords: Carbon sequestration, Climate-smart agriculture, Greenhouse gas mitigation, Soil organic carbon, Sustainable farming systems

Introduction

Agriculture plays a vital role in ensuring global food security and supporting the livelihoods of millions of people worldwide. However, the agricultural sector is highly sensitive to climate change and environmental degradation (Ajmal *et al.*, 2025). Rising global temperatures, irregular rainfall patterns, prolonged droughts, floods, heat waves and other extreme climatic events are increasingly affecting crop productivity, soil fertility, water availability and overall agricultural sustainability. Over the 20th century, the average global surface temperature has risen by approximately 0.6 ± 0.2 °C (IPCC, 2001). Climate change not only threatens food production systems but also poses serious challenges to the economic stability and nutritional security of many developing countries. In recent decades, the increasing concentration of greenhouse gases in the atmosphere has become a major environmental concern, leading to global warming and changes in climatic conditions. Among the different sectors, agriculture is considered one of the significant contributors due to various farming practices and land use activities. Agricultural activities release large quantities of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) into the atmosphere. Carbon dioxide emissions mainly arise from deforestation, intensive tillage, fossil fuel consumption, residue burning and soil organic matter decomposition. Methane emissions are predominantly associated with flooded rice cultivation and livestock production, while nitrous oxide emissions mainly result from excessive nitrogen fertilizer application and inefficient nutrient management practices. These greenhouse gases possess high global warming potential and contribute substantially to climate change. Conventional agricultural practices that involve intensive soil disturbance, excessive use of synthetic fertilizers, monocropping and improper residue management have accelerated soil degradation, reduced soil organic carbon and increased carbon losses from agricultural ecosystems. Consequently, there is an urgent need to

develop sustainable agricultural systems that can maintain productivity while minimizing environmental impacts and enhancing climate resilience.

Carbon farming has recently emerged as a promising climate smart agricultural strategy that focuses on reducing atmospheric carbon dioxide levels while improving agricultural productivity and ecosystem health. Carbon farming refers to the implementation of agricultural practices that enhance carbon sequestration in soils and vegetation while reducing greenhouse gas emissions from farming systems. It involves the adoption of management practices that capture atmospheric carbon and store it in the form of soil organic matter and plant biomass. Soil acts as one of the largest terrestrial carbon reservoirs and increasing soil organic carbon can significantly contribute to climate change mitigation. This chapter highlights the principles, practices, benefits, challenges and future prospects of carbon farming in achieving climate-resilient and sustainable agriculture.

Concept and principles of carbon farming

Carbon farming is a sustainable agricultural approach that focuses on capturing atmospheric carbon dioxide and storing it in soil and plant biomass through eco-friendly farming practices. It aims to reduce greenhouse gas emissions while improving soil fertility, crop productivity and environmental sustainability. The concept of carbon farming is closely linked with the agricultural carbon cycle, where plants absorb carbon dioxide through photosynthesis and transfer carbon into the soil through roots, residues and organic matter decomposition. Soil organic carbon plays an important role in maintaining soil health by improving soil structure, nutrient availability, water-holding capacity and microbial activity. The dynamics of soil organic carbon depend on the balance between carbon addition and carbon loss from the soil. Carbon sequestration occurs through mechanisms such as residue retention, reduced tillage, cover cropping, agroforestry, organic amendments, and biochar application, which help increase stable carbon storage in agricultural soils and support climate-resilient sustainable agriculture.

Major carbon farming practices

a) Conservation agriculture

- ✓ **Minimum tillage:** Minimum tillage reduces soil disturbance and helps conserve soil organic carbon by minimizing oxidation of organic matter. It improves soil structure, microbial activity, and moisture conservation while reducing fuel consumption and

greenhouse gas emissions. Reduced soil disturbance also decreases erosion and enhances long-term soil sustainability.

- ✓ **Crop residue retention:** Crop residue retention involves leaving crop residues on the soil surface after harvest to improve soil organic matter content and reduce carbon loss. Residues protect the soil from erosion, conserve moisture, and support microbial activity. Residue incorporation also improves nutrient cycling and enhances soil carbon sequestration.
- ✓ **Crop rotation:** Crop rotation involves growing different crops sequentially on the same land to maintain soil fertility and reduce pest and disease incidence. Diverse cropping systems improve biomass production and increase carbon input into the soil. Legume-based rotations also enhance nitrogen availability and reduce dependency on synthetic fertilizers.

b) Cover cropping

Cover crops are grown between main cropping seasons to protect the soil and improve soil health. They reduce soil erosion, suppress weeds, improve nutrient recycling, and increase soil organic carbon through biomass addition. Cover crops also enhance water infiltration and microbial diversity in agricultural soils.

c) Agroforestry systems

Agroforestry combines trees with crops and livestock in the same farming system to improve productivity and environmental sustainability. Trees capture atmospheric carbon and store it in biomass and soil, thereby enhancing carbon sequestration. Agroforestry systems also improve biodiversity, soil fertility, and microclimatic conditions.

d) Organic farming

Organic farming relies on natural inputs such as compost, farmyard manure, green manures, and biofertilizers instead of synthetic chemicals. It improves soil organic matter, microbial activity, and nutrient cycling while reducing environmental pollution. Organic farming also supports sustainable crop production and long-term soil health.

e) Biochar application

Biochar is a carbon-rich material produced through the pyrolysis of organic biomass under limited oxygen conditions. Its application improves soil carbon storage, nutrient retention,

water-holding capacity, and microbial activity. Biochar also helps reduce nitrous oxide emissions and enhances long-term soil fertility.

f) Integrated nutrient management

Integrated nutrient management combines organic manures, crop residues, biofertilizers, and inorganic fertilizers for balanced nutrient supply. This approach improves nutrient-use efficiency, maintains soil fertility, and enhances soil organic carbon accumulation. It also reduces nutrient losses and minimizes greenhouse gas emissions from agricultural soils.

g) Precision nutrient and water management

Precision nutrient and water management use advanced technologies to apply fertilizers and irrigation based on crop requirement and soil conditions. These practices improve resource-use efficiency, reduce nutrient losses, and minimize greenhouse gas emissions. Efficient management also enhances crop productivity and conserves natural resources.

h) Drip irrigation and water-saving technologies

Drip irrigation supplies water directly to the root zone in a controlled manner, reducing water loss through evaporation and runoff. Water-saving technologies improve water-use efficiency and reduce methane emissions in crop production systems. They also help maintain soil aeration and support sustainable agricultural intensification.

i) Direct seeded rice and methane mitigation

Direct-seeded rice reduces methane emissions by avoiding continuous flooding and puddling associated with conventional transplanted rice cultivation. Improved soil aeration under direct-seeded systems suppresses methane-producing microorganisms. This practice also reduces water consumption, labour requirement, and production costs while supporting sustainable rice cultivation.

j) Integrated crop livestock systems

Integrated crop-livestock systems combine crop production and livestock management to improve nutrient recycling and farm sustainability. Animal manure is used as an organic nutrient source, which enhances soil fertility and carbon sequestration. These systems improve resource-use efficiency, diversify farm income, and support ecological balance.

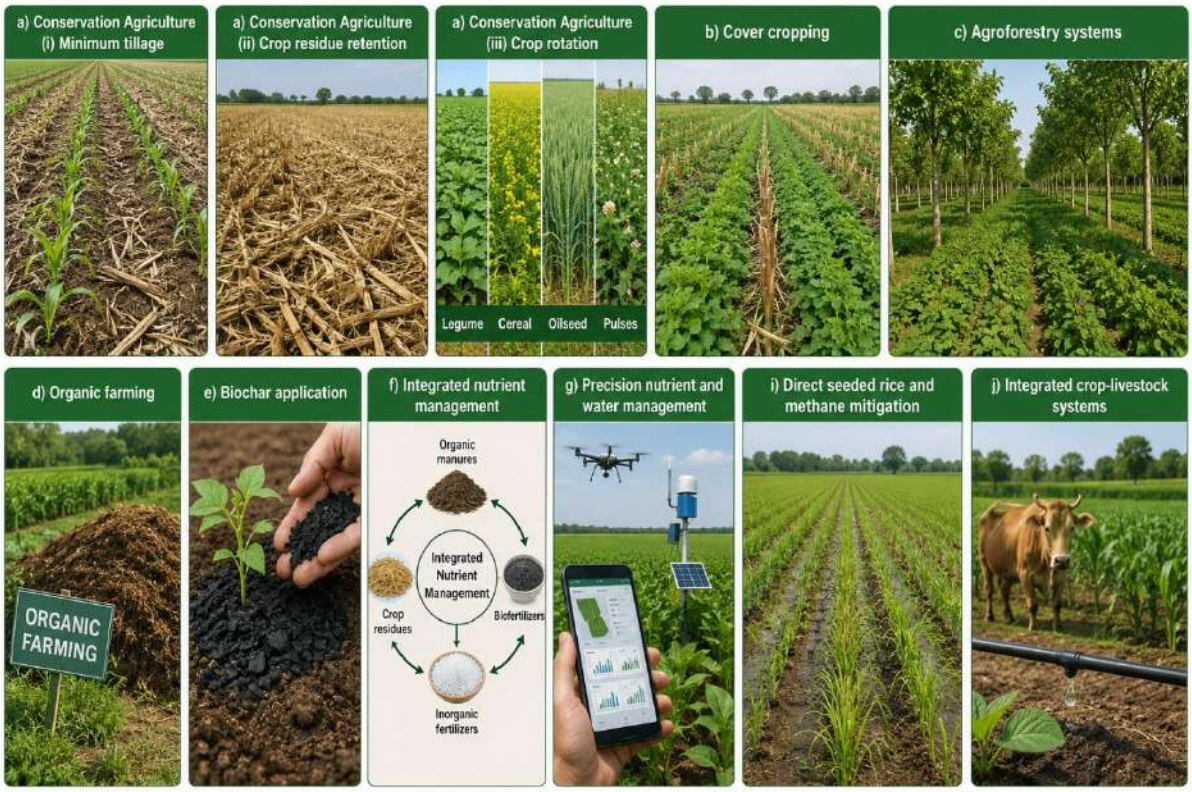


Fig. 1. Major carbon farming practices

Carbon farming and greenhouse gas mitigation

Methane reduction

Methane is mainly produced in agriculture under anaerobic conditions, especially in continuously flooded rice fields, where methanogenic microorganisms decompose organic matter in the absence of oxygen. Carbon farming reduces methane production by improving water, residue and soil aeration management. In rice systems, alternate wetting and drying has been reported to reduce methane emissions by about **30 to 70%**, depending on soil type, water regime and crop management (Zhang *et al*., 2021). Recent studies also showed that alternate wetting and drying reduced cumulative methane emissions by **72 to 90%** and global warming potential by **25 to 73%** compared with continuous flooding, mainly because periodic soil drying introduces oxygen and suppresses methane-producing microbes **(Lal, 2020)**. Direct seeded rice is another important methane mitigation practice because it avoids puddling and prolonged standing water during early crop growth. Compared with transplanted flooded rice, direct seeded rice reduces anaerobic soil conditions, lowers methane production and decreases methane transport through rice plants. Research evidence indicates that direct seeded rice significantly reduces methane

emissions from paddy fields, mainly due to changes in root morphology, lower flooding duration, reduced water input and improved root oxidative capacity (Ramesh *et al.*,2019).

Nitrous oxide mitigation

Nitrous oxide is mainly released from agricultural soils through nitrification and denitrification processes, especially when nitrogen fertilizer is applied in excess or when soil moisture fluctuates between aerobic and anaerobic conditions. It is a highly powerful greenhouse gas, with a 100 year global warming potential of about **265 to 273 times greater than carbon dioxide**, depending on the accounting method used (Ajmal *et.*, 2025). Carbon farming mitigates nitrous oxide emission by improving nitrogen use efficiency, synchronizing nitrogen supply with crop demand, using organic manures judiciously, adopting split nitrogen application, and applying enhanced efficiency fertilizers such as nitrification inhibitors, urease inhibitors, and controlled-release fertilizers.

The main reason behind nitrous oxide reduction is that improved nitrogen management reduces the amount of mineral nitrogen left unused in the soil. When excess ammonium and nitrate are present, soil microbes convert them into nitrous oxide under suitable moisture and oxygen conditions. Conservation tillage practices also influence nitrous oxide emission. A meta-analysis reported that reduced tillage and no-tillage significantly reduced soil nitrous oxide emissions by **12.3% and 14.3%**, respectively (Whang *et al*., 2021). The reduction was mainly associated with improved soil structure, reduced soil disturbance, better aggregation, and more efficient nitrogen cycling. Biochar application is another promising carbon farming strategy for nitrous oxide mitigation. Biochar improves soil aeration, increases nutrient retention, adsorbs ammonium and nitrate, and modifies microbial processes involved in nitrification and denitrification. Recent studies reported that biochar reduced nitrous oxide emissions by about **24%** in fertilized soils, while other broader assessments observed reductions of around **40%** in non-arid conditions (Li *et al*., 2019). However, the effect of biochar depends on feedstock, pyrolysis temperature, soil type, biochar ageing, and fertilizer dose.

Carbon dioxide sequestration

Carbon dioxide mitigation in carbon farming occurs mainly through carbon sequestration, where atmospheric carbon dioxide is captured by plants through photosynthesis and stored in soil as organic carbon. Soil carbon is increased when carbon inputs from crop residues, roots, compost, farmyard manure, cover crops, green manures and biochar exceed carbon losses

through decomposition, erosion, and oxidation. Practices such as conservation tillage, residue retention, cover cropping, agroforestry, diversified crop rotation, and organic amendments enhance soil organic carbon by increasing biomass return and reducing soil disturbance. Research evidence shows that conservation based practices can substantially improve soil carbon storage. A meta-analysis reported that straw return increased soil organic carbon content by **23.7%**, while reduced tillage with straw return increased it by **5.5%** and no-tillage with straw return by **4.4% (Lal, 2020)**. The reason behind this increase is that residues and root biomass add organic carbon to soil, while reduced tillage protects soil aggregates and slows organic matter decomposition (Smith *et al*., 2020). Agroforestry further enhances carbon sequestration by storing carbon in tree biomass, litter, roots, and deeper soil layers.

Carbon Credit and Carbon Markets

Carbon credit and market systems have emerged as important tools for reducing greenhouse gas emissions and promoting sustainable agricultural practices. Carbon trading allows industries and organizations to buy and sell carbon credits generated through activities that reduce or remove carbon dioxide from the atmosphere. In agriculture, carbon credits can be earned through practices such as conservation tillage, agroforestry, cover cropping, residue retention, organic farming and improved nutrient and water management that enhance carbon sequestration and reduce greenhouse gas emissions. These mechanisms provide additional income opportunities for farmers while encouraging environmentally sustainable farming systems. Carbon markets also promote climate smart agriculture by supporting long term soil health and ecosystem conservation. Several international initiatives, including the Kyoto Protocol, Paris Agreement, and the “4 per 1000” initiative, encourage carbon sequestration and sustainable land management practices globally. Therefore, carbon credit programs can play a significant role in improving farmer livelihoods and mitigating climate change.

Advantages of carbon farming

Climate change mitigation

Carbon farming helps mitigate climate change by increasing carbon sequestration in soil and vegetation while reducing greenhouse gas emissions from agricultural activities. Practices such as conservation tillage, residue retention and direct seeded rice have been reported to reduce carbon dioxide and methane emissions compared to conventional farming systems.

Soil fertility improvement

Carbon farming improves soil fertility by increasing soil organic carbon, nutrient availability and microbial activity. Organic amendments, crop residues and cover crops that enhance soil structure, water holding capacity and long-term soil productivity.

Enhanced biodiversity

Carbon farming practices such as agroforestry, crop rotation and organic farming support greater biodiversity in agricultural ecosystems. Increased soil organic matter and reduced chemical disturbances promote beneficial soil microorganisms, insects and pollinators.

Water conservation

Carbon farming enhances soil moisture retention and improves water use efficiency through practices such as residue mulching, conservation tillage and drip irrigation. Studies have shown that soils rich in organic carbon can store more water and reduce runoff losses.

Improved crop productivity

Improved soil health and nutrient cycling under carbon farming practices contribute to better crop growth and higher productivity. Research findings indicate that conservation based farming systems can sustain crop yields while improving environmental quality.

Economic benefits to farmers

Carbon farming reduces input costs by improving nutrient and water use efficiency and minimizing soil degradation. In addition, carbon credit programs may provide extra income opportunities for farmers adopting sustainable carbon sequestration practices.

Challenges in carbon farming

Carbon farming faces several challenges that limit its large scale adoption and implementation. Accurate measurement of soil carbon sequestration and greenhouse gas reduction is difficult due to variations in soil type, climate and management practices. Policy limitations, lack of standardized guidelines and inadequate institutional support also restrict the promotion of carbon farming initiatives. In many regions, farmers have limited awareness and technical knowledge regarding carbon farming practices and their long term benefits. Economic constraints such as high initial investment, limited financial incentives and uncertain carbon market returns further discourage adoption. In addition, verification and monitoring of carbon credits remain complex, time consuming and costly processes.

Future perspectives and research needs

- Integration of artificial intelligence and precision agriculture can improve carbon monitoring, nutrient management, irrigation scheduling and resource use efficiency in carbon farming systems.
- Advanced remote sensing and GIS technologies can help assess soil carbon stocks, land use changes and greenhouse gas dynamics at large spatial scales.
- Strong policy support, financial incentives and carbon credit programs are essential to encourage farmers to adopt carbon farming practices.
- Development and adoption of climate smart technologies such as conservation agriculture, drip irrigation, biochar application and low emission crop management practices can enhance carbon sequestration and reduce greenhouse gas emissions.
- Sustainable intensification approaches should focus on increasing agricultural productivity while conserving natural resources, improving soil health and minimizing environmental degradation.

Conclusion

Carbon farming represents an integrated and sustainable approach to address the interconnected challenges of climate change, soil degradation, and food security. By promoting carbon sequestration and reducing greenhouse gas emissions, carbon farming can improve agricultural resilience, restore soil health, conserve natural resources and support sustainable crop production systems. Therefore, the adoption of carbon farming practices is becoming increasingly important for ensuring long term agricultural sustainability and environmental protection in the face of global climate change.

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UNLOCKING DORMANCY: THE ROLE OF THE WATER GAP COMPLEX IN PHYSICALLY DORMANT SEEDS

Article ID: AG-VO6-I07-26

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Abstract

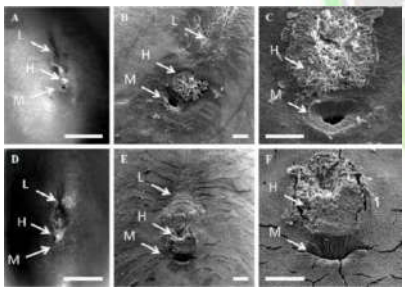
Seed dormancy is an adaptive mechanism that prevents germination until conditions become favourable. In physical dormancy, a water-impermeable seed or fruit coat restricts water uptake. The water gap complex is a specialized structure that controls water entry and plays a key role in dormancy release and germination. Water gaps vary among plant families and are commonly classified as slit-shaped, lid-shaped or plug-shaped structures that open in response to environmental signals such as temperature and moisture. Additional structural features, including pleurograms and specialized regions of the seed coat, also influence water entry and permeability. Understanding the diversity and function of water gap complexes provides valuable insights into seed dormancy mechanisms and supports advances in seed technology, crop production and ecosystem restoration.

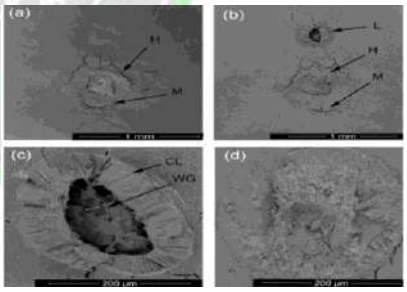
Key words: Water gap complex, Physical dormancy, Seed dormancy, Seed germination, Seed coat impermeability, Pleurogram.

1.Introduction:

Seed dormancy is an important adaptive mechanism that enables seeds to survive unfavourable environmental conditions and germinate only when conditions are suitable for seedling establishment (Finch-Savage & Leubner-Metzger, 2006). Physical dormancy (PY) is caused by a water-impermeable seed coat that restricts water uptake and delays germination (Willis et al., 2014). A specialized structure known as the water gap complex regulates water entry and plays a central role in dormancy release (Baskin & Baskin, 2014). In response to environmental cues such as temperature fluctuations, moisture, fire or mechanical disturbance, the water gap opens, allowing rapid imbibition and initiating germination (Baskin et al., 2000). Water gap complexes occur in various forms, including slit, lid and plug-shaped structures and are essential for seed survival, germination timing and ecological adaptation. Understanding their structure and function has important applications in seed technology, agriculture, conservation and ecosystem restoration (Jaganathan et al., 2019). The water gap complex acts as an environmental sensor, ensuring that germination occurs only under favourable conditions. Its diversity among plant species reflects evolutionary adaptations that enhance survival and persistence in different ecosystems.

During Development **During Dormancy breaking**





Seed coat closes Hilum closes (Lens become more distinct) Micropyle closes embryo

Water-gap opens Water enters and hydrates

2.Role of the Water Gap Complex in Regulating Seed Dormancy and Germination

The water gap complex is a specialized morpho-anatomical structure found in physically dormant seeds that regulates water entry into the seed. It plays a central role in controlling the transition from dormancy to germination (Jaganathan et al., 2019).

Favorable conditions → Water pore will not open → Formation of water gap complex (Prevents the entry of water) → Seed dormancy

Unfavorable conditions → Water pores will be opened → Allows the entry of water → Seed germination

2.1. Location of water gap complex

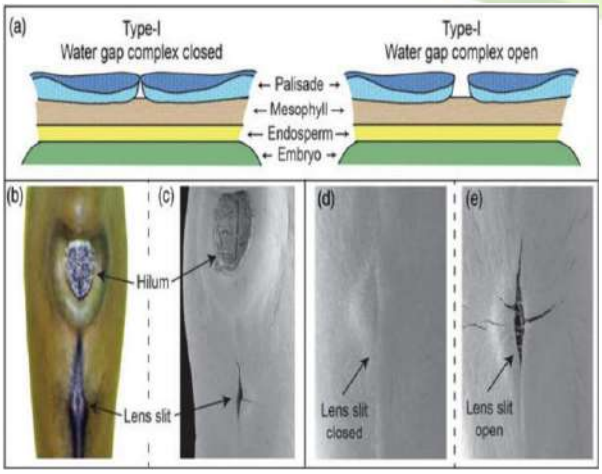
Family	Location of water gap	Reference
Malvaceae	Chalaza	Egley, 1986
Fabaceae	Lens	Manning & Van Staden, 1987
Cannaceae	Raphal Scar	Grootjen & Bouman, 1988
Leguminaceae	Hilum	Bhattacharya and Saha, 1990
Convolvulaceae	Micropyle	Jayasuriya et al., 2007

3.Types of water gap complex

3.1. Type: 1

The water gap forms as a narrow opening of occluded palisade cells that separate or pulled apart and thus allow water entry through the seed (Geneve *et al*., 2018).

Slit shaped water pore (eg: Yellow wood seeds)





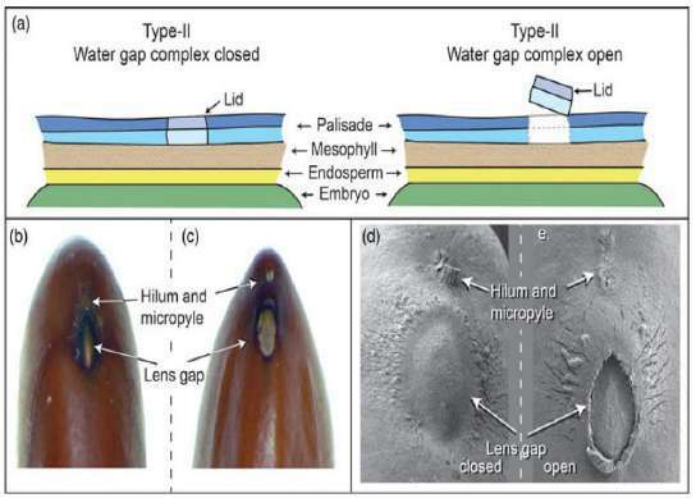
3.2. Genus with Type-I Primary water gap structure

Water-gap complex type	Primary water-gap structure	Genus (Family)
Type-I	Hilar slit	*Caenothus* (Rhamnaceae)
	Lens slit	*Cladrastis* (Fabaceae)
	Micropyle slit	*Cardiospermum* (Sapindaceae)
	Endosperm suture	*Stylobasium* (Surianaceae)

3.3.Type: 2

A group of specialized cells forms a circular or linear lid like structure that is dislodged and separates from the seed surface where upon water enter into the seed coat. (Geneve *et al*., 2018).

Cap/Lid shaped water pore (eg: *Mimosa sp*)





Genus with Type-II Primary water gap structure

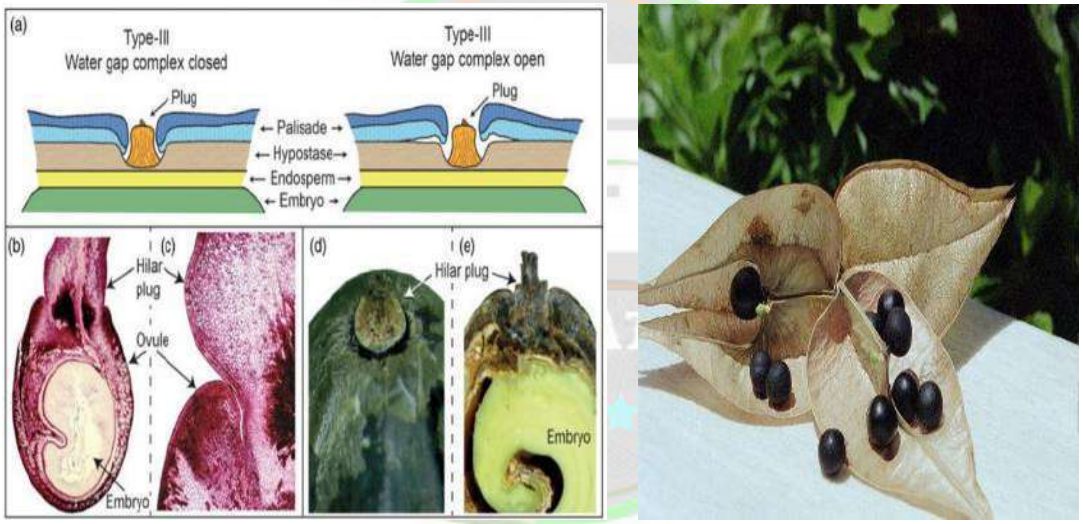
Water-gap complex type	Primary water-gap structure	Genus (Family)
Type -II	Carpellary blister gap	*Rhus (*Anacardiaceae)
	Gap adjacent to hilum	*Canna* (Cannaceae)
	Bulge gap	*Chardioclamys* (Convolvulaceae)

	Pesudolens gap	*Cercis* (Fabaceae)
	Lens gap	*Acacia* (Fabaceae)
	Hinged valve gap Protuberance organ	*Geranium* (Geraniaceae) *Nelumbo* (Nelumbonaceae)

3.4. Type: 3

A circular plug like structure formed by sclerenchyma cells separates from the adjacent palisade cells, thereby causing the coat to become permeable. (Geneve *et al*., 2018).

Plug shaped water pore (eg: Golden rain tree seeds (Koelreuteria)



3.5.Genus with Type-III Primary water gap structure

Water-gap complex type	Primary water-gap structure	Genus (Family)
Type-III	Chalazal oculus	*Helianthemum* (Cistaceae)
	Chalazal blister gap	*Sida* (Malvaceae)
	Chalazal slit	*Kosteletzkya* (Malvaceae)
	Hilar ocuus	*Kostelezkya* (Sapindaceae)

4.Spatial aspects of the water gap

4.1. Simple Water Gap Complex

A simple water gap complex consists of a single specialized structure that functions as the

site of water entry into a physically dormant seed. Upon exposure to dormancy-breaking environmental cues such as temperature fluctuations or moisture. This structure opens and permits water uptake. The mechanism is localized and involves only one anatomical feature controlling seed permeability. (Jaganathan *et al*., 2019)

4.2. Compound Water Gap Complex

A compound water gap complex consists of two or more interconnected structures that collectively regulate water entry into the seed. Water movement occurs through a coordinated system of specialized anatomical features, making the mechanism more complex than that of a simple water gap complex. (Jaganathan *et al*., 2019)

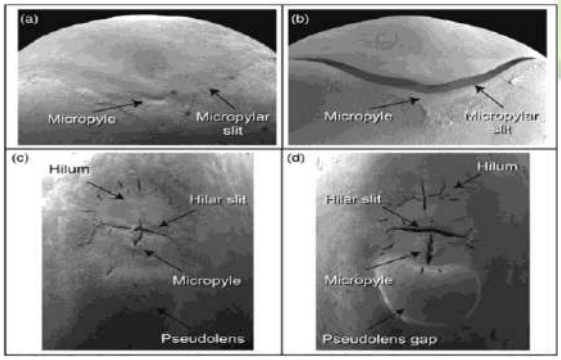
4.3. Primary Water Gap

The primary water gap is the first structure to respond to environmental signals and serves as the main pathway for initial water entry during dormancy release. It plays a crucial role in initiating seed imbibition and germination. (Jaganathan *et al*., 2019)

4.4. Secondary Water Gap

The secondary water gap comprises additional structures that facilitate or enhance water movement after the primary water gap has opened. These structures act as supplementary pathways, ensuring efficient hydration of the seed and supporting the germination process. (Jaganathan *et al*., 2019)

Simple and Compound water gaps (Geneve *et al*., 2018)



A,B- Cardiospermum sp

C,D- Cercis sp

5.Temporal Aspects of the Water Gap

The opening of water gaps in physically dormant seeds is regulated by environmental cues such as temperature fluctuations, heat shock, fire and moisture. These signals trigger structural changes that allow water entry and dormancy release. Such responses ensure that germination

occurs only under favourable conditions for seedling establishment and survival (Henna et al., 1984; Jayasuriya et al., 2009; Fernandez-Pascual et al., 2021).

6.Procedure to identify the water gap

Seed source

↓

Preliminary investigation

↓

Physical dormancy breaking

↓

Morphological changes after dormancy break

↓

Dye tracking

↓

Light microscopy

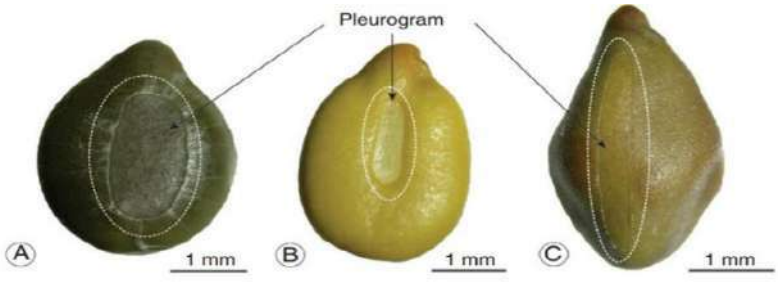
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Blocking experiment

7.Pleurogram

A pleurogram is a specialized groove or marked region on the seed coat of many Fabaceae species, located away from the hilum (Corner, 1951). Although traditionally used as a taxonomic character, it may also regulate water permeability and physical dormancy. In some species, structural changes in the pleurogram facilitate water entry during dormancy release and germination, but its function varies among species and it is not always the primary water gap**.**

Example: *Senna alata* seeds, only the Pleurogram acted as a water gap (Rodrigues *et al*., 2019)



Species	Water Entry Site	Change in Palisade Layer
Senna alata	Pleurogram only	Moves outward, exposing hourglass cells
Senna reniformis	Pleurogram + hilar region	Moves outward, exposing hourglass cells
Senna silvestris	Pleurogram + hilar region	Palisade layer destroyed

8.Physical Dormancy

Physical Dormancy (PY) is caused by a hard, water-impermeable seed or fruit coat that prevents water uptake and delays germination. It results from lignified palisade cells and sealed seed-coat structures. Dormancy is broken by environmental factors such as temperature fluctuations, fire and weathering or by treatments like scarification and hot water. Common in Fabaceae and Malvaceae, Physical dormancy ensures germination occurs only under favourable conditions (Jaganathan, 2016).

9. Ecological Significance of the Water Gap Complex

The water gap complex regulates the timing of water entry and germination, ensuring that seeds germinate only under favourable environmental conditions. This mechanism enhances seed survival, promotes successful seedling establishment and contributes to species persistence and biodiversity conservation.

10. Future Perspectives

Future research should focus on the genetic and molecular regulation of water-gap development, the effects of climate change on dormancy release and the development of precision seed treatments to improve agricultural productivity, ecosystem restoration and biodiversity conservation.

Conclusion

The water gap complex is a specialized structure that controls water entry in physically dormant seeds. It remains closed under unfavourable conditions and opens in response to environmental cues such as temperature, moisture or heat, thereby initiating germination. By regulating dormancy release and germination timing, the water gap plays a key role in seed survival, seedling establishment and ecological adaptation.

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THE FUTURE OF SUSTAINABLE POLLINATION IN INDIA- MELIPONICULTURE

Article ID: AG-VO6-I07-27

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Abstract

Meliponiculture, the management and rearing of native stingless bees (Dammer bees), presents a transformative frontier for sustainable agriculture and ecosystem stabilization in India. While conventional apiculture relies heavily on *Apis* species, stingless bees (*Tetragonula iridipennis* and *Tetragonula bengalensis*) offer distinct evolutionary advantages, including high thermal tolerance, non-stinging behavior, and exceptional adaptation to protected cultivation environments like polyhouses. This paper evaluates the ecological mechanics of stingless bees, their economic viability through the production of high-value medicinal honey, and their role as a climate-resilient insurance policy for smallholder farmers. Ultimately, we outline a strategic pathway to transition meliponiculture from an informal, wild-harvested practice into a standardized, community-led micro-enterprise across India.

Keywords: Meliponiculture, Stingless Bees, *Tetragonula iridipennis*, Sustainable Pollination, Polyhouse Farming, Rural Livelihoods.

Introduction

Indian agriculture stands at a critical juncture, caught between expanding food security demands and severe ecological pressures. Pollinator decline, driven by habitat loss, intensive pesticide usage, and climate volatility, threatens the yield security of over 70% of the country's leading crop species. While commercial apiculture using western honeybees (*Apis mellifera*) has traditionally filled this gap, these introduced species face steep operational boundaries in changing environments. The Meliponiculture is the scientific husbandry of native stingless bees. Locally known as Dammer bees, these insects belong to the tribe Meliponini. Though small, their role in preservation and food production is massive. As India seeks decentralized, low-cost,

and climate-resilient agricultural solutions, scaling up native stingless bee populations offers an alternative pathway for sustainable pollination and high-value organic farming.

India's Native Stingless Bees: Species and Architecture

India hosts a rich diversity of stingless bee species, finely adapted to regional microclimates. Unlike true honeybees that build vertical wax combs, stingless bees construct irregular cluster networks using cerumen a biocidal compound made by mixing secreted bee-wax with antimicrobial plant resins and propolis.

The two primary species in India's sustainable pollination are:

1. ***Tetragonula iridipennis*:** The most thoroughly studied and widely distributed species across Peninsular India (Including Kerala, Tamil Nadu, Karnataka, and Maharashtra). Highly adaptable, they readily nest in household backyards and artificial structures.
2. ***Tetragonula bengalensis*:** Dominant throughout the humid forest ecosystems of Northeast India, renowned for navigating dense forest canopies and producing intensely aromatic, rare medicinal honey.

The Mechanics of Elite Pollination

As Indian farmers increasingly adopt protected cultivation—such as greenhouses and polyhouses, to shield crops from volatile weather, conventional honeybees fail to adapt. When introduced into enclosed spaces, *Apis* species suffer from "skyward orientation," flying repeatedly against transparent ceilings until they drop from exhaustion. Their defensive stinging behavior also complicates manual crop maintenance.

Stingless bees resolve both limitations seamlessly:

1. **Enclosure Adaptation:** They orient perfectly within covered structures without exhibiting self-destructive flight patterns.
2. **Safety:** Lacking operational stings, they present zero hazard to farm workers during routine cultivation.
3. **Physical Efficiency:** Because of their minute body size, they easily navigate complex, tightly closed floral architectures (like those of solanaceous crops) that larger bees overlook.

Field trials show that introducing stingless bees into polyhouse tomato setups can increase fruit set by up to **460%**. They provide similarly high pollination efficiencies across major open and protected crops, including mangoes, papayas, avocados, cardamom, and cucumbers.

Climate Resilience and Thermal Tolerance

Conventional honeybees are notorious thermal delicate characters; foraging drops drastically when ambient temperatures exceed 30°C or dip below 20°C. In contrast, stingless bees are evolutionary marvels of climate resilience. They maintain active, efficient foraging patterns across a wide thermal spectrum, from **18°C up to 36°C**. Whether enduring sudden monsoon windows or intensifying heatwaves, these native insects continue to fly, serving as a reliable agricultural insurance policy for crop fertilization amidst erratic shifting weather patterns.

Economic Multiplying Potential: "Liquid Gold"

For smallholder farmers, tribal communities, and women's self-help groups (SHGs), meliponiculture functions as an accessible, low-input micro-enterprise. It demands minimal physical labor, zero expensive protective gear, and an exceptionally small spatial footprint.

While a single stingless bee colony yields far less volume than a commercial honeybee hive averaging between **200g to 900g per colony annually**—the financial returns follow an exponential scale.

Challenges and the Path to Scaling

Despite these ecological and economic windfalls, India's meliponiculture sector remains heavily informal. Scaling this frontier requires addressing three clear structural mandates

- **Transition to Scientific Rearing:** Phasing out destructive wild-colony poaching in favor of modern, non-destructive box designs and controlled colony division techniques standardized by institutions like the Indian Council of Agricultural Research (ICAR) and state agricultural universities.
- **Developing National Policy Support:** Establishing clear testing and purity frameworks for stingless bee honey within national food safety regimes (like FSSAI) to protect local producers from cheap adulterations and open formal export lines.
- **Community-Led Multiplication:** Leveraging rural development budgets to distribute stingless bee colonies across local villages, establishing specialized "Honey Villages" where ecological stability and financial self-reliance grow together.

Conclusion

Meliponiculture represents a vital bridge between traditional ecological knowledge and modern, climate-resilient agriculture. By deploying these small, non-stinging native bees, India

can safeguard its vulnerable pollinator networks, boost greenhouse crop productivity, and open up high-value revenue streams for rural smallholders. Embracing meliponiculture is no longer just an alternative conservation choice, it is a cornerstone for the future of sustainable food production in India.

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WATER SCARCITY AS A SYSTEMIC CRISIS: DRIVERS, IMPACTS, AND PATHWAYS TO SUSTAINABLE WATER SECURITY

Article ID: AG-V06-I07-28

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Abstract

Water scarcity has emerged as one of the most pressing challenges of the twenty-first century, threatening agricultural productivity, food security, environmental sustainability, and human well-being. The crisis is driven by a combination of climatic variability, unsustainable agricultural practices, rapid population growth, urbanization, and weak water governance. Agriculture, which consumes the largest share of freshwater resources, plays a critical role in both contributing to and experiencing the effects of water scarcity. The consequences include declining crop productivity, economic instability among farming communities, environmental degradation, and increased social vulnerability. Addressing this challenge requires an integrated approach involving technological innovations, climate-smart agricultural practices, effective water governance, and behavioural change. Sustainable solutions such as micro-irrigation, rainwater harvesting, crop diversification, groundwater regulation, and community-based water management can significantly improve water-use efficiency and resilience. Ensuring long-term water security demands coordinated efforts from governments, researchers, extension agencies, and local communities.

Keywords: Water Scarcity, Climate Change, Sustainable Agriculture, Groundwater Depletion, Water Governance, Water Security

INTRODUCTION

"Thousands have lived without love, not one without water." – W. H. Auden

Water is the foundation of life, agriculture, and economic development. However, growing demand, climate change, and unsustainable resource use have transformed water scarcity into

one of the most pressing global challenges of the twenty-first century. Ensuring water security is essential for achieving sustainable agriculture, environmental protection, and human well-being. This article examines the major drivers, impacts, and sustainable solutions for addressing water scarcity in a changing world.

WHY WATER SCARCITY MATTERS TODAY

Water scarcity has emerged as one of the defining challenges of the twenty-first century. Climate change, rapid population growth, urbanization, and increasing demand for water have placed unprecedented pressure on freshwater resources. Altered rainfall patterns, frequent droughts, and changing hydrological cycles have reduced the reliability of water supplies, making water security a critical concern for sustainable development. In countries like India, where agriculture consumes nearly 80 per cent of available freshwater resources, the challenge is particularly severe.

AGRICULTURE: BOTH A VICTIM AND A CONTRIBUTOR

Agriculture lies at the centre of the water crisis. Water-intensive crops such as rice and sugarcane are often cultivated in regions facing water stress, resulting in excessive groundwater extraction. Traditional flood irrigation methods further contribute to water losses through runoff, seepage, and evaporation. As groundwater levels decline, farmers are compelled to drill deeper bore wells, increasing production costs and placing additional pressure on already depleted aquifers.

THE RIPPLE EFFECTS OF WATER SCARCITY

The consequences of water scarcity extend far beyond water shortages. Agricultural productivity declines due to unstable water availability, increasing the risk of crop failure and income losses. Environmental impacts include groundwater depletion, land degradation, desertification, and biodiversity loss. Socially, water scarcity contributes to rural distress, migration, increased workload for women, and conflicts among competing water users. Thus, water scarcity affects food security, livelihoods, and overall societal well-being.

PATHWAYS TO SUSTAINABLE WATER MANAGEMENT

Addressing water scarcity requires an integrated approach that combines technology, policy, and community participation. Water-saving technologies such as drip and sprinkler irrigation, precision farming, and rainwater harvesting can significantly improve water-use efficiency. Climate-smart agricultural practices, including crop diversification, millet promotion,

conservation agriculture, and drought-resilient varieties, help reduce water demand while enhancing resilience. Effective governance through groundwater regulation, Integrated Water Resource Management (IWRM), and participatory water management is equally important for long-term sustainability.

THE POWER OF KNOWLEDGE AND COMMUNITY ACTION

Technology alone cannot solve the water crisis. Extension services play a crucial role in educating farmers about water-efficient practices and facilitating the adoption of sustainable technologies. Training programmes, field demonstrations, and farmer-to-farmer learning approaches encourage behavioural change and strengthen local capacity. Experiences from semi-arid regions of India demonstrate that combining traditional water harvesting systems with community participation can significantly improve water availability and livelihood security.

A LESSON FROM SEMI-ARID INDIA

Several drought-prone regions of India have demonstrated that water scarcity can be addressed through locally adapted and community-driven solutions. The restoration of traditional tanks, farm ponds, and rainwater harvesting structures has improved groundwater recharge and enhanced water availability for agriculture. Farmers adopting millet-based cropping systems have reduced dependence on irrigation while maintaining stable productivity and income. These experiences highlight that sustainable water management is not solely dependent on large-scale infrastructure but can also be achieved through the integration of traditional knowledge, community participation, and climate-smart agricultural practices. Such success stories offer valuable lessons for building resilient and water-secure farming systems across the country.

LOOKING AHEAD: BUILDING WATER-SECURE FUTURES

The future of water management lies in innovation and integration. Digital technologies such as remote sensing, Geographic Information Systems (GIS), Internet of Things (IoT)-based monitoring, and climate-informed decision support systems are transforming the way water resources are managed. At the same time, adopting a water-energy-food nexus approach can improve resource-use efficiency and reduce environmental trade-offs. Building water-secure futures will require coordinated efforts from governments, researchers, extension agencies, and communities.

A CALL FOR COLLECTIVE RESPONSIBILITY

Water is not merely a natural resource; it is the foundation of food security, economic

development, environmental sustainability, and human survival. Ensuring its sustainable use demands a collective commitment from all stakeholders. The choices made today will determine whether future generations inherit a world of water scarcity or a future of water security.

Conclusion

Water scarcity is no longer merely an environmental issue but a multidimensional challenge affecting agriculture, livelihoods, ecosystems, and economic development. The crisis is driven by climate change, unsustainable resource use, increasing demand, and governance limitations. Its impacts are particularly severe in agriculture, where water availability directly influences productivity and livelihood security. Sustainable water management therefore requires an integrated strategy combining technological innovation, climate-smart agriculture, effective policy interventions, and community participation. Strengthening water-use efficiency, promoting resilient farming systems, regulating groundwater extraction, and enhancing awareness through extension services are critical steps toward achieving long-term water security. The future of sustainable development depends on recognizing water as a finite and valuable resource and managing it through collective responsibility and informed decision-making. Ultimately, the future of water is not determined by how much water we have, but by how wisely we choose to manage it.

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A SIMPLE AND CHEMICAL-FREE NATURAL LIP BALM FORMULATION USING BEESWAX

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Abstract

The increasing demand for natural, eco-friendly, and chemical-free personal care products has encouraged the development of simple formulations based on naturally available ingredients. Beeswax, a valuable product of honey bees, possesses excellent emollient, protective, and moisturizing properties, making it an ideal ingredient for lip care formulations (Bogdanov, 2017). Coconut oil complements beeswax by providing antimicrobial, antioxidant, and skin-conditioning effects (Surjushe et al., 2008). The present study describes a simple method for preparing a natural lip balm using beeswax and coconut oil through the double-boiler technique. The formulation contains one part beeswax and two parts virgin coconut oil, producing a smooth, stable, and moisturizing lip balm without synthetic preservatives, artificial colours, fragrances, or petroleum-based ingredients. The product is economical, biodegradable, and suitable for household preparation, cottage industries, and apiculture-based value addition.

Keywords: Beeswax, Coconut oil, Natural cosmetics, Lip balm, Organic skincare, Value addition.

Introduction

Consumer preference has shifted significantly towards herbal and natural cosmetic products due to growing concerns regarding the long-term use of synthetic chemicals in personal care products (Pavithra, 2018). Conventional lip balms often contain petroleum jelly, paraffin wax, artificial fragrances, synthetic preservatives, and colouring agents, which may cause

irritation or allergic reactions in sensitive individuals (Rieger, 2000).

Beeswax is one of the most valuable products obtained from honey bees. It has been widely used in cosmetics because of its excellent film-forming ability, pleasant texture, stability, and skin-protective properties (Bogdanov, 2017). Beeswax forms a thin protective layer over the lips that reduces trans-epidermal water loss while allowing the skin to breathe. It also improves the consistency and shelf stability of cosmetic formulations (Rieger, 2000).Virgin coconut oil is rich in medium-chain fatty acids, particularly lauric acid, together with vitamin E and natural antioxidants. These constituents provide moisturizing, antimicrobial, and anti-inflammatory effects that help prevent dry and cracked lips (Surjushe et al., 2008). Natural plant-derived ingredients have gained considerable attention because of their safety, biocompatibility, and environmental sustainability (Ali et al., 2015).

The present research note describes a simple, economical, and chemical-free formulation of natural lip balm using beeswax and coconut oil. The preparation method is suitable for educational demonstrations, self-help groups, beekeepers, and small-scale rural entrepreneurs interested in value addition to bee products.

Materials and Methods

Materials

The following ingredients were used:

Ingredient	Proportion	Function
Pure beeswax	1 part	Base material, hardener, protective barrier (Bogdanov, 2017)
Virgin coconut oil	2 parts	Moisturizer, emollient, antimicrobial agent (Surjushe et al., 2008)

Equipment

- Heat-resistant glass bowl
- Double boiler setup
- Stainless steel spoon or glass stirrer
- Small sterilized lip balm containers
- Digital weighing balance

Method of Preparation

Step 1. Melting of Beeswax

Measured beeswax was transferred into a clean heat-resistant bowl and melted using the

double-boiler method by placing the bowl over boiling water. Direct heating was avoided to prevent degradation of beeswax and preserve its desirable physical properties (Bogdanov, 2017).

Step 2. Mixing

After complete melting, two parts of virgin coconut oil were gradually added to one part of molten beeswax with continuous stirring until a homogeneous mixture was obtained (Pavithra, 2018).

Step 3. Filling

The hot liquid mixture was immediately poured into sterilized lip balm containers while maintaining fluidity.

Step 4. Cooling

The containers were allowed to cool naturally at room temperature (25–30°C) for approximately 20–30 minutes until complete solidification.

Step 5. Storage

The prepared lip balm was stored in airtight containers at room temperature away from direct sunlight to maintain product quality and extend shelf life (Rieger, 2000).

Results and Discussion

The prepared lip balm possessed a smooth texture, pleasant consistency, and uniform appearance. The formulation spread easily on the lips without excessive hardness or stickiness. The combination of beeswax and coconut oil produced an ideal balance between firmness and softness.

Beeswax served as a natural thickening agent and created a protective layer that reduced transepidermal water loss (Bogdanov, 2017). Coconut oil penetrated the superficial layers of the skin, providing hydration and helping repair dry, cracked lips because of its emollient and antimicrobial properties (Surjushe et al., 2008). Similar observations on herbal lip balm formulations have been reported by Pavithra (2018). Since no synthetic preservatives or artificial additives were incorporated, the formulation remained completely natural and environmentally friendly (Ali et al., 2015).

Advantages of the Formulation

- Prepared entirely from natural ingredients (Bogdanov, 2017).
- Free from petroleum products and synthetic chemicals (Pavithra, 2018).
- Moisturizes and protects dry lips (Surjushe et al., 2008).

- Simple and inexpensive preparation.
- Suitable for small-scale commercial production.
- Environmentally friendly and biodegradable (Ali et al., 2015).
- Promotes value addition to bee products.

Scope for Future Improvement

The formulation may be enriched with natural ingredients such as vitamin E oil, cocoa butter, shea butter, almond oil, calendula extract, beetroot extract, and essential oils to improve antioxidant activity, texture, fragrance, and consumer acceptability (Ali et al., 2015; Pavithra, 2018).

Conclusion

The present formulation demonstrates that an effective natural lip balm can be prepared using only beeswax and virgin coconut oil through a simple double-boiler technique. The product provides excellent moisturizing and protective properties without the use of synthetic preservatives, artificial fragrances, colours, or petroleum derivatives. Such formulations offer considerable opportunities for rural entrepreneurship, beekeeping-based value addition, cottage industries, and educational training programmes (Bogdanov, 2017). Further studies on physicochemical characteristics, microbial stability, shelf life, and consumer acceptability are recommended before large-scale commercialization (Rieger, 2000; Pavithra, 2018).

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CYBER EXTENSION IN AGRICULTURAL EXTENSION

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Abstract

Cyber extension (also known as e-extension) may be defined as extension over the cyber space, the imaginary space created by the interconnected telecommunication and computer networks. Cyber Extension include effective use of Information and Communication technology, Information and communication technologies facilitate the processing and transfer of information, i.e. communication by electronic means Information Needs of Farmers Accessing Agricultural Information Constitute the Tools of Cyber Extension, ICT initiatives for agricultural development in India Cyber extension project

Key words: Cyber extension, ICT, Telnet, FTP, www

Introduction

Cyber extension (also known as e-extension) may be defined as extension over the cyber space, the imaginary space created by the interconnected telecommunication and computer networks. It means using the power of online network, computer communications and digital interactive multimedia to facilitate dissemination of farm information. Cyber extension includes effective use of information and communication technology, national and international information networks, the internet, expert systems, multimedia learning system and computer-based training system, to improve information access to the farmers, extension workers, research scientists and extension managers. cyber extension is expected to contribute to increasing the productivity and sustainability of the agricultural sector in the future.

Cyber Extension

Cyber Extension thus can be defined as the Extension over Cyber Space. Cyber Extension means "using the power of online networks, computer communications and digital interactive multimedia to facilitate dissemination of agricultural technology". Cyber Extension include effective use of Information and Communication technology, national and international information Networks, Internet, Expert Systems, Multimedia Learning Systems and Computer based training systems to improve information access to the Farmers, Extension Workers, Research Scientists and Extension Managers. According to Mishra 1999, Cyber Extension may be defined as extension over the cyberspace, the imaginary space behind the interconnected telecommunication and computer-networks, the virtual world.



Information and communication technologies (ICT)

Information and communication technologies facilitate the processing and transfer of information, i.e. communication by electronic means. ICT generally link Information processing devices like computers with telecommunication technologies like telephones, wired or wireless networks. ICTs are a range of electronic technologies which when converged in new configurations are flexible, adaptable, enabling and capable of transforming organizations and redefining social relations". The range of technologies is increasing all the time and „there is a convergence between the new technologies and conventional media"

The sphere of ICT has advanced so much that today they are defined as a booming congregation of technologies that are utilized for collection, storage and sharing of information & knowledge between people using multiple devices and multiple media.

Milestones In Cyber Extension

- At first during 1995, ARIS (Agricultural Research Information System) was established to help students & farmers to get immediate information regarding agriculture.
- During 1997, Agrisnet was started by GOI (Government of India).





- Then, during 1999, ATIC was started under NATP project. Pilot projects to connect rural community to the cyber space are underway at various locations.

Information Needs of Farmers

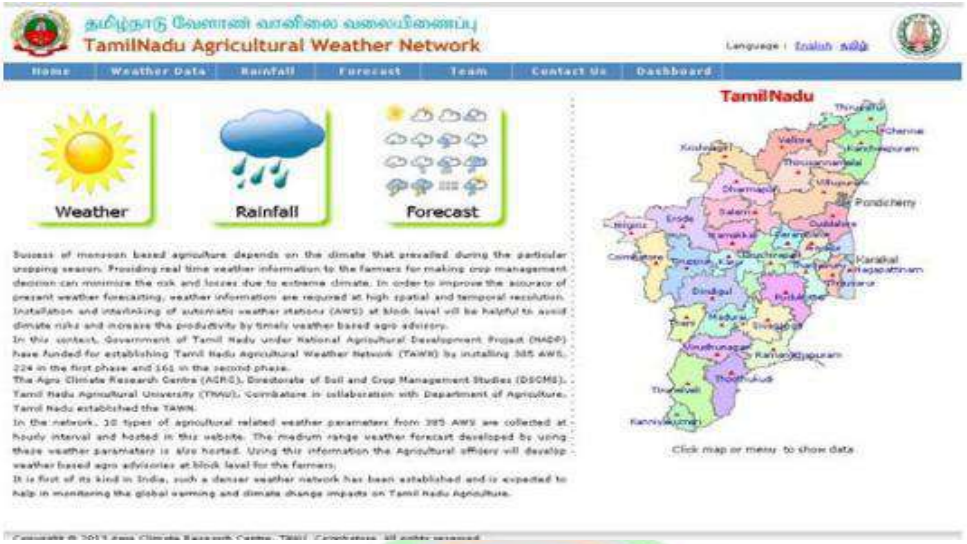






- Market information
- Information on latest techniques and technologies
- Information about rural development programs and subsidies

- Weather forecasting



- Latest (best) packages of practices
- Post-harvest technology
- Soil testing and soil sampling information
- General agricultural news

Accessing Agricultural Information Constitute the Tools of Cyber Extension

- E-mail: E- mail electronic mail) is the most frequently used application in cyber extension. Currently is being used by over 50 million people for business and personal use. E-mail allows us to share the messages with other users of the internet





- Telnet: telnet is an application that allows individual to log on toa remote computer. It is like a terminal emulation programme.
- FTP (file transfer protocol)
- Video conferencing



- Web conferences / Webinars
- Cell centres and satellite communication Network
- Gopher, Archie, Veronica
- Usenet Newsgroups: newsgroups provide a bulletin board type area where users can read other opinions and are sent entries of their own to be posted.
- World Wide Web: WWW is an organization of hypertext document containing tests, images, animation, sound, video and increasingly interactive programmes. It is an easy-to-use interface. The www is thus the most important tool for of cyber extension (http://tawn.tnau.ac.in) (http://e-vivasaya.rtbi.in/aas/index.php) (http://www.agritech.tnau.ac.in/dmi/2013/index.html#october23) (http://agritech.tnau.ac.in

ICT initiatives for agricultural development in India: Cyber extension project

- Gyandoot project-Madhya Pradesh
- Warana Wired Village project – Maharashtra
- Information Village project of the M S Swaminathan Research Foundation (MSSRF) – Pondicherry
- iKisan - Andhra Pradesh
- Automated Milk Collection Centres of Amul dairy cooperatives – Gujarat
- Land Record Computerisation (Bhoomi) – Karnataka
- Knowledge Network for Grass Root Innovations – Society for Research and Initiatives (SRISTI) – Gujarat

The methods for cyber extension:

- Providing interaction among research scientists, extension workers, farmers and other rural people through e-mail;
- Providing up-to-date news and information services, such as market prices and weather conditions;
- A question-and-answer service among Scientists, Extension Functionaries and Farmers, where experts respond to queries on specialized subjects;
- Creation and maintenance of Statistical Databases on critical agricultural and rural development parameters that can be queried on demand; Providing the details of Poverty Alleviation Schemes on the Internet;
- Providing status of various Government Programmes and details about their implementation mechanism on demand basis;
- Hosting web sites by major institutions participating m agricultural extension, putting latest packages of practices (with more situation specific packages), for various agro-eco regions. These institutions, particularly the Project Directorates may also place the diagnostic and pre-emptive farm practices for the major crops particularly the commercial crops, well in advance of the concerned crop season. This can help the extension workers to access latest information on IPM (Integrated Pest Management), INM (Integrated Nutrients Management) and other such practices for high value important commercial crops. The institutions will also be able to get direct customer feedback for their packages.
- Launching online rural development and extension journals, newsletters etc. (with or without print version);
- Providing Internet access at district and block level agriculture and rural development offices. This service may also be open for rural communities on fixed days. This connectivity can also be used to download online publications on useful topics from anywhere in the world;
- Opening of cyber cafes to enable educated rural people and extension workers at village level to have direct access to world wide web for having market information etc.;

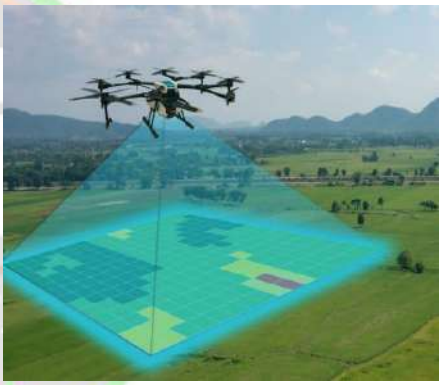
Providing maps that display different features, such as population density, crops planted, etc.;

- Providing video clips to demonstrate complex procedures; and audio files for re-broadcast on local radio stations (FAQ, 1999);
- Providing mechanism of user/ beneficiary feedback for the Public Sector Schemes.

Advantages of Cyber Extension

- Cyber Extension will save money, time and effort
- Cyber Extension will save time, cut steps from extension process
- Cyber Extension will be information rich and interactive
- Cyber Extension will off er instant international reach
- Cyber Extension will be continuously available





Disadvantages of Cyber extension

- Sometimes information given is not in the local language.
- Some information given may not hold good for local extension.
- Illiterate farmers cannot get the benefit of cyber extension.
- Dissemination of technology through Cyber extension in highly remote areas is a difficult task

Conclusion

Cyber Extension is a significant step in modernizing agricultural extension and supporting sustainable agricultural development. By utilizing information technology, it is hoped that farmers can increase productivity, welfare, and overall food security. To achieve its maximum potential, there needs to be cooperation between all stakeholders in the agricultural sector. Cyber extension is one of the information systems that can be used as a driver for the

mechanism of management, dissemination, documentation, re-search, and agricultural innovations needed by agricultural development actors so that they can support the development of sustainable agricultural innovations.

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BLUE CARBON: NATURE'S HIDDEN WEAPON AGAINST CLIMATE CHANGE

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Abstract

Blue carbon refers to the carbon captured and stored by coastal and marine ecosystems such as mangrove forests, seagrass meadows, and tidal salt marshes. These ecosystems play a vital role in mitigating climate change by sequestering atmospheric carbon dioxide while providing numerous ecological and socioeconomic benefits, including coastal protection, biodiversity conservation, fisheries support, and improved water quality. However, increasing anthropogenic activities, habitat degradation, and climate change threaten their carbon storage capacity and ecosystem services. Conserving and restoring blue carbon ecosystems through sustainable management, scientific research, and community participation can significantly contribute to climate resilience and global carbon reduction efforts. This article highlights the importance of blue carbon ecosystems, their role in climate change mitigation, associated threats, conservation strategies, and their significance for India in achieving sustainable coastal development and environmental conservation.

Keywords: Blue carbon, climate change, carbon sequestration, mangroves, seagrass meadows, salt marshes, coastal ecosystems, climate mitigation.

Introduction

Blue carbon is a climate change mitigation concept that refers to the capture and long-term storage of carbon by coastal and marine ecosystems. It primarily includes tidal marshes, mangrove forests, and seagrass meadows, which absorb atmospheric carbon dioxide and store it in their vegetation and sediments. Although the inclusion of macroalgae (seaweeds) as blue

carbon ecosystems is still debated, these coastal habitats are widely recognized for their role in reducing greenhouse gas emissions and supporting ecosystem-based climate adaptation. However, when they are damaged or destroyed, the stored carbon is released back into the atmosphere, contributing to climate change. Blue carbon management is considered an ocean-based biological carbon dioxide removal (CDR) strategy that relies on the natural ability of marine ecosystems to capture and store carbon through biological processes. Researchers are exploring ways to enhance the carbon sequestration capacity of these ecosystems to strengthen their role in mitigating climate change. However, the long-term efficiency and reliability of blue carbon as a carbon removal solution remain subjects of ongoing scientific research and discussion. In addition to coastal blue carbon, the concept of deep blue carbon refers to the storage of carbon in the deep ocean, where it can remain isolated from the atmosphere for extended periods.

Nature provides a free lunch, but only if we control our appetites.

- William Ruckelshaus

What is Blue Carbon?

According to the IPCC, blue carbon refers to the carbon captured, transferred, and stored through biological processes in marine ecosystems that can be managed for climate benefits. It mainly includes the organic carbon stored in coastal habitats such as mangrove forests, seagrass meadows, and tidal salt marshes, which efficiently absorb atmospheric carbon dioxide and store it in their biomass and sediments. These vegetated coastal ecosystems are often called "blue forests" because of their role in carbon sequestration, similar to terrestrial forests. In addition to coastal ecosystems, the concept of deep blue carbon includes carbon stored in offshore waters, continental shelf regions, deep ocean waters, and seafloor sediments beyond national jurisdictions. Although these deep-ocean carbon reservoirs contain the majority of the ocean's stored carbon, their management and long-term monitoring remain difficult due to limited scientific knowledge and data.

Blue Carbon Ecosystems

Mangrove Forests

Mangrove forests are salt-tolerant trees and shrubs found along tropical and subtropical coastlines. They are among the most productive ecosystems on Earth and store large amounts of carbon in both their biomass and waterlogged soils. Besides carbon sequestration, mangroves

reduce coastal erosion, protect shorelines from cyclones and tsunamis, improve water quality, and provide breeding grounds for fish, crustaceans, and birds. Conserving mangroves therefore offers both climate and biodiversity benefits.

Seagrass Meadows

Seagrasses are flowering marine plants that grow in shallow coastal waters. Although they cover a relatively small area of the ocean floor, they store carbon efficiently in their roots and sediments for centuries. Seagrass meadows stabilize sediments, improve water clarity, support fisheries, and provide habitat for endangered species such as sea turtles and dugongs.

Salt Marshes

Salt marshes are coastal wetlands dominated by salt-tolerant grasses and shrubs. They capture atmospheric carbon through photosynthesis and store it in deep, organic-rich soils. Salt marshes also reduce flooding, filter pollutants, and serve as important feeding and nursery habitats for many aquatic organisms.

Figure 1 illustrates the carbon cycling processes in mangrove–seagrass ecosystems and highlights how these coastal habitats contribute to long-term carbon sequestration and air–sea carbon exchange.

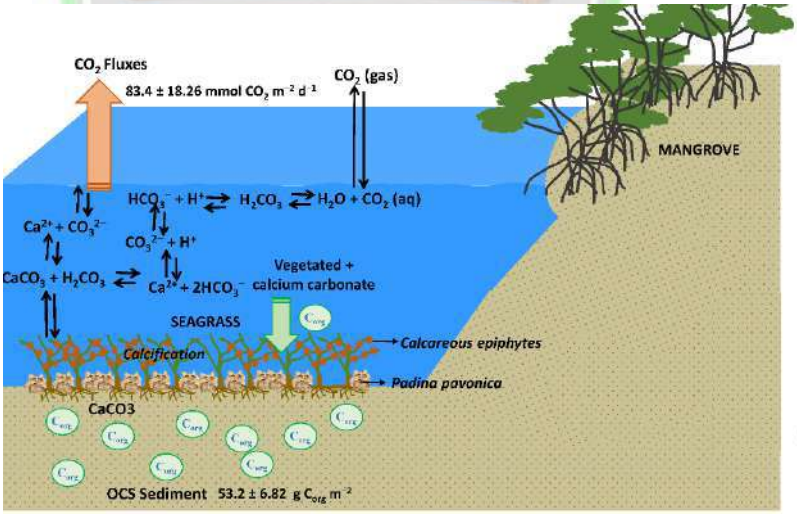


Figure 1. Carbon cycling in mangrove–seagrass ecosystems.

Source: Latifah et al. (2023).

Benefits of Blue Carbon Ecosystems

Blue carbon ecosystems provide numerous ecological, economic, and social benefits beyond carbon sequestration. They protect coastal communities from erosion, storms, and

flooding while supporting fisheries, aquaculture, and tourism. These ecosystems improve water quality by filtering pollutants and trapping sediments, thereby maintaining healthy coastal environments. They also serve as breeding and nursery grounds for a wide range of marine organisms, helping sustain biodiversity and food security.

Blue Carbon and Climate Mitigation

Blue carbon refers to the carbon captured and stored by coastal and marine ecosystems such as mangrove forests, seagrass meadows, and tidal salt marshes. These ecosystems act as natural carbon sinks by absorbing atmospheric carbon dioxide (CO_2) through photosynthesis and storing it in their biomass and sediments for long periods. Besides mitigating climate change, they protect coastlines, support marine biodiversity, improve water quality, and sustain fisheries. However, habitat degradation caused by pollution, coastal development, and climate change can release the stored carbon back into the atmosphere, increasing greenhouse gas emissions. Therefore, conserving and restoring blue carbon ecosystems is an effective nature-based solution for climate change mitigation and sustainable coastal management.

Threats to Blue Carbon Ecosystems

Blue carbon ecosystems, including mangrove forests, seagrass meadows, and tidal salt marshes, are increasingly threatened by human activities and climate change. Major threats include coastal development, conversion of wetlands for aquaculture and agriculture, pollution from industrial and agricultural runoff, overharvesting of natural resources, and rising sea levels. These pressures degrade coastal habitats, reducing their ability to store carbon and support marine biodiversity. When blue carbon ecosystems are damaged or destroyed, the carbon stored in their biomass and sediments is released back into the atmosphere, accelerating greenhouse gas emissions and climate change. Therefore, protecting and restoring these ecosystems is essential for maintaining their ecological functions and climate mitigation potential.

Conservation Measures

Protecting blue carbon ecosystems requires effective conservation and sustainable management practices. Key measures include restoring degraded mangrove forests, seagrass meadows, and tidal salt marshes; preventing coastal habitat destruction; reducing pollution and plastic waste; promoting sustainable fisheries and aquaculture; and strengthening coastal protection policies. Community participation, scientific research, and climate-smart coastal planning are also essential to enhance carbon sequestration, conserve biodiversity, and improve

the resilience of coastal ecosystems against climate change.

Blue Carbon and the Sustainable Development Goals

Blue carbon ecosystems contribute directly to several United Nations Sustainable Development Goals (SDGs). They support SDG 13 (Climate Action) by removing carbon dioxide from the atmosphere, SDG 14 (Life Below Water) by conserving marine biodiversity, SDG 15 (Life on Land) through ecosystem restoration, and SDG 1 (No Poverty) and SDG 2 (Zero Hunger) by supporting fisheries, tourism, and coastal livelihoods. Investing in blue carbon conservation therefore provides environmental, social, and economic benefits.

Blue Carbon in India

India has approximately 4,992 km² of mangrove forests, accounting for about 3% of the world's mangrove cover. These ecosystems are distributed across the Sundarbans, Bhitarkanika, Pichavaram, Muthupet, Gulf of Kachchh, Gulf of Mannar, and the Andaman and Nicobar Islands. They play a crucial role in supporting fisheries, protecting coastlines from cyclones and storm surges, conserving biodiversity, and storing significant amounts of carbon. Strengthening restoration and conservation initiatives will help India achieve its climate and Blue Economy goals.

Emerging Research and Future Perspectives

Recent advances in remote sensing, GIS, drones, and satellite technology have improved the mapping and monitoring of blue carbon ecosystems. Scientists are also investigating the carbon sequestration potential of seaweed farming and deep-ocean carbon storage. Future research should focus on improving carbon accounting methods, restoring degraded coastal habitats, and integrating blue carbon into national climate policies. Emerging technologies such as artificial intelligence, environmental DNA (eDNA), satellite remote sensing, and carbon accounting models are improving the monitoring and valuation of blue carbon ecosystems. These innovations are expected to support carbon credit programs, ecosystem restoration, and evidence-based coastal management in the future.

Key Facts About Blue Carbon

Mangroves can store three to five times more carbon per hectare than many terrestrial forests.

- More than 90% of blue carbon is stored in coastal sediments.

- Blue carbon ecosystems protect millions of people from coastal flooding and storm surges.
- Restoring degraded mangroves is one of the most cost-effective nature-based climate solutions.

Role of Local Communities

The participation of coastal communities is essential for the long-term conservation of blue carbon ecosystems. Community-based mangrove restoration, sustainable fishing practices, pollution control, and environmental awareness programs help protect these valuable habitats. Involving local people in conservation efforts not only improves ecosystem health but also creates employment opportunities through ecotourism, sustainable aquaculture, and habitat restoration projects.

Challenges in Blue Carbon Conservation

Although blue carbon ecosystems are increasingly recognized for their role in climate regulation, several challenges hinder their conservation. These include inadequate policy implementation, limited public awareness, insufficient long-term monitoring, financial constraints, and rapid coastal urbanization. Climate change, sea-level rise, and habitat fragmentation further threaten the sustainability of these ecosystems. Addressing these challenges requires integrated management, scientific research, and active participation from governments, researchers, and local communities.

Conclusion

Blue carbon ecosystems are among the most effective natural solutions for mitigating climate change. Protecting and restoring mangrove forests, seagrass meadows, and tidal salt marshes not only enhances carbon sequestration but also conserves biodiversity, supports coastal livelihoods, and safeguards ecosystems for future generations. Investing in blue carbon conservation is therefore essential for building a sustainable and climate-resilient future. Protecting blue carbon ecosystems today is not only an investment in climate change mitigation but also a commitment to preserving healthy oceans and sustainable livelihoods for future generations.

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CROP BREEDING FOR STRESS RESISTANCE UNDER CLIMATE-RESILIENT AGRICULTURE: INTEGRATING CONVENTIONAL AND GENOMIC APPROACHES FOR SUSTAINABLE FOOD SECURITY

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Abstract

The impact of climate change has already started to affect agricultural production in the form of increased occurrences and severity of drought, heat, salinity, flooding, and new pests and diseases. These stresses threaten crop production, yield stability, and, consequently, global food security. There is an urgent need to develop new breeding strategies that ensure resilience without compromising genetic gains. The crop breeding discipline has evolved from conventional phenotypic selection to an integrative approach that combines quantitative genetics, molecular breeding, genomics, and advanced breeding technologies. However, conventional breeding still provides a fundamental basis for developing climate-resilient crops. At the same time, marker-assisted selection, genomic selection, speed breeding, genome editing, and high-throughput phenotyping have accelerated the utilization of favorable alleles for stress tolerance. The combination of conventional and genomic approaches offers a sustainable solution for developing crop varieties that are resilient to climate change while maintaining productivity. These strategies are critical for ensuring food security, conserving natural resources, and promoting climate-smart agriculture for future generations.

Keywords: Climate-resilient agriculture, Stress-resistant crop breeding, Conventional breeding, Molecular breeding, Genomic selection, Sustainable food security.

Introduction

Agriculture has been dependent on climate for millennia, but the changing climate patterns in recent decades have created multiple challenges for crop production worldwide. Rising temperatures, erratic rainfall, prolonged droughts, sudden floods, salinity, and the rapid

emergence of new pests and diseases are major concerns for crop production, threatening yield stability, food security, and the livelihood of millions of farmers. Climate change is becoming one of the most important challenges of this century as the world's population grows and the demand for food increases.

Plant breeding has played a critical role in improving crop productivity since the beginning of agriculture. The crop varieties that were developed during the Green Revolution increased yield potential and contributed to food security in many countries. However, most of these varieties were developed under optimal conditions, and their performance was not evaluated under multiple stresses. Modern plant breeding is increasingly focusing on developing cultivars that have higher yield potential under multiple abiotic and biotic stresses, particularly drought.

Stress tolerance is a polygenic trait that is controlled by complex regulatory mechanisms and is influenced by the environment. Conventional breeding methods such as hybridization, pedigree, recurrent selection, and backcross have been successfully used to develop stress-tolerant crop varieties. However, the success of these approaches depends on the level of genetic variability present in the breeding populations. Modern genomic tools have enhanced the accuracy of selection, resulting in faster genetic gains.

Recent advances in molecular genetics and genomics have transformed crop improvement strategies by shifting the emphasis from phenotypic selection to knowledge-based breeding. Molecular markers, quantitative trait locus (QTL) analysis, marker-assisted selection, genomic selection, high-throughput phenotyping, speed breeding, and genome editing are some of the modern approaches that have accelerated the development of stress-tolerant crop varieties. On the other hand, crop wild relatives, traditional landraces, and diverse germplasm collections are valuable resources that can be tapped to introgress multiple stress-tolerance genes into modern cultivars. These resources, in combination with modern breeding technologies, have enhanced crop improvement programs, resulting in the development of resilient varieties with shorter breeding cycles.

Climate-resilient agriculture requires crop varieties that have high yield potential under multiple stresses while conserving natural resources. The combination of conventional and genomic approaches is essential for developing such varieties. This review discusses recent

advances in crop breeding for stress tolerance and highlights the role of conventional and genomic approaches in climate-resilient agriculture.

Climate Change and the Biological Basis of Crop Stress

Climate change has affected the agro-ecological conditions in which crops have been growing for thousands of years. Temperature, rainfall, drought, salinity, flooding, and new pests and diseases are some of the abiotic and biotic stresses that have increased in recent decades. Unlike controlled experiments, crops experience multiple stresses in the field, and their combined effect is much severe. These stresses often affect physiological processes, biomass production, and yield potential of crops.

Abiotic stresses are responsible for significant yield losses worldwide. Drought is a major threat to crop production as it reduces soil moisture, which affects nutrient uptake, cell expansion, and photosynthesis. Heat stress disturbs membrane fluidity, protein structure, enzyme activity, and cellular respiration, ultimately affecting grain-filling capacity, crop maturity, and yield quality. Salinity causes osmotic and ionic stress that inhibits photosynthesis and disturbs nutrient uptake and plant metabolism. Similarly, flooding reduces oxygen availability to the roots and affects respiration, while cold stress decreases membrane fluidity and enzyme activity. In addition, climate change has influenced the distribution and prevalence of pests and diseases, thereby increasing biotic stress in many crops.

Multiple abiotic and biotic stresses often overlap, and their combined effect is more damaging than individual stress. Physiological and biochemical mechanisms play an essential role in plant tolerance to these stresses. For instance, stress-tolerant crops have deeper and more extensive root systems that allow them to access soil moisture and nutrients. Such crops also have efficient osmotic adjustment, antioxidant defense systems, and cellular mechanisms that help them maintain stability under stress. These mechanisms are often controlled by multiple genes that require precise regulation. Consequently, stress tolerance is a complex trait that is very challenging to improve using traditional breeding methods.

Conventional Breeding: The Foundation of Stress-Resistance Improvement

Conventional breeding has been the backbone of crop improvement for over a century. Breeding programs have resulted in the development of many stress-tolerant crop varieties that are currently grown in different parts of the world. Many of these varieties were developed using traditional approaches such as selection and hybridization. Conventional breeding has enabled

plant breeders to harness natural genetic diversity and develop improved cultivars with higher yield and better tolerance to drought, disease, and salinity.

The process of conventional breeding starts with the selection of parents with desirable traits. Hybridization between selected parents generates genetic diversity that can be harnessed to develop improved crop varieties. For instance, pedigree breeding has been very effective in developing self-pollinated crops, as it allows breeders to develop superior cultivars by evaluating the performance of different families. On the other hand, recurrent selection has been used to increase the frequency of favorable alleles in a given population, particularly for traits that are controlled by multiple genes. Backcross breeding has also been used to transfer specific genes or quantitative trait loci (QTLs) from a donor parent to a recurrent parent while maintaining the superiority of the latter.

One of the main advantages of conventional breeding is that it allows plant breeders to evaluate the performance of selected genotypes in the target environment. Most crops are often exposed to multiple abiotic and biotic stresses, and only those genotypes that are tolerant to these stresses can be recommended for cultivation. Field evaluation is, therefore, critical in conventional breeding as it allows breeders to accurately determine genotype × environment interactions. Multilocation trials are also useful in understanding the stability of a given genotype and its adaptability to different environments.

Despite the success of conventional breeding in developing stress-tolerant crop varieties, it has several limitations. For instance, most of the traits that are economically important are quantitative traits that are governed by multiple genes and are often influenced by the environment. Consequently, phenotypic selection requires extensive field trials before desirable genotypes can be identified and released for commercial use. However, conventional breeding provides a solid genetic foundation for modern crop improvement approaches such as genomic selection.

Physiological Breeding: Linking Plant Function with Genetic Improvement

Physiological breeding has enhanced crop improvement by providing a mechanistic link between plant physiology and genetics. This approach allows breeders to use physiological parameters as selection criteria and develop crop varieties with desirable traits. Physiological breeding is important in ensuring that the selected crop varieties are productive and resilient to multiple abiotic and biotic stresses.

Root architecture plays a critical role in determining the ability of crops to tolerate drought. Deep and extensive root systems allow plants to access water from deep in the soil, maintain turgidity, and continue with photosynthesis. Rooting depth, root length density, and hydraulic conductivity are physiological traits that have been used in breeding programs to improve crop tolerance to drought stress. Physiological breeding offers a unified framework that can be used to harness genetic diversity and develop cultivars that are resilient to multiple stresses while maintaining high yield potential.

Future breeding programs should focus on developing crop varieties that are tolerant to multiple stresses rather than single stresses. The combination of conventional breeding, genomics, digital agriculture, artificial intelligence, and precision phenotyping can be used to develop climate-resilient crops that are highly productive while conserving natural resources.

Conclusion

Climate change has forced crop improvement programs to change their focus from increasing yield potential to enhancing resilience to multiple stresses. Crop varieties that are able to tolerate abiotic and biotic stresses while maintaining high yield potential are critical for ensuring food security in the face of climate change. Developing such varieties requires an integrative approach that combines conventional and genomic breeding methods. Conventional breeding methods have enabled plant breeders to develop many stress-tolerant crop varieties by harnessing natural genetic diversity. On the other hand, genomic selection, marker-assisted selection, and other modern approaches have accelerated the breeding process by shortening the time needed to develop new varieties. The combination of conventional and genomic approaches has enhanced crop improvement, ultimately increasing agricultural productivity while conserving natural resources.

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TRADITIONAL FOODS IN THE ERA OF GLOBALIZATION: OPPORTUNITIES, CHALLENGES, AND FUTURE PERSPECTIVES

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Introduction

Traditional foods are those culinary products, recipes, and preparation methods that have been passed down through generations by generation, reflecting the unique history, geography, climate, and cultural traditions of a community or region. They are prepared using locally available ingredients and traditional techniques, representing far more than nutrition—symbolizing one's cultural identity, collective heritage and social values (Rocillo-Aquino et al., 2021). Traditional foods play a central role in festivals, religious ceremonies, family gatherings, and everyday life, strengthening community bonds and preserving indigenous knowledge (Manik et al., 2024). In many regions, they also contribute to nutritional security, sustainable agriculture, and local economies (Ghosh et al., 2023). As globalization transforms food systems and consumer preferences, traditional foods remain an essential link between the past and the present, reminding us of the importance of preserving culinary heritage while embracing innovation and cultural exchange.

In an increasingly globalized world, preserving food heritage is essential for safeguarding cultural identity, biodiversity, and traditional knowledge. Local and traditional foods reflect the history, customs, and values of communities, connecting generations through shared recipes and culinary practices (Reddy & Van Dam, 2020). However, the widespread availability of standardized, processed, and fast foods has led to the gradual decline of many indigenous food traditions. Protecting food heritage helps maintain unique flavors, supports local farmers and artisans, conserves native crop varieties, and promotes sustainable agricultural practices. It also

contributes to food security by encouraging the use of climate-resilient local crops and traditional production methods. By valuing and preserving traditional foods while embracing responsible innovation, societies can celebrate their cultural diversity, strengthen rural livelihoods, and ensure that these rich culinary traditions continue to inspire and nourish future generation (Subrahmanyam, 2026).

Traditional Food Around the world

Traditional foods have crossed geographical boundaries to become symbols of cultural identity and culinary excellence, demonstrating how globalization can create opportunities while preserving heritage. Country like Japan, widely consumed fermented food which content probiotics serving both nutritional and functional properties. *Kurosu* (black rice vinegar), *shoyu* (soy sauce), *natto*, *tempeh* and *miso* (soybean-barley paste) are popular traditional fermented foods exploiting cultural uniqueness and traditional methods of the country (Murooka & Yamshita, 2008). Before it was only regional specialty, but now it is enjoyed throughout the world giving the familiar surroundings to the people of Japan which is far from their country without losing its traditional essence. For Korea, *Kimchi* and *Jang, Kanjang, Doenjang, and Kochujang* (fermented soybean sauce and paste) are unique fermented foods which revealed the lifestyle and deep-rooted cultural history of the ancestors. Now these foods have gained popularity all around the corner of the world internationally representing Korean culture (Kwon et al., 2023).

Italy's Neapolitan Pizza and Parmigiano Reggiano cheese have become household names, with quality protected through geographical indication (GI) systems that preserve their authenticity. Mexico's Tortillas and Tacos have evolved from traditional staples into globally loved foods, while Ethiopia's Injera has introduced international consumers to the rich heritage of East African cuisine. In India, Basmati rice, Darjeeling Tea, and traditional millets have emerged as global success stories. The declaration of 2023 as the International Year of Millets by the United Nations further boosted awareness of these ancient, climate-resilient grains, increasing their demand in international markets. Improved processing technologies, better packaging, digital marketing, food tourism, and expanding global trade have all contributed to the worldwide popularity of these traditional foods. These success stories illustrate that when cultural authenticity is respected and supported by innovation, quality standards, and effective

branding, traditional foods can thrive in global markets while preserving the heritage, identity, and livelihoods of the communities from which they originate.

Sr No	Food/Cuisine	Origin	Cultural importance	Globalization Influence
1	Kimchi	Korea	Related to Kimjang (Ancient Korean tradition of preparing and sharing of kimchi which Promotes social boding)	One of the major foods in international gut-health diets.
2	Sushi	Japan	Japanese cookery, Seasonality, Simplicity.	Adapted worldwide, aesthetically pleasing food premium exports.
3	Pizza (Nepolitaan)	Naples, Italy	Traditional legacy passed down through generation, Enlisted in UNESCO Intangible cultural heritage.	These legacy bridges "heritage" and "McDonaldization" into a localized globalism known as Verace Glocal Pizza.
4	Tortillas	Mexico	Cornerstone of Mesoamerican civilization & dietary, Represents sacred connection to corn, community and cycle of life, Intangible cultural heritage.	Driven by surging popularity of Mexican and Tex-Mex cuisines, Popularised worldwide through Mexican restaurants.
5	Injera	Ethiopia	Deeply knitted into cultural identity, sharing from same Injera is a symbol of unity, communal harmony and respect.	Globalization leads to massive export of packaged flatbreads worldwide. International rise of *teff* as a gluten-free super grain attracting health conscious

				and vegan population.
6	Couscous	Morocco, Algeria, Tunisia	Regional/tribal origin, developed as a survival strategy for storing and cooking food in hot and dry conditions. UNESCO Heritage, Symbol of collectiveness in families and communities in throughout the generations across North Africa.	Adopted as a rapid base for salads or as a quick alternative to rice and noodles. Industries implement continuous pressing and steaming technology to produce ready-o-cook couscous.
7	Pho	Vietnam	National dish, symbol of communal harmony and balance, cultural identity. Mix blend of French and Chinese influences.	Major drivers for globalization are Vietnamese Diaspora. Transformed from labours food into symbol of Vietnamese culinary art.
8	Pad Thai	Thailand	Survival food during World War II to reduce rice consumption, promote nationalism, Thai identity.	It encouraged the establishment of Thai restaurants globally through culinary diplomacy/gastrodiplomacy.
9	Natto	Japan	Fermented soybean food having health benefits, energizing breakfast staple, ancient heritage.	International exports increased in recent years. Gaining popularity among health-conscious peoples as a protein rich, Nattokinase, probiotic, functional superfood.
10	Dosa	Southern	Fermented, south Indian	The masala dosa was

		India	culinary heritage.	ranked in the top 10 list of the world's best pancakes by the international food atlas. The global Ready-to-Heat Dosa market is growing at an 8.5% Compound Annual Growth Rate.
11	Idli	Southern India	Fermented, steamed, nutritious rice cake.	The idli has evolved from local kitchens into a thriving, multi-crore international market. The Indian wet batter market (for idli and dosa) is estimated to be worth over ₹1,500–4,000 crore
12	Dhokla	Gujarat, India	Gut-friendly fermentation, deeply ingrained in local culture, it has also become a celebrated staple of India's healthy breakfast culture	Transformed dhokla from a regional Gujarati staple into a global health-conscious snack
13	Akhuni	Nagaland, NE India	Highly prized by tribes like the Sümi and Ao, it is rich in protein and nutrients, it serves as a vital anchor of Naga cultural identity, representing indigenous ecological knowledge and an expression of home,	Globalization has drastically altered its market trajectory, transforming it from a localized tribal staple into a highly sought-after commercial product across mainland India.

			belonging, and heritage.	
14	Ngari	Manipur, NE India	Deeply rooted in Manipuri heritage, it is the cornerstone of local cuisine.	Globalization has transformed Ngari from a localized, rural commodity into a commercialized product, opening broader regional markets, attracting external producers, and necessitating standardized food safety and packaging for modern consumers
15	Eromba	Manipur, NE India	Culturally significant dish of the Meitei and Naga communities in Manipur, Northeast India. symbolizes the deep-rooted bond between the region's geography, seasonal foraging, and indigenous heritage	By digitizing food culture and utilizing modern e-commerce, it bridges traditional indigenous consumption and modern urban culinary appreciation.

Benefits and challenges of globalization

Globalization has transformed the way traditional foods are produced, marketed, and consumed, creating both significant opportunities and notable challenges. It has expanded international markets, allowing local food producers to reach consumers across the globe and generate higher incomes (Ghosh et al., 2023). Advances in food processing, packaging, cold-chain logistics, and digital marketing have improved product quality, shelf life, and accessibility. Some product includes instant *Dosa*, *Idle*, *Dhokla*, Canned *Eromba* ingredient, *Egusi* soup, *Papeda* flour in ready to cook form are all results of the advance processing techniques influenced by globalization. Food tourism has further strengthened this trend by encouraging travellers to explore authentic local cuisines, thereby promoting cultural exchange and supporting rural economies (Rapinski et al., 2023). Destinations known for their unique culinary

heritage, such as Korea, Thailand, India, Italy, Mexican, Philippines etc attract millions of visitors seeking traditional dining experiences, cooking workshops, and regional food festivals (Sanmee, 2024). However, for every light has its shadow, globalization also poses risks to traditional food systems. The growing popularity of fast foods and highly processed products has contributed to changing dietary habits, especially among younger generations, leading to the decline of indigenous recipes and cooking practices. Commercialization may result in recipe modifications, mass production, and the loss of authenticity to suit international tastes (Quintero-Angel et al., 2022; Yulistiyono et al., 2023). Small-scale producers often face intense competition from multinational food companies, while traditional crop varieties and local biodiversity may be threatened by standardized agricultural practices (Feldman & Wunderlich, 2023). Therefore, achieving a balance between global market expansion and the preservation of culinary heritage is essential. By promoting responsible food tourism, protecting geographical indication (GI) products, and supporting local producers, globalization can become a powerful tool for preserving and celebrating traditional food cultures rather than replacing them (Manik et al., 2024).

Impact of Sustainability and innovation on Traditional Food Products

Traditional food systems often rely on locally sourced ingredients, seasonal production, and indigenous knowledge, making them inherently sustainable and supportive of biodiversity. Sustainability and innovation are increasingly shaping the future of traditional foods, ensuring that culinary heritage is preserved while meeting the demands of modern consumers (Subrahmanyam, 2026). Many traditional crops, such as millets, sorghum, and teff, are climate-resilient, require fewer inputs, and contribute to environmentally friendly agricultural practices. At the same time, innovation has opened new opportunities to enhance the quality, safety, and marketability of these foods without compromising their authenticity (Kennedy et al., 2022). Modern processing technologies, improved packaging, cold-chain logistics, and digital marketing have extended shelf life, reduced post-harvest losses, and enabled traditional products to reach global markets. Innovations such as vacuum packaging, freeze-drying, and eco-friendly packaging help preserve flavor and nutritional value while meeting international quality standards. By standardizing indigenous fermentation procedure food product liked *Akhuni/Akone, Soibum, Kinema, Ngari, Hentak* etc from northeast India has been widely available and accessible in global market. Digital platforms, e-commerce, and food storytelling

through social media have also increased consumer awareness and appreciation of regional cuisines. However, innovation should complement rather than replace traditional knowledge and practices. Maintaining authentic recipes, protecting geographical indication (GI) products, and involving local communities in product development are essential for safeguarding cultural identity (Sanmee, 2024). By integrating sustainable production methods with responsible technological advancements, traditional foods can remain economically viable, environmentally sustainable, and culturally significant (Trolio et al., 2016). This balanced approach not only supports rural livelihoods and conserves natural resources but also ensures that future generations continue to enjoy the rich diversity of the world's food heritage.

Future Scope

The future of traditional foods lies in combining cultural heritage with innovative technologies. Smart packaging equipped with freshness indicators and eco-friendly biodegradable packaging can improve product quality while reducing environmental impact. Artificial Intelligence (AI) can assist producers in quality assessment, demand forecasting, and supply chain optimization, making traditional food production more efficient. Blockchain-based traceability offers consumers transparent information about the origin, authenticity, and production journey of traditional foods, helping protect geographical indication (GI) products. Meanwhile, digital marketing and e-commerce platforms enable small-scale producers to reach global consumers and promote regional specialties beyond local markets. Equally important is youth engagement through entrepreneurship, culinary education, food innovation competitions, and social media campaigns, inspiring the next generation to preserve and modernize traditional food heritage. By embracing these innovations responsibly, traditional foods can remain authentic, sustainable, and competitive in an increasingly globalized world.

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SERICIN: A HIDDEN TREASURE FROM SILK FOR HUMAN HEALTH

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Abstract

Sericin, the glycoprotein coating that holds silkworm cocoon fibers together, has shifted from a discarded textile by-product to a closely studied biomedical material. For more than two thousand years, silk farmers and reelers across China, India, and Southeast Asia have done the same thing with sericin. They boiled it off, washed it away, and let it drain into open channels as wastewater. The protein had no commercial value. It was simply the gum that had to be removed before fibroin, the shiny load-bearing fiber, could be woven into fabric. Today, that discarded gum is being studied in laboratories for wound dressings, cancer drug carriers, nerve repair scaffolds, and skincare formulas. Few materials have traveled as far, from drain to clinic, in such a short span of research history. Recovering sericin from silk processing wastewater also reduces effluent treatment costs and creates a secondary income stream for sericulture-dependent rural communities. Commercialization still faces hurdles, including extraction variability, purification costs, and limited farmer awareness, but ongoing research into recombinant production and combination biomaterials suggests sericin is positioned to become a mainstream biomedical ingredient.

Keywords : Sericin; Biomedical applications; Wound healing; Drug delivery systems; Tissue engineering; Sericulture

Silk Proteins

A silkworm cocoon is built from two proteins working together. Fibroin forms the core filament, the strong, lustrous thread that gives silk its commercial identity. Sericin coats that filament like a natural glue, holding the loose threads together and protecting the developing pupa from microbes and physical damage. In the cocoon of *Bombyx mori*, the mulberry silkworm that supplies most of the world's silk, sericin makes up roughly 20 to 30 percent of the total cocoon weight.

Silk processing depends on removing this coating through a step called degumming, usually done by boiling cocoons in a mild alkaline or soap solution. The fibroin comes out soft, lustrous, and ready for weaving. The sericin, however, dissolves into the boiling water and is discarded as effluent. Global silk fiber production reached approximately 175,000 tons in 2020, valued at close to seven billion US dollars (Aramwit *et al*., 2012; Kabir *et al*., 2024). A by-product of that scale, generated every single reeling season, represents tens of thousands of tons of protein that the textile sector has historically treated as a disposal problem rather than a resource.

What Makes Sericin a "Wonder Protein"?

Few natural proteins combine so many useful traits in one package. Sericin dissolves easily in water, which makes it simple to process into films, gels, sprays, and coatings without harsh solvents. It forms stable films on skin and tissue surfaces, locking in moisture rather than letting it evaporate. It degrades naturally in the body over time, leaving no toxic residue behind. It triggers a low immune response when properly purified, so the body tolerates it well rather than attacking it as a foreign substance.

Add to that an antioxidant capacity that rivals several synthetic preservatives, a documented ability to inhibit certain bacteria, and a chemical structure rich in amino acid side groups that chemists can modify and cross-link with other materials. Few single ingredients check this many boxes for both medicine and cosmetics at once. That combination, biocompatible, biodegradable, antioxidant, antimicrobial, and chemically versatile, is exactly why researchers reach for the word "wonder" when describing it (Kunz *et al*., 2016; Lamboni *et al*., 2015).

Extraction and Sources of Sericin

Recovering sericin starts with the same degumming process silk mills already run, just redirected so the dissolved protein gets captured instead of poured away. Several extraction methods are used, and the choice matters a great deal because it determines the quality and chain length of the final protein.

Hot water extraction is the gentlest option. It preserves the protein's structure well but recovers a smaller fraction of the total sericin present in the cocoon. Alkaline extraction, using sodium carbonate at boiling temperature for around 30 minutes, is the standard industrial method because it is fast and cheap, though the harsh conditions break the protein into shorter chains and reduce some of its biological activity. High temperature and high-pressure treatment speeds up recovery further. Microwave-assisted degumming has emerged as the most efficient chemical method tested so far, recovering essentially all of the sericin contained in a cocoon batch, a finding reported by researchers comparing four degumming techniques side by side. Enzymatic and ultrasonic methods sit between these extremes, offering milder conditions at a higher processing cost.

A separate and increasingly important source is the wastewater itself. Rather than extracting sericin directly from cocoons, ultrafiltration membranes can pull the protein out of the spent degumming liquid that silk mills already produce, recovering more than 97 percent of the dissolved sericin in laboratory and pilot-scale trials. This approach solves two problems at once: it lowers the chemical oxygen demand of the wastewater, which can exceed 6,000 mg per liter and is expensive for mills to treat, and it produces a saleable protein powder that can be spray-dried and stored. Optimized chemical-free extraction trials have reported yields between 9 and 18 percent of usable sericin from raw cocoon waste, depending on the temperature, time, and solid-to-liquid ratio used (Kabir *et al*., 2024; Mathew *et al*., 2024).

Biochemical and Functional Properties of Sericin

Sericin is built from 18 amino acids, and its composition leans heavily toward a handful of them. Serine accounts for roughly 32 percent of the protein, glycine around 19 percent, aspartic acid about 16 percent, and alanine close to 11 percent. This serine-rich backbone is unusual among structural proteins and gives sericin many of its functional advantages. Serine, threonine, and asparagine side chains carry hydroxyl and amide groups that bind water molecules tightly, explaining why sericin performs so well as a moisturizer.

The same residues can chelate metal ions and neutralize free radicals, which underlies its antioxidant behaviour.

Molecular weight varies enormously depending on how the protein was extracted, ranging from small fragments of around 10 kilodaltons up to intact chains exceeding 400 KDa. This matters in practice. Higher molecular weight sericin tends to show stronger antioxidant and antibacterial activity, greater viscosity, and better mechanical strength once formed into a gel or film, while shorter fragments process more easily into nanoparticles. Engineers choosing an extraction method are, in effect, choosing which version of sericin's biology they want to keep.

Once recovered, sericin can be cast into thin films, freeze-dried into porous sponges, spun into nanofibers, formed into hydrogels, or precipitated into nanoparticles and microspheres. This flexibility is what allows the same starting material to end up in a wound dressing, a drug capsule, and a face cream, each shaped to suit a different job.

Antioxidant, Antimicrobial, and Biocompatible Nature of Sericin

Three properties do most of the work in explaining why sericin succeeds in living tissue. The first is antioxidant capacity. Sericin scavenges reactive oxygen species, the unstable molecules that damage cell membranes and DNA during inflammation, sun exposure, and aging. Several studies have measured sericin's ability to reduce UVB-induced oxidative damage in skin cells and to lower lipid peroxidation, a marker of cellular stress.

The second is antimicrobial action. Pure sericin shows some inherent inhibition of bacterial growth, and that effect strengthens considerably when sericin is combined with silver nanoparticles or other antimicrobial agents. Research teams have tested sericin-silver nanofiber membranes against *Escherichia coli* and *Staphylococcus aureus*, both common wound pathogens, and recorded strong inhibition of both gram-negative and gram-positive strains (Ma *et al*., 2025).

The third, and arguably most important for medical use, is biocompatibility. Purified sericin supports the attachment and growth of human fibroblasts and keratinocytes in laboratory cultures rather than killing or repelling them. Cytotoxicity testing across multiple studies has found sericin-based scaffolds safe for skin contact and internal implantation when the protein is properly purified to remove residual fibroin fragments, which are the actual source of most silk-related allergic reactions. This distinction matters: silk allergy concerns generally trace back to fibroin contamination, not to sericin itself.

Role of Sericin in Wound Healing and Tissue Regeneration

Wound care is where sericin has moved furthest from laboratory curiosity toward practical product. The protein speeds up healing through several connected mechanisms. It stimulates keratinocytes and fibroblasts, the two cell types responsible for rebuilding skin, to multiply faster. It boosts collagen production, which restores the structural scaffold a wound needs to close properly. It keeps the wound bed moist, a condition now well established as faster and less scarring than letting a wound dry out. And it shortens the inflammatory phase of healing, helping the tissue move into the proliferative, rebuilding phase sooner.

Several formulations have been tested directly against this benchmark. A hydrogel combining sericin with chitosan and silver nanoparticles accelerated wound closure while controlling infection, addressing both healing speed and microbial risk in one dressing. Sericin-coated electrospun nanofibers loaded with silver nanoparticles outperformed commercial wound dressings in burn-healing models, supporting faster closure with confirmed safety in cytotoxicity testing. A combination of sericin, alginate, and aloe vera produced a scaffold with strong blood-clotting, antimicrobial, and blood-vessel-forming properties, useful for both everyday wound care and emergency hemostasis (Ma *et al*., 2025; Mathew *et al*., 2024). Hydrogels made purely from silk sericin have also been tested directly against acute wounds, with promising healing outcomes and good tissue compatibility.

The broader pattern across this research is consistent. Sericin does not simply cover a wound. It actively participates in the biology of repair.

Applications in Drug Delivery Systems and Biomaterials

Sericin has a useful structural quirk for drug delivery: it is amphipathic, meaning parts of the protein chain attract water while other parts repel it. That dual character lets sericin encapsulate both water-soluble and fat-soluble drugs inside the same particle, something many synthetic carriers cannot do as easily.

Researchers have built sericin into nanoparticles, microspheres, hydrogels, and dissolving microneedles, each engineered to release a drug at a controlled rate rather than all at once. One notable example combined sericin nanoparticles with the chemotherapy drug doxorubicin and a light-absorbing dye, creating a system that delivers chemotherapy and heat-based tumor destruction together while sparing healthy tissue, with measurable reductions in tumor growth in animal trials. Microneedle patches built from methacrylated sericin and loaded with silver

nanoparticles have been designed to release antimicrobial silver ions steadily into infected wounds while doubling as a photothermal antibacterial agent. Sericin hydrogels have even carried recombinant proteins, such as lactoferrin, through the digestive tract for oral delivery, protecting the protein from stomach acid long enough to reach the intestine intact (Ma *et al*., 2025).

Beyond drug carriers, sericin has shown promise in nerve repair. Sericin-based nerve conduits implanted in animal models supported nerve regeneration across a gap, with functional recovery approaching that of an autologous nerve graft, the current surgical gold standard. A sericin-alginate interpenetrating network hydrogel has also been engineered specifically as a platform for delivering both cells and drugs together, expanding the protein's reach from passive carrier toward active tissue-support material (Zhang *et al*., 2015).

Sericin in Regenerative Medicine and Tissue Engineering

Tissue engineers build scaffolds that guide cells into forming new tissue, and the scaffold material itself needs to support cell attachment, allow nutrients and oxygen through, and break down at a rate that matches new tissue formation. Sericin checks each of those requirements reasonably well, which has pushed it into bone, cartilage, muscle, and nerve research.

For bone regeneration, sericin has been combined with bioactive minerals to create nanoplatforms that promote both new blood vessel formation and bone cell activity, tested specifically in models of periodontitis-related bone loss. For muscle tissue, a flexible, porous scaffold built from sericin and wool keratin using an in-situ bubble-forming technique created a structure with the mechanical give that muscle tissue engineering requires, an improvement over stiffer, less forgiving synthetic scaffolds. For nerve repair, the conduits described earlier extend the same logic to one of the hardest tissues in the body to regenerate.

A recurring theme across these studies is combination. Sericin rarely works completely alone in advanced tissue engineering; it tends to perform best paired with a second material, fibroin, alginate, chitosan, keratin, or a mineral additive, each contributing a property sericin lacks on its own, such as greater mechanical strength or a specific bioactive signal. The protein functions less like a finished product and more like a highly adaptable base that other materials build upon.

Environmental and Economic Importance of Sericin Utilization

The environmental case for recovering sericin is almost as strong as the medical one.

Degumming wastewater carries a heavy organic load, with chemical oxygen demand readings that can exceed 6,000 mg per liter, well above levels that can be released untreated. Silk mills currently spend money treating this effluent in biological treatment plants before disposal. Every kilogram of sericin pulled out of that wastewater through membrane filtration or precipitation is a kilogram that no longer needs costly treatment, while at the same time becoming a protein powder with market value in cosmetics, pharmaceuticals, and food packaging.

This is a clean fit for circular economy thinking applied to agriculture. Sericulture is fundamentally an agro-based rural industry. India alone practices sericulture across more than 52,000 villages and supports millions of livelihoods, many of them women in smallholder farming households who grow mulberry and rear silkworms as a supplementary income source (Savithri *et al*., 2013). For these households, cocoon sales and raw silk remain the primary income stream, but sericin recovery opens a secondary one, turning a material that currently costs money to dispose of into one that earns money instead. Reeling units that install simple filtration or ultrafiltration systems can sell recovered sericin powder to cosmetic and pharmaceutical buyers, diversifying farm and mill income without requiring any change to silkworm rearing practices upstream.

At a global scale, an estimated 50,000 tons of sericin are generated worldwide every year through silk processing, the overwhelming majority of it still discarded. Capturing even a modest share of that volume for biomedical and cosmetic use would meaningfully reduce both industrial waste and the cost of producing high-value biomaterials that currently rely on more expensive synthetic alternatives.

Challenges in Commercialization and Large-Scale Applications

Despite the promise, sericin has not yet become a mainstream pharmaceutical ingredient, and the reasons are mostly practical rather than scientific. The biggest hurdle is batch-to-batch variability. Sericin extracted by alkaline degumming differs in molecular weight, purity, and biological activity from sericin recovered by hot water or enzymatic methods, and even cocoons from different silkworm races or geographic regions produce protein with slightly different properties. Pharmaceutical regulators expect consistent, well-characterized raw materials, and the silk industry has not historically needed that level of standardization because its main product, the fiber, was never sericin in the first place.

Purification adds further cost. Medical-grade sericin needs to be free of residual fibroin fragments, the actual allergen of concern in silk-related reactions, along with any processing chemicals used in degumming. Achieving that purity reliably at industrial scale requires equipment, such as ultrafiltration membranes or chromatography systems, that many small and mid-sized reeling units in rural sericulture regions simply do not have access to or cannot afford. Regulatory approval pathways for a novel biomaterial sourced from agricultural waste are also less well mapped than those for established synthetic polymers, adding time and cost to bringing any sericin-based medical device to market.

There is also an awareness gap. Many farmers and small-scale silk reelers, who are best positioned to capture sericin at the source, have limited knowledge of its value or the simple equipment changes needed to recover it. Closing that gap will require targeted extension programs, the kind of practical training already used to introduce other value-added sericulture products such as silkworm pupae protein and mulberry leaf extracts.

Future Prospects of Sericin-Based Biomedical Products

The research pipeline suggests sericin's biomedical role will keep expanding rather than plateau. Genetic and biotechnological approaches are being explored to produce recombinant sericin with consistent molecular weight and purity, sidestepping the variability problem that natural extraction currently carries. Three-dimensional bioprinting is another active direction, using sericin-based bio-inks to print patient-specific wound dressings or tissue scaffolds with precise geometry rather than relying on flat sheets or generic shapes.

Combination materials look likely to dominate near-term product development. Pairing sericin with chitosan, alginate, keratin, or synthetic polymers lets formulators dial in exactly the mechanical strength, degradation rate, and drug-release profile a specific application needs, rather than accepting whatever sericin offers alone. Smart wound dressings that change color to signal infection or excess moisture, several of which already incorporate sericin as the base material, point toward a future where wound care becomes diagnostic as well as protective.

For sericulture regions such as Karnataka, Andhra Pradesh, Tamil Nadu, West Bengal, and Jammu and Kashmir in India, or similar mulberry-growing belts in China and Southeast Asia, the opportunity extends past the laboratory. Government extension services and farmer cooperatives that help reeling units install basic sericin recovery equipment, and that connect recovered protein to cosmetic, pharmaceutical, and food-packaging buyers, could turn a

centuries-old agricultural by-product into a genuine second revenue line for an industry that already supports millions of rural households.

Conclusion

Sericin spent most of its industrial history as an obstacle, the sticky coating that had to be washed away before silk could be sold. Three decades of biochemical and biomedical research have rewritten that role entirely. The same properties that once made sericin a nuisance to remove, its water solubility, its film-forming behavior, its resistance to breaking down quickly, now make it valuable for wound dressings, drug carriers, cosmetic formulas, and tissue scaffolds. The science is genuinely strong: documented antioxidant activity, antimicrobial performance when combined with the right partners, low immunogenicity once properly purified, and a track record of accelerating wound healing in both animal and early clinical studies.

What remains is largely a matter of infrastructure and coordination: standardizing extraction, building purification capacity at scale, training farmers and reeling units to capture the protein rather than discharge it, and guiding products through regulatory approval. None of those obstacles are scientific mysteries. They are the ordinary work of turning a proven laboratory material into a commercial one. Given how much of that work is already underway across India, China, Italy, and several other research centers, sericin looks set to move from a research curiosity to a standard ingredient in biomedical and skincare products within the next decade, built on the same cocoons that have supplied silk for thousands **of years.**

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CRYPTOSPORIDIOSIS: A NEGLECTED ZOONOTIC DISEASE

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Introduction

An emerging zoonotic disease of both developed and developing countries is Cryptosporidiosis caused by *Cryptosporidium* spp. (Soulsby, 1982). *Cryptosporidium muris* was first recognised by Tyzzer in 1907 from the gastrointestinal tract of mouse and in 1912 he identified a second species smaller than *Cryptosporidium muris* and named it as *Cryptosporidium parvum*. Since then more than 25 species have been reported from domestic and wild animals, birds, fish, reptiles and humans. Till 1970, the parasite was generally considered non-pathogenic. The first report of human cryptosporidiosis was recorded in a 3 years -old child in USA during 1976, who suffered from severe diarrhoea for two weeks. After that a number of cases have been recorded in immuno-compromised and immuno-competent persons from all over the world including India. In 1993 more than 400,000 people developed diarrhoea during a water-borne outbreak in Milwaukee (Wisconsin) and estimated loss of $64.6 million. It has been estimated that United Kingdom will make expenditure for £23 million/year to meet the requirements for removal of *Cryptosporidium* from the drinking water sources.

In recent years, cryptosporidiosis has come to national attention as a potential cause of water-borne disease in humans, due to contamination of the water supply by infected animal faeces. However, as well as being a potential human disease, cryptosporidiosis is also a significant cause of disease in young animals in the farms.

Cattle are commonly infected with 4 *Cryptosporidium* species worldwide: Cryptosporidium parvum, Cryptosporidium andersoni, Cryptosporidium bovis and

Cryptosporidium ryanae (Fayer et al., 1997 & 2008; Paul et al., 2009). Besides these 4 recognized *Cryptosporidium* species, cattle could be infected with at least 10 *Cryptosporidium* species or genotypes and have been considered the major source for human infections (Xiao and Feng, 2008).

Spread of disease:

Cryptosporidium infection is directly transmitted by ingestion of sporulated oocysts through contaminated feed and water. Cross infection occurs between domestic and laboratory animals and man. Autoinfection also takes place due to excystment of thin wall cyst within the gut of the host (Soulsby, 1982). In human beings, infection usually takes place due to direct contact with infected animals but many cases have been reported with contaminated water supplies. Some outbreaks have also been recorded with treated water supplies that could be due to small size of the oocysts and their resistance to chlorination. Swimming pools and water park wave pools have also been associated with outbreaks of cryptosporidiosis. Untreated river water, pond water or well water used for drinking may be sources of infections.

Life cycle of the parasite:

Cryptosporidium is a monoxenous parasite and its entire life cycle completes within a single host (Soulsby, 1982). Oocyst sporulates within the host and contains four sporozoites. Two types of oocysts are formed. The thick walled oocysts are passed in the faeces/stool whereas the thin walled excyst within the gut and release their sporozoites causing auto infection. After ingestion of sporulated oocysts and their excystation, the sporozoites invade the microvillus brush border of the enterocytes or other tissues such as the respiratory tract and the trophozoites rapidly differentiate to form schizonts with 4-8 merozoites. Two types of schizonts develop. The type I schizonts produce up to eight merozoites that recycle, producing either more first type schizonts or generation of second schizonts. The second schizonts produce four merozoites that become gametocytes. Upon fertilization of the macrogamonts by the micro gametes, zygotes are formed. From zygotes, two different types of oocysts are produced, the thick-walled, which is commonly excreted from the host and the thin-walled oocyst which is primarily involved in autoinfection. Oocysts are infective upon excretion, thus permitting direct and immediate faecal-oral transmission, The extensive recycling of merozoites from type I schizonts or autoinfection within the host is responsible for massive infections.

Pathogenesis by *Cryptosporidium*:

Pathogenesis of cryptosporidiosis varies with immune status of the host. It has been hypothesized that cells of the epithelial mucosa release cytokines that activate resident phagocytes. These activated cells release soluble factors that increase intestinal secretion of water and chloride and inhibit absorption. Cell death is a direct result of parasite invasion, multiplication and extrusion. Cell damage may occur through T cell-mediated inflammation, producing villus atrophy and hyperplasia. Diarrhoea in cryptosporidiosis is due to malabsorption associated with villus atrophy of an immature population of epithelial cells on the surface and occupation of a large portion of the surface area of absorptive cells by the organism. In the neonate of ruminants C*ryptosporidium* frequently occurs concurrent with E. *coli*, rota or corona virus. In the immunodeficient patients developmental stages are not only confined to the gastrointestinal tract but have been reported from lung, pancreas and liver causing respiratory problems, pancreatitis and cholangitis.

Clinical signs:

Cryptosporidiosis is usually seen in calves between one and two weeks of age. It is very rare in animals older than a month old, because by this age most animals may become immune to infection. Clinical disease occurs in neonates and immunologically compromised animals. Older animals are less severely affected. The prepatent period varies between 2-12 days depending on host species (Soulsby, 1982). Profuse watery diarrhoea, abdominal tension and inappetance, resulting in dehydration are symptomatic of clinical cryptosporidiosis. In young ruminants (cattle, sheep and goats) the prepatent period is usually of 2-5 days and is followed by profuse diarrhoea that may persist for 7 days. Many infected calves fail to develop diarrhoea, the reason for this is not known In many cases, *Cryptosporidium* is seen with other diseases, particularly rotavirus infection. In this case disease is often more severe with more affected calves.

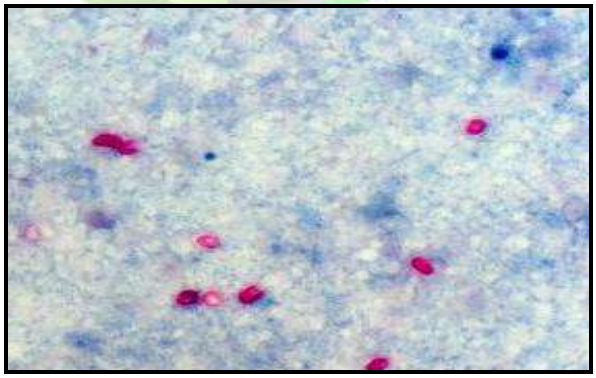
Infection in dogs, cats, small rodents, rabbits, hamsters and guinea pigs normally remains asymptomatic, unless associated with other infections. In turkey and peacock chicks, upper respiratory tract infection of *Cryptosporidium* with 30% morbidity and 20% mortality is on record. In peacock chicks, the symptoms observed are depression, gurgling respiration, coughing, serous ocular discharge and sneezing.

Diagnosis of cryptosporidiosis:

On the basis of the identification of *Cryptosporidium* oocysts in the faecal/stool sample

diagnosis can be made by conventional and immunodiagnostic methods. Several techniques have been tried singly or in combination for the demonstration and identification of *Cryptosporidium*. Oocysts can be directly visualized under phase contrast microscopy after concentration of the stool sample (Soulsby, 1982). Various methods can be used to concentrate oocysts. Sheather's sugar/Zinc sulphate (specific gravity 1.18-1.20) floatation methods, formalin-ether concentration, and formalin-ethylacetate sedimentation are the common methods for concentration of *Cryptosporidium* oocysts in the stool.

- Modified Ziehl-Neelson (MZN) staining method is the most common conventional method for the identification of oocysts in the faeces. Both hot and cold modified Ziehl-Neelson (MZN) staining methods work well for the staining of oocysts (Kumar *et al.,* 2004). Staining can also be done with carbol fuchsin as an alternative quick technique. Modified acid-fast staining may not detect carriers or the patients having mild grade of infection. The patient should only be declared negative if samples are found negative even after 5 to 6 times examination.
- Molecular Genotyping by PCR-restriction fragment length polymorphism (RFLP) and gene sequence analysis showed the presence of all the 4 major *Cryptosporidium* species of cattle, *Cryptosporidium andersoni*, *Cryptosporidium ryanae*, *Cryptosporidium parvum* and *Cryptosporidium bovis*. *C. andersoni* was widely distributed in calves of Tamil Nadu, Karnataka and Puducherry whereas in Andhra Pradesh *C. ryanae* was the major species reported by Venu *et al.* (2012).



(*Cryptosporidium* oocysts (pink colour) in MZN staining)

Treatment:

- Many cases will recover without treatment. If calves become dehydrated then electrolytes should be given.

- In severe conditions, halfuginone can be used to reduce disease severity and prevent spread to other animals.

Prevention and Control:

- Avoid ingestion of infected oocysts by animals. Use clean water for drinking purpose in the farms.
- Treat the infected animals with proper management and avoid contamination of its faeces with the water and feeds.
- For effective control of *Cryptosporidium*, good management and hygiene is vital. The major source of *Cryptosporidium* is left over oocysts from previously infected calves (Soulsby, 1982). These oocysts can be killed by freezing and by composting, but they are very resistant to disinfectants.
- Most commercial disinfectants are ineffective at recommended safe concentrations.
- Hot washing of surfaces followed by thorough drying is effective.

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BIOCHAR: A PROMISING APPROACH TO SOIL HEALTH RESTORATION AND CROP PRODUCTIVITY

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Introduction

Soil health refers to the capacity of soil to function as a living ecosystem within natural and managed land-use systems, sustaining biological productivity, maintaining environmental quality, regulating water flow, cycling nutrients, and promoting the health of plants, animals, and humans. Healthy soils perform essential functions such as supporting plant growth, storing and recycling nutrients, filtering pollutants, buffering environmental changes, and transforming organic and inorganic materials. However, soil health has been declining due to intensive agricultural practices, reduced biomass return to the soil, depletion of soil organic matter, and accelerated decomposition of organic residues. The continuous loss of soil organic carbon has adversely affected soil fertility, crop productivity, and environmental sustainability. Biochar has emerged as a promising soil amendment for restoring soil health and enhancing sustainable crop production. It is a stable, carbon-rich material produced by heating biomass under limited oxygen conditions (pyrolysis) at temperatures ranging from 300 to 1000°C. Unlike natural biomass decomposition or open burning, which rapidly releases carbon into the atmosphere, biochar stabilizes carbon in a recalcitrant form, thereby slowing the carbon cycle and contributing to long-term carbon sequestration. In addition to its role in climate change mitigation, biochar improves the physical, chemical, and biological properties of soil. It enhances soil structure, increases water-holding capacity, improves nutrient retention and availability, stimulates beneficial microbial activity, and promotes better root growth and nutrient uptake. Biochar also helps reclaim degraded and heavy metal-contaminated soils by immobilizing toxic elements such as chromium (Cr), thereby reducing their bioavailability. The application of

biochar not only improves soil fertility and crop productivity but also reduces greenhouse gas emissions from agricultural soils and provides an environmentally sound method for utilizing agricultural and forestry residues. These multiple benefits have generated considerable interest among researchers, extension professionals, and farmers in promoting biochar as a sustainable soil amendment for climate-resilient agriculture and long-term soil health management.

As agricultural science has advanced, plant nutrients have been recognized as essential components of soil health, particularly for sustaining biological productivity. Soil is one of the most valuable natural resources, serving as the primary medium for the production of food, fodder, and fiber. Among the various constituents of soil, carbon plays a pivotal role in maintaining soil health due to its profound influence on physical, chemical, and biological processes. Soil organic carbon contributes to improved soil structure, enhanced water-holding capacity, increased nutrient availability, greater microbial activity, and efficient nutrient cycling, all of which are fundamental for sustainable crop production. Biochar, a carbon-rich material produced through the pyrolysis of biomass under limited oxygen conditions, has emerged as an effective soil amendment. During the pyrolysis process, biomass is converted into three major products: biochar (solid), bio-oil (liquid), and a combustible gaseous mixture known as syngas. Among these products, biochar is particularly valuable for agriculture because of its stability and long residence time in the soil. The application of biochar enhances soil quality by increasing the soil's capacity to retain water and nutrients, thereby improving nutrient use efficiency and reducing nutrient losses through leaching. Essential nutrients such as nitrogen, calcium, potassium, and magnesium are retained more effectively in the root zone, making them readily available for plant uptake. Although biochar is not a fertilizer and supplies only limited amounts of plant nutrients, it acts as an excellent soil conditioner by improving soil physical, chemical, and biological properties. Consequently, biochar contributes to enhanced soil fertility, increased crop productivity, and long-term sustainability of agricultural production systems.

Biochar

Biochar is a stable, carbon-rich material produced by heating organic biomass such as crop residues, wood chips, forestry waste, animal manure, and other agricultural by-products under high temperatures (typically 300–1000°C) in a low-oxygen environment through a process known as pyrolysis. During pyrolysis, most volatile compounds are released, leaving behind a highly porous and chemically stable form of carbon. Due to its unique molecular structure,

biochar is significantly more resistant to biological and chemical decomposition than the original organic material from which it is produced. This stability enables biochar to remain in the soil for decades to centuries, making it an effective means of long-term carbon sequestration while improving soil quality and supporting sustainable agricultural production. Although biochar resembles charcoal in appearance, it differs in its intended purpose and production standards. Biochar is specifically produced for environmental and agricultural applications, particularly as a soil amendment to improve soil health, enhance nutrient and water retention, stimulate beneficial microbial activity, and mitigate climate change through carbon storage. In contrast, charcoal is generally produced as a fuel. Other carbonaceous materials, such as activated carbon and naturally formed black carbon, differ from biochar in their production methods, physical properties, and intended uses, although all are generated by heating carbon-rich materials under varying

Biochar: Types, Applications, and Benefits for Soil Health and Crop Production

Char

Char is the solid carbonaceous residue produced during the thermal decomposition of natural or synthetic organic materials under limited oxygen conditions. It is a general term that includes materials formed during forest fires, biomass burning, and incomplete combustion of fossil fuels. Examples include char produced during wildfires and soot generated from incomplete combustion.

Charcoal

Charcoal is produced by the thermal decomposition of wood and other lignocellulosic materials, primarily for use as a fuel for cooking and heating. Traditional charcoal production occurs at temperatures of approximately 450–500°C in kilns with limited oxygen. Compared with modern pyrolysis systems, traditional methods have lower conversion efficiencies, often yielding only about 10% of the original dry biomass, whereas controlled pyrolysis can achieve yields of 30–35%. In traditional production, the combustible gases and bio-oil generated are usually lost, reducing overall energy efficiency.

Activated Carbon

Activated carbon is manufactured by heating carbon-rich materials at temperatures generally above 500°C, followed by activation using steam or chemical agents to develop an extensive pore structure. It possesses an exceptionally high surface area and adsorption capacity,

making it ideal for applications such as water purification, wastewater treatment, air filtration, and removal of contaminants. Unlike biochar, activated carbon is not commonly used as a soil amendment.

Black Carbon

Black carbon is a broad term encompassing carbon-rich materials formed through the incomplete combustion of biomass and fossil fuels. It includes soot, charcoal, and other refractory organic materials. Because black carbon is produced under a wide range of combustion conditions, its physical and chemical properties vary considerably.

Nutrient Composition of Biochar

The chemical composition of biochar depends largely on the feedstock and pyrolysis conditions. Reported nutrient concentrations include:

- Total carbon: 172–905 g kg^{-1}
- Organic carbon: Generally <500 g kg^{-1}
- Total nitrogen: 1.8–56.4 g kg^{-1}
- Total phosphorus: 2.7–480 g kg^{-1}
- Total potassium: 1.0–58.0 g kg^{-1}

These values vary with the type of biomass used and the pyrolysis temperature.

Biochar Application

Biochar is most commonly applied by uniformly spreading it over the soil surface and incorporating it into the root zone through ploughing or tillage. Application rates depend on soil type, crop, biochar quality, climatic conditions, and management practices. Research studies have demonstrated beneficial effects at application rates ranging from 5 to 50 t ha^{-1} (approximately 0.5–5.0 kg m^{-2}). For maximum effectiveness, biochar is often applied together with compost, farmyard manure, or recommended fertilizers.

Effects of Biochar on Soil Physico-Chemical Properties

Biochar improves several important physical and chemical characteristics of soil:

- Reduces soil bulk density, thereby improving soil structure.
- Increases total porosity, resulting in better aeration and root penetration.
- Enhances water-holding capacity, particularly in sandy soils.
- Improves cation exchange capacity (CEC), increasing nutrient retention.
- Raises soil pH in acidic soils, reducing aluminium toxicity.

- Minimizes nutrient leaching and improves fertilizer-use efficiency.
- Increases the availability of essential plant nutrients.

Even relatively low application rates (around 2% w/w) have been reported to significantly improve soil physical properties.

Effects of Biochar on Soil Biological Properties

Biochar creates a favourable habitat for beneficial soil microorganisms due to its highly porous structure. It enhances:

- Microbial biomass and activity.
- Populations of beneficial bacteria and fungi.
- Arbuscular mycorrhizal fungi (AMF), which improve nutrient uptake.
- Soil enzyme activities involved in nutrient cycling.
- Overall soil biological health and resilience.

These improvements contribute to better nutrient availability, enhanced soil fertility, and sustainable crop production.

Effect of Biochar on Crop Yield

Numerous studies have shown that biochar application increases crop growth and productivity. Benefits include:

- Improved seed germination and seedling establishment.
- Enhanced root growth and nutrient uptake.
- Increased biomass production.
- Higher grain and economic yields.
- Improved fertilizer-use efficiency.

Long-term field experiments indicate that the benefits of biochar become more pronounced over successive cropping seasons as it integrates into the soil system.

For example, research conducted at the Indian Agricultural Research Institute (IARI), New Delhi, demonstrated that the application of 1.9 t ha^{-1} wheat straw biochar along with the recommended fertilizer dose (180:80:80 kg $N_2O_{52}O$ ha^{-1}) significantly increased maize yield in Inceptisol soils.

Biochar and Carbon Sequestration

One of the most important environmental benefits of biochar is its ability to sequester carbon in soils. During photosynthesis, plants absorb atmospheric carbon dioxide (CO_2) and

convert it into biomass. When this biomass is converted into biochar through pyrolysis, a substantial portion of the carbon becomes highly stable and resistant to decomposition.

By incorporating biochar into agricultural soils:

- Carbon is stored in the soil for decades to centuries.
- Atmospheric CO_2 concentrations are reduced.
- Greenhouse gas emissions such as methane (CH_4) and nitrous oxide (N_2O) are lowered.
- Soil organic carbon stocks are increased.
- Climate change mitigation and sustainable agriculture are promoted simultaneously.

Thus, biochar transforms agricultural residues into a valuable resource while creating a long-term carbon sink.

Sequestering 'biochar' in soil, which makes soil darker in colour (Lehmann, 2007)



Conclusion

Maintaining soil health is essential for ensuring sustainable agricultural productivity, environmental quality, and food security. Biochar has emerged as a promising soil amendment that improves the physical, chemical, and biological properties of soil while contributing to long-term carbon sequestration. Its application enhances nutrient retention, increases cation exchange capacity, improves soil structure and water-holding capacity, reduces soil acidity and nutrient losses, suppresses greenhouse gas emissions, and stimulates beneficial soil microbial activity. These combined benefits result in improved soil fertility, higher crop productivity, greater resilience to climate change, and more sustainable farming systems. Consequently, biochar represents an effective strategy for restoring degraded soils, improving resource-use efficiency, and supporting climate-smart agriculture.

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EXOTIC VEGETABLES: A COLOURFUL REVOLUTION ON OUR PLATES

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Introduction

The demand for exotic vegetables has increased rapidly in recent years, revolutionising urban kitchens and modern agriculture. Earlier these vegetables were associated with international cuisines and premium restaurants but now these are being grown and consumed in India especially in urban and peri-urban areas. Exotic Vegetables are an important part of a healthy and diversified diet, not only because they make dishes more appealing on the eyes, but also because they have better nutritional value and unique flavours.

What are Exotic Vegetables?

Exotic Vegetables are vegetables of less common or non-native origin. They are foreign but are successfully grown under local conditions. These crops are mainly introduced to meet the growing demand of hotels, restaurants and health conscious consumers. Examples that are popular include broccoli, lettuce, zucchini, cherry tomato, red cabbage, baby corn, asparagus and coloured capsicum.

Nutritional and Health Benefits

Exotic Vegetables are often considered nutritional powerhouses. They are packed with vitamins, minerals, antioxidants and dietary fibre. For example, broccoli has Vitamin C and cancer fighting compounds and lettuce provides important hydration and fibre. Cherry tomatoes are a good source of nutrition. They are rich in lycopene, a powerful antioxidant which has a positive effect on heart health. Consumption of these vegetables in daily meals helps us to

increase immunity, enhances digestion and reduces the risk of chronic diseases.



Scope of Cultivation in India

India's varied agro-climatic conditions offer excellent scope for cultivation of exotic vegetables. Protected Cultivation techniques such as polyhouse, shade nets and hydroponics have helped in easy and efficient cultivation of these crops. In some of the states like Karnataka, Maharashtra, Tamil Nadu and Himachal Pradesh, exotic vegetables are being produced. The high market value and export potential of these crops have led to an increasing number of farmers shifting towards them.

Role in Modern Agriculture

Exotic Vegetables are heavily depended on by modern agriculture as they promote diversification and increase the income of the farmers. These crops have shorter growing periods and higher yields than traditional vegetables. They are also appropriate for urban agriculture, vertical farming and rooftop gardening that contribute to sustainable agricultural practices.

Challenges in Cultivation

Cultivation of exotic vegetables has many problems like high cost of production due to requirement of quality seed and protected cultivation structure. These crops are climate sensitive and require proper irrigation, nutrient management and technical knowledge for successful production. They are also prone to pests and diseases and have a short shelf-life, so post-harvest handling and cold storage is important. Moreover, their profitability and adoption might be impacted by price changes within the market and consumer knowledge gaps in certain areas.

Market Demand

The demand for exotic vegetables in the market is gradually increasing due to changing

life styles, increasing health consciousness and growing preference for international cuisines. The main consumers of these vegetables are hotels, restaurants, supermarkets and online grocery platforms. Rising urbanisation coupled with higher disposable income has further broadened the market, making cultivation of exotic vegetables a profitable proposition for farmers.

Conclusion

Exotic Vegetables are gaining popularity due to high nutritional value, unique taste and increase market demand. Farming them provides an opportunity to earn more for the farmers and also to satisfy the needs of health-conscious consumers and food industry. They have a great potential to contribute to sustainable agriculture and nutritional security in the future with improved cultivation practices, protected farming and better market access.

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GLOBE ARTICHOKE (*CYNARA SCOLYMUS* L.): AN UNDERUTILIZED FUNCTIONAL VEGETABLE CROP

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Abstract

Globe artichoke (*Cynara scolymus* L.) is a nutrient-rich perennial vegetable crop belonging to the family Asteraceae and is recognized as one of the most valuable functional foods because of its exceptional nutritional and therapeutic properties. Although widely cultivated in Mediterranean countries, it remains underutilized in many parts of the world despite its considerable potential for enhancing nutritional security, crop diversification, and sustainable horticulture. The edible immature flower buds are an excellent source of dietary fiber, vitamins, minerals, and bioactive phytochemicals, including phenolic compounds, flavonoids, cynarine, and inulin, which possess antioxidant, hepatoprotective, anti-inflammatory, hypocholesterolemia, antidiabetic, and prebiotic activities. In addition to its nutritional significance, globe artichoke has gained increasing attention from the pharmaceutical, nutraceutical, and food-processing industries due to its wide range of health-promoting compounds. The crop is also valued for its adaptability to temperate environments, relatively low input requirements, and potential role in sustainable agriculture and climate-resilient farming systems. However, limited awareness, inadequate availability of quality planting material, and insufficient research on cultivar improvement and production technologies have restricted its wider adoption, particularly in developing countries. This review highlights the botanical characteristics, origin and distribution, nutritional composition, phytochemical profile, health benefits, cultivation practices, economic importance, and future prospects of globe artichoke. Promoting research, conservation, and

commercialization of this underutilized vegetable crop can contribute significantly to functional food production, dietary diversification, and the development of resilient horticultural systems, while creating new opportunities for farmers and the food industry.

Introduction

Artichoke (*Cynara scolymus* L.) is an herbaceous plant belonging to Asteraceae family, native to the Mediterranean (North Africa and southern Europe) and extensively cultivated in Italy, Spain, Egypt, and Morocco. In fact, according to FAOSTAT, 1.5 million tons of artichokes were produced globally in 2020, being Italy and Egypt the principal two producers worldwide. It is cultivated primarily for its large, edible immature flower buds, which are valued for their delicate flavor, tender texture, and exceptional nutritional and medicinal properties. Globe artichoke is recognized as a functional food due to its rich composition of dietary fiber, vitamins (particularly vitamin C and folate), minerals, and bioactive compounds such as phenolics, flavonoids, and cynarin. These compounds exhibit strong antioxidant, hepatoprotective, hypocholesterolemia, and digestive health-promoting properties, making the crop increasingly important in both nutrition and pharmaceutical industries. The edible flower buds are consumed fresh, canned, frozen, or processed into value-added products.

Artichoke is a high nutritional value food and has several known beneficial effects. Regarding the nutritional composition, artichoke is low in calories, carbohydrates and lipids, it mainly contains water (85%) and is a good source of fibers (5%). Potassium is the principal mineral aside from phosphor, sodium, magnesium and calcium, and it is also a source of vitamin C, folates and other vitamins of the B complex (biotin, niacin, and pyridoxine) and carotinoides. Traditionally, artichoke has been used as a medicine to treat hepato-biliary disease and indigestion problems. In previous studies, extracts of artichoke heads and leaves have shown a reduction in cholesterol and blood pressure and prevented atherosclerotic deposits, which contribute to the prevention and treatment of coronary heart diseases. Antioxidant, anti-inflammatory, hepatoprotective and anti-cancer effects have also been demonstrated.

In recent years, the cultivation of globe artichoke has gained attention because of the growing demand for healthy foods and nutraceuticals. Improvement in cultivars, optimized crop management practices, and advances in breeding and biotechnology have enhanced its productivity and adaptability. Consequently, globe artichoke has emerged as a high-value

vegetable crop with significant economic, nutritional, and medicinal importance, offering considerable potential for diversification of horticultural production and sustainable agriculture.



Fig. Artichoke plant

Botanical Description

Rank	Classification
Kingdom	Plantae
Division	Magnoliophyta (Angiosperms)
Class	Magnoliopsida (Dicotyledons)
Order	Asterales
Family	Asteraceae (Compositae)
Genus	*Cynara*
Species	*Cynara cardunculus* var. *scolymus*
Synonym	*Cynara scolymus* L.
Chromosome Number	2n = 34

Morphological characters

Globe artichoke (*Cynara cardunculus* var. *scolymus* L.) is a robust, herbaceous perennial vegetable belonging to the family Asteraceae. The plant develops a deep taproot system with numerous lateral roots, enabling efficient uptake of water and nutrients and allowing it to survive

for several years under favorable conditions. It produces an erect, stout, and branched stem that may attain a height of 1.0–2.0 m. During the vegetative phase, the plant forms a large basal rosette of alternate, deeply pinnatifid leaves that are grayish-green in color due to the presence of fine pubescence.

Root system

Globe artichoke possesses a deep, strong taproot accompanied by numerous fibrous lateral roots that enable efficient absorption of water and nutrients. The extensive root system also contributes to drought tolerance and perennial growth.

Stem

The plant develops a stout, erect, branched stem that reaches 1.0–2.0 m in height. The stem is ridged, green to grayish-green, and supports several large flower buds.

Leaves

Leaves are large, alternate, deeply lobed (pinnatifid), and grayish-green due to a dense covering of fine hairs (pubescence). Basal leaves may grow up to 80–100 cm long, while upper leaves are comparatively smaller and less dissected. The foliage forms a rosette during the vegetative stage.



Fig. Artichoke morphological characters

Reproductive characters

Characteristic	Description
Flower type	Bisexual, complete, epigynous
Inflorescence	Capitulum (head)
Pollination	Predominantly cross-pollinated by insects, especially bees

Flower colour	Violet to bluish-purple
Edible part	Fleshy receptacle (heart) and the tender basal portions of the involucral bracts
Reproductive nature	Perennial crop, generally propagated vegetatively through suckers, offshoots, or crown divisions to maintain varietal uniformity

Table. Floral and Reproductive Characteristics of Globe Artichoke

Inflorescence

The inflorescence is a solitary **terminal capitulum** (flower head), characteristic of the family Asteraceae. It consists of numerous sessile florets arranged on a thick, fleshy receptacle and enclosed by overlapping fleshy involucre bracts. The immature flower bud is the edible portion.

Flowers

Individual florets are tubular, bisexual, and predominantly violet to bluish-purple in colour. Each floret contains five fused petals, five stamens with syngenesious anthers, and a bicarpellary inferior ovary. Flowering occurs if buds are not harvested.

Fruit

The fruit is a dry, indehiscent cypsela (commonly referred to as an achene), usually brown to black in colour and crowned with a persistent pappus that aids in wind dispersal.

Seeds

Seeds are oblong, compressed, and grayish-brown to black. Although viable, seed propagation often results in genetic variability; therefore, commercial cultivation commonly relies on vegetative propagation through suckers, offshoots, or tissue culture.



Fig. Floral morphology of Artichoke

Nutritional Value of Globe Artichoke

Globe artichoke is regarded as a highly nutritious functional vegetable owing to its rich composition of essential nutrients and health-promoting phytochemicals. The edible flower buds are low in calories and fat while providing appreciable amounts of dietary fiber, carbohydrates, and plant proteins. They are an excellent source of vitamins, particularly vitamin C, folate (vitamin B9), vitamin K, and small amounts of vitamins A, E, and B-complex vitamins. Globe artichoke also supplies important minerals such as potassium, magnesium, phosphorus, calcium, iron, and manganese, which contribute to normal physiological functions and overall health.

One of the most remarkable nutritional attributes of globe artichoke is its abundance of bioactive compounds, including phenolic acids, flavonoids, cynarin, chlorogenic acid, luteolin, and the prebiotic carbohydrate inulin. These compounds possess strong antioxidant properties that help neutralize free radicals and reduce oxidative stress. Inulin promotes the growth of beneficial gut microorganisms, thereby improving digestive health and mineral absorption. Additionally, cynarin and chlorogenic acid have been associated with hepatoprotective, hypocholesterolemic, anti-inflammatory, antidiabetic, and cardioprotective effects, making globe artichoke an important ingredient in functional foods and nutraceutical products.

The unique combination of nutrients and phytochemicals makes globe artichoke a valuable dietary component for promoting human health and preventing chronic diseases. Regular consumption has been linked with improved liver function, better cholesterol metabolism, enhanced gastrointestinal health, and reduced risk of cardiovascular diseases. Owing to its nutritional richness and therapeutic potential, globe artichoke is increasingly recognized as a functional vegetable crop with significant applications in the food, pharmaceutical, and health industries, supporting both nutritional security and healthy dietary patterns.

Economic Importance and Uses of Globe Artichoke

Globe artichoke (*Cynara cardunculus* var. *scolymus* L.) is an economically important high-value vegetable crop cultivated for its edible immature flower buds, which are marketed as fresh, frozen, canned, or processed products. Owing to its premium market value and increasing consumer preference for functional foods, the crop offers attractive income opportunities for farmers, particularly in temperate and Mediterranean regions. In addition to fresh consumption, globe artichoke is widely utilized in the food-processing industry for the preparation of salads,

soups, dips, pizzas, pasta dishes, pickles, and ready-to-eat products. The crop also has considerable export potential due to the growing global demand for healthy, nutrient-dense vegetables. Furthermore, its leaves and processing by-products can be used as livestock feed, compost, or as a source of natural bioactive compounds, thereby enhancing resource-use efficiency.

Beyond its culinary value, globe artichoke has significant importance in the pharmaceutical, nutraceutical, and herbal medicine industries. The leaves and flower heads contain bioactive compounds such as cynarin, chlorogenic acid, flavonoids, and inulin, which are extracted for the production of dietary supplements, herbal formulations, functional beverages, and medicinal preparations. These compounds exhibit antioxidant, hepatoprotective, hypocholesterolemic, anti-inflammatory, antidiabetic, and digestive health-promoting properties. The increasing demand for plant-based nutraceuticals and natural antioxidants has expanded the commercial value of globe artichoke, making it a promising crop for value addition, agro-industrial development, and diversification of sustainable horticultural production systems.

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BUILDING RESILIENCE IN SUGARCANE PRODUCTION AMIDST GEOPOLITICAL DISRUPTIONS

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Introduction

Imagine a scenario when a farmer visits the fertiliser shop only to find that fertiliser prices have doubled. The reason is not local; it begins thousands of kilometers away in conflict zones such as Ukraine and West Asia. How can Indian sugarcane farmers protect themselves from such global shocks? This article sheds light on the biological interventions to sustain sugarcane production in India, jeopardised due to the rising cost of fertilisers and declining soil health.

Sugarcane, a member of the family Poaceae is an important commercial crop worldwide. Several thousand farming families rely solely on sugarcane for their livelihood. Sugarcane is the main source of sugar, jaggery and ethanol in tropical countries. It is a nutrient exhaustive crop demanding a huge quantum of fertilisers to achieve its yield potential. Unanticipated geopolitical crises such as the hostilities between Russia-Ukraine, and the USA-Iran have caused the *Domino* effect. One such causality is the agriculture sector with peaking fertiliser rates by almost 200% worldwide. Developing countries including India, heavily rely on import of chemical fertilisers, spiking the cost of subsidies and/or cultivation. Beyond this latest woe, excessive use of chemical inputs, monocropping, intensive cultivation, and poor drainage are some of the reasons for declining soil health in India.

Sugarcane, a Glutton for Nutrients

As of 2026, India grows sugarcane in nearly 56.9 lakh hectares, with an average productivity of 83.5 t ha^{-1}. Sugarcane is a nutrient exhaustive crop, taking up great amounts of

essential elements in the order of potassium (K) > nitrogen (N) > sulphur (S) > phosphorus (P) > magnesium (Mg) > calcium (Ca). The luxuriant habit of sugarcane, a long duration crop (12 - 18months), warrants intensive application of inputs, especially, water and chemical fertilisers to achieve the targeted yield. Similar to many field crops, sugarcane is highly dependent on the major nutrients N, P and K for normal growth and development (Table 1). Following the 4R nutrient stewardship, application of the right amount of nutrient, in the right form, at the right time and right place is more important for sugarcane than just adding excess. Excessive application specifically of nitrogenous fertilisers renders the crop vulnerable to pest and diseases, and also delays ripening. Fertiliser recommendation for sugarcane in tropical India is 250-350, 75-170, 80-190 kg ha^{-1} NPK, while in sub-tropical states, it is 150-250, 60-80, 40-120 kg ha^{-1} NPK. In India, across the major agricultural crops, farmers apply higher dose of N, recommended dose of P and lower dose of K than the recommended levels.

The current soil organic carbon (SOC) in India is 0.3 to 0.5%, while the desirable level is 1.5% or above. Less water retention, poor microbial diversity, and inefficient nutrient cycling has increased dependence on chemical inputs for yield improvement. This article throws light on the interventions to build resilience to sugarcane production systems, to reduce the dependence on chemical fertilisers and offer sustainable solutions to improve the soil health.

Table 1 Major nutrients required for sugarcane growth and yield

Nutrient	Biological function	Effect of deficiency	Recommended dose in India
Nitrogen	Leaf and stem growth, photosynthesis	Stunted growth, yellow leaves, fewer number of millable canes	150 to 350 kg N ha^{-1}
Phosphorus	Root development, early establishment	Poor tillering, weak ratoons	60 to 170 kg P_2O_5 ha^{-1}
Potassium	Water regulation, sugar transport to stalks	Poor juice quality, more susceptible to stress	Up to 200 kg K_2O ha^{-1}

From Green Revolution to Fertiliser Dependence

It is a story that started in the 1960s, when India, in order to circumvent the severe food shortage crisis, adapted to the Green Revolution. New high yielding varieties were not only productive and successful, but also reliant on fertiliser application. Governments heavily

subsidized chemical fertilisers to increase adoption among farmers. Luckily, food production went up incredibly high to help India gain food security. But on the flip side, soil health declined due to indiscriminate use of fertilisers alongside unavailability or high cost of organic manures. Today, it is ironic that application of chemical fertilisers is essential even to realise the baseline yield in major agricultural crops. India spends around 1.74 lakh crore rupees every year on chemical fertilisers, most of which are imported from other countries. Despite having the technical capability to produce urea, India relies on natural gas from countries like Qatar for urea manufacture. Further, India depends on countries such as China, Saudi Arabia, and Morocco for import of diammonium phosphate (DAP), a major fertiliser used in Indian farms.

When Global Conflicts Raise Fertiliser Bills

Russia is the world's biggest fertiliser exporter. Together with Belarus, it supplies about 40% of global potash. As a single country, Russia supplies 16% of global nitrogen fertilisers. When war started in February 2022, global fertiliser markets were severely affected. Prices went up by nearly 50% in just two months. By end of 2022, prices had increased almost 200% from 2020 levels. Globally, around 27 million people were forced to poverty due to the crisis of rising food and fertiliser prices.

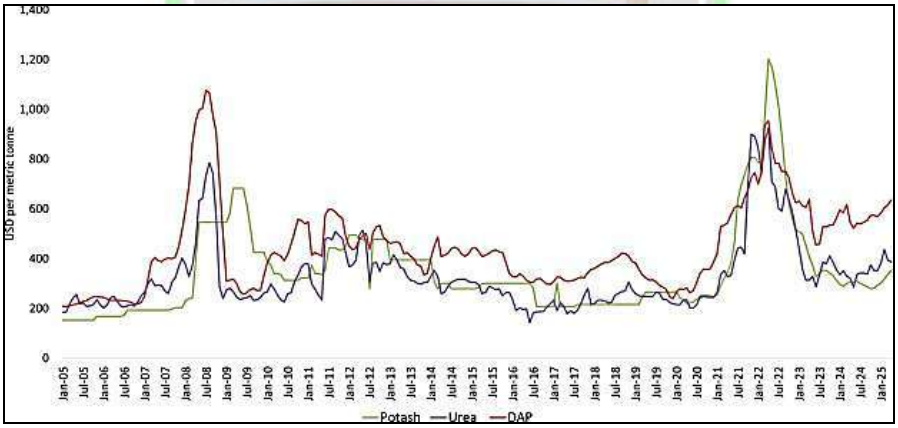


Figure 1 Trend in international prices for potash, urea and DAP from 2005 to 2025

(Source: Yao and Hernandez, 2026)

Fertiliser prices are highly volatile and have exhibited important spikes over the past years, particularly during the 2008 global food crisis and 2022 energy crisis (Fig. 1). India's domestic urea factories run on natural gas, most of them comes from Qatar. Issues in West Asia conflict, sanctions, or trade breakdown directly hits India's urea manufacturing. This situation is different from the Russia-Ukraine situation, wherein prices escalated. But in this case the actual

physical supply of fertiliser could be affected. Even small shortages cause serious problems. In states like Andhra Pradesh and Maharashtra, even 10 to 15% shortage created long queues, and stress for farmers, warranting immediate efforts to strengthen our inherent soil productivity by adopting various sustainable solutions.

The Silent Crisis Beneath Our Feet

A healthy soil holds a balanced proportion of nutrient ions, organic matter, earthworms and microorganisms like bacteria and fungi. Microorganisms break down the dead plants and animals into a simpler form, which enriches the soil, and increases the bioavailability of nutrient ions for plant uptake by roots. SOC, an important indicator of soil health is running at about one quarter of the preferable value in Indian soils. Indiscriminate use of chemical inputs over the years since the Green Revolution is a pivotal point, as SOC is not the only component of soil health, but it is often the foundation upon which many other functions depend (Fig. 2). Excessive use of chemical fertilisers, continuous cropping in the same land (foregoing the benefits of a fallow year), deep ploughing, loss of biodiversity due to pesticide misuse, soil encroachment and reduced use of organic manures have together severely reduced agricultural productivity. Low water retention weakens microbial activity and increases nutrient loss, forcing farmers to use additional chemical fertilisers, which further results in the soil degradation, creating a vicious cycle of cause-and-effect.

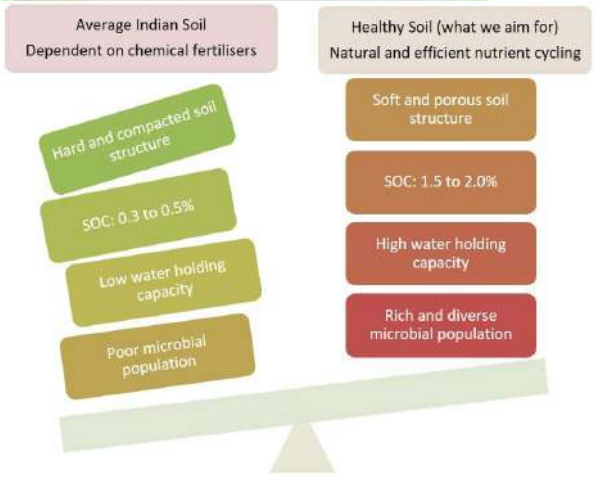


Figure 2 Comparison of soil health indicators in Indian soils against the ideal

Interventions to Sustain Sugarcane Production

Biofertilisers are environment-friendly products containing living microorganisms like bacteria and fungi, which increase the bioavailability of nutrient ions in the rhizosphere, in turn

aiding plant uptake from unavailable and fixed sources. These microorganisms work in cohesion with plant roots, rhizosphere and surrounding soil layers to mine the inherent nutrient ions. N fixing bacteria such as *Gluconacetobacter diazotrophicus, Azospirillum brasilense,* and *Herbasprillum* sp. fix N from the atmosphere, while P solubilising bacteria including *Bacillus megatherium* and *Pseudomonas striata* mobilise phosphate ions from fixed sources, and enhance plant uptake. Plant growth promoting bacteria like *Pseudomonas fluorescens* produce phytohormones that modify the root architecture and morphology.

Table 2 Organic inputs and their benefits for sugarcane

Input	Nutrient content	Primary benefit	Recommendation in sugarcane
Filter press mud	N, P, K, Ca, Fe, Organic matter	Circular nutrient return; rebuilds soil carbon	20 to 25 t ha^{-1} before planting
Farm yard manure/ Compost	Organic carbon, macro and micronutrients	Rebuilds soil biological activity	12.5 t ha^{-1} (FYM) or 25 t ha^{-1} (compost) before planting
Green manure crops (eg.: Danicha, Sunhemp)	Biological N fixation	Adds N and organic matter at low cost	Raised in fallow land, or as intercrops, incorporated before seed setting
Sugarcane trash	N, P, K, micronutrients	Carbon addition, surface mulching, prevent weed growth, increase water retention	8 to 10 t ha^{-1}, spread uniformly between the rows
Leguminous crop residues	Residual soil N from nodules	Reduces N demand of following crop	Crop rotation

Mycorrhizal fungi such as *Rhizophagus irregularis* and *Funneliformis mosseae* colonise roots and increase the root exploratory network, aiding uptake of water and nutrients. Several reports confirmed the effectiveness of biofertiliser inoculation in sugarcane, which helped to reduce application of chemical fertilisers without compromising on cane yield in India. Meanwhile, studies from Brazil reported that commercial sugarcane varieties contributed 60 to

80% of biological N fixation, with 95% reduction in N leaching. Organic amendments that replenish the SOC of Indian soils is the key to sustenance of beneficial microorganisms, in turn aiding effective nutrient cycling in the rhizosphere (Table 2).

Restoring Soil, Securing Sugarcane

Sugarcane farmers of India need to wake up to the harsh reality that we can no longer rely on global supply chains to meet the requirement of fertilisers. Considering the urgency to address the declining soil health and environmental sustainability, outreach programmes such as the *Campaign on Balanced Use of Fertilisers*, and *Kheti Bachao Abhiyan* are being upscaled to sensitise every individual farmer in India. Here is the good news: the solution isn't some unrealistic, expensive technology from another realm; it's right under our feet. By utilizing the existing knowledge, the first step would be to restore the soil health and productivity by increasing organic amendments, followed by shifting focus towards crop rotation and intercropping of sugarcane with leguminous crops. Under such a scenario, reducing the dose of chemical fertilisers and compensating with biofertilisers would aid in sustaining the yield of sugarcane. This isn't just a theory; agricultural scientists are working towards such sustainable solutions to help the farming community in India. The next fertiliser crisis may not be far away. Every tonne of press mud applied, every green manure crop incorporated, every layer of trash retained in the field, and every biofertiliser inoculated is an investment in building resilience. The future of sugarcane may depend less on chemical fertiliser and more on the living biology beneath our feet.

Acknowledgement

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GENDER ISSUES IN FARMING: CHALLENGES AND NEEDED INSTITUTIONAL INTERVENTIONS

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Introduction

The feminisation of agriculture has resulted in more of our women doing farm operations in rural India. From being a primary work force, off late their structural shift towards skilled labour has seen their increase in proportion from 48 percent in 2018 -2019 to 59.4 percent in 2023 revealing that they are more involved or employed in specialised farm operations in our nation. On the other hand, the stastical figures also reveal that the women participation is very higher to the tune of 50 percent in the cultivation of commercial crops like cotton, sugarcane, tea, coffee and cashew. However, the lack of comprehensive gender sensitive land policy has resulted in states playing an important role in the redistribution programmes.

Often single women, widows, women without formal documentation who needed land as a vital resource or asset are left out in this development process. This has resulted in women getting very limited land-owning rights which also inhibits their access to capital resources for carrying out farm related operations in rural areas of our nation. On the other hand, with the present-day climate change issues becoming the new normal these farm issues are affecting the farm production and productivity in a big way. Being dependent on men or their family members for taking up farm decisions or for carrying out farm operations in time has made climate resilient farming a herculean task.

Women farmers

The women farmers from SC / ST communities in rural areas and hilly tracts face even more discrimination in their access to resources due to their many limiting factors and social handicaps like poor education, access to institutional credit and health facilities, besides cultural

and social diversity issues with the census figures of 2011 revealing that the less literacy rate among the tribal women as 49.4 percent compared to the national female literacy rate of 64.63 percent. However, the evidences of gender-based development from Kerala's Kudumbashree program reveals that community led development involving the panchayat raj institutions has assisted women in attaining gender equality and economic freedom.

Gender Inequality Index (GII)

The present Gender Inequality Index (GII) places our nation at the 122nd out of 191 countries. Similarly, the Global Gender Gap Index (GGGI) ranks India at 135th rank out of 146 countries. These reports highlight the failure or deficiency of our women development or assistance programmes in meeting the needs, requirements, priorities and productive investments to be made to inform, educate, empower and finance their economic ventures with access to improved training and marketing facilities. Our public health care infrastructure also needs to be further strengthened particularly in rural areas as our maternal mortality rate of 103 deaths per 100, 000 live births have to be drastically reduced in the near future.

Mahila Sakthi Kendra Scheme

The present day Mahila Sakthi kendra initiatives of empowering women through community-based interventions by providing them access to information, resources and government schemes if implemented involving the panchayat raj institutions in rural areas is sure to bring about a remarkable transformation in the near future. The budgetary allocation of 3 lakhs crores to Nari Sakthi program needs to be imparted in our informal sectors of our nation where majority of women employed in urban and rural areas and have very limited or less social participation.

Conclusion

So, to improve the women access to farm assets and to reduce the present-day unequal access to land and other productive assets which remains as a steady barrier for the economic upliftment of women in rural areas of our nation more policy reforms are the need of the hour. With nearly 66 percent of women lacking on land ownership rights in their names and with land being serving as a colleterial security for accessing farm credit, more struggles needed to be organised involving women organisations, farm trade unions, peasant organisations to bridge this long standing gender gap in rural areas of our nation and ensure that unequal access to land does

not remain as a hurdle or impediment towards the climate resilient farming advocated by central and state governments

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MICROALGAE-INTEGRATED BIOFLOC SYSTEMS WITH AGRICULTURAL WASTE-DERIVED CARBON FOR SUSTAINABLE *LITOPENAEUS VANNAMEI* CULTURE

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Introduction

Global shrimp production is growing fast. World output is projected to rise by around 6% to roughly 5.8 million metric tonnes by the end of 2025 (Kontali Analyse, 2024). India is a major contributor to this growth, producing an estimated 716,004 MT, with production concentrated in coastal states such as Andhra Pradesh, Gujarat, Odisha, and Tamil Nadu. Andhra Pradesh alone accounts for nearly 456,300 MT, most of it from the Nellore and Prakasam belts (MPEDA, 2024; Rajesh et al., 2024). This expansion has not been without setbacks. Tridge Insights (2024) projects a decline of close to 20% in Indian *L. vannamei* production in 2024, driven by a combination of softer export demand, rising input and energy costs, and disease pressure on farms pressures that together squeeze both supply and farmer margins. This shortfall highlights how sensitive the sector still is to production shocks, even as global demand keeps climbing.

Part of the problem lies in how intensively shrimp are now farmed. As stocking densities have increased, water quality has come under growing strain. Rising organic loads have created favourable conditions for disease, and problems such as vibriosis, white gut, and white faecal disease are now recurring in *L. vannamei* culture systems (Feed Planet, 2025). Improving farming technologies, culture conditions, and production efficiency has therefore become essential for the long-term sustainability of the industry (Kumar et al., 2018). Biofloc technology (BFT) has been used since the 1990s to raise shrimp productivity. Even so, conventional intensive aquaculture still carries real environmental costs. Feed inefficiency and the build-up of excreta and uneaten feed generate ammonia and nitrite, both of which weaken shrimp immunity and raise the risk of disease outbreaks and the economic losses that follow (Zhang et al., 2025). Beyond the pond itself, intensive culture can degrade coastal habitats and introduce non-native

species (Krummenauer et al., 2020). Fry quality, feed quality, environmental management, and disease control particularly viral and bacterial threats remain the key factors determining farm output (Lee et al., 2022).

BFT offers a genuinely sustainable alternative to conventional systems (Khanjani et al., 2024). It works by encouraging bacteria, algae, and protozoa to form microbial aggregates biofloc that absorb and recycle nutrients and organic matter in the water column, while doubling as a supplementary food source for the shrimp (Ji et al., 2022). The water savings are striking: BFT uses only about 100 L of water per kilogram of shrimp produced, compared with roughly 64,000 L in conventional systems (Zhang et al., 2025). It also supports higher stocking densities and better feed efficiency, helped along by low-salinity culture techniques. Biofloc itself is a nutrient-dense food source, contributing an estimated 29–32% of shrimp growth in BFT systems (Crab et al., 2012), by converting waste nitrogen into microbial biomass through careful management of the carbon-to-nitrogen (C:N) ratio. The outcome is better water quality, an additional natural protein source for the shrimp, and compared with conventional farming improved growth, feed efficiency, biosecurity, profitability, and environmental performance (Kumar et al., 2018).

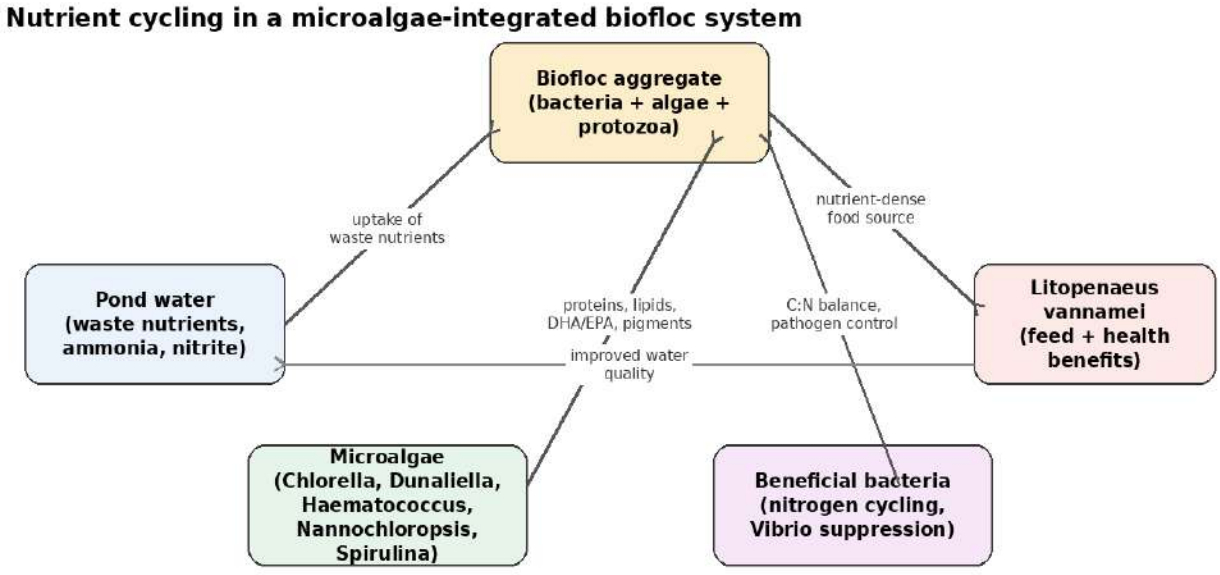


Figure 1. Nutrient cycling in a microalgae-integrated biofloc system — microalgae and beneficial bacteria take up waste nutrients from pond water and convert them into a nutrient-dense food source for shrimp, while stabilising water quality and suppressing

pathogens. (Author's own compilation, based on concepts from Ji et al., 2022; Jiménez-Ordaz et al., 2021; Pacheco-Vega et al., 2018.)

Integration of Microalgae in Biofloc Systems

The rapid, worldwide expansion of *L. vannamei* farming has brought disease outbreaks that have cost the industry heavily. Adopting environmentally sound, biosecurity-focused management practices is now essential to managing this risk (Ferreira et al., 2015).

One way to strengthen biofloc's performance is to bring naturally occurring (native) microalgae and beneficial bacteria into the system, rather than relying solely on costly commercial probiotics (Kumar et al., 2018). Microalgae add proteins, lipids, and fatty acids notably DHA to the biofloc, while also helping remove nitrogen, stabilise water quality, and suppress pathogens. In practical terms, microalgae take up waste nutrients from the water and release oxygen through photosynthesis, which in turn supports the bacterial community; compounds they release help bind and stabilise floc particles, improving both water quality and system performance.

Specific species illustrate this potential well. *Haematococcus pluvialis* and *Dunaliella salina* are valued for their carotenoid content astaxanthin and β-carotene respectively which strengthens antioxidant capacity and immune response in cultured shrimp. *Chlorella vulgaris* and *Scenedesmus* species are prized for their protein and vitamin content and are widely used to enrich live feeds during larviculture. *Nannochloropsis* sp. and *Phaeodactylum tricornutum* are important sources of the omega-3 fatty acid EPA, while *Schizochytrium* sp. is a leading natural source of DHA both essential for membrane integrity and growth performance in aquaculture species (Tocher, 2015). *Arthrospira platensis* (Spirulina) contributes phycocyanin, a pigment-protein with antioxidant and immune-stimulating properties. Diatoms such as *Grammatophora* and *Navicula* further diversify the food resources available within the floc and support beneficial microbial communities (Ferreira et al., 2015).

Bacteria play a complementary role. Given their metabolic diversity, several species act as effective water-quality regulators and are themselves nutrient-rich additions to aquaculture diets (Gamboa-Delgado & Márquez-Reyes, 2018). The relationship between microalgae and bacteria is best understood as a primary symbiosis shaped by millions of years of co-evolution; in biofloc systems, this partnership has been shown to help control *Vibrio harveyi* and related *Vibrio* pathogens (Pacheco-Vega et al., 2018).

Taken together, integrating microalgae into biofloc systems overcomes some of the limits of biofloc alone: it reduces dependence on commercial feed, improves shrimp health and growth, and makes hyperintensive *P. vannamei* culture more sustainable and cost-effective for farmers (Jiménez-Ordaz et al., 2021).

Use of Agricultural By-Products for a More Sustainable System

The carbon source used to build biofloc strongly shapes its characteristics, since carbon content and degradability vary widely between materials; sources that support fast ammonia removal and generate high floc volume are considered the most effective (El-Sayed, 2021). Commonly used options include simple sugars such as dextrose, sugarcane molasses, glucose, and sucrose, alongside complex-carbohydrate sources such as rice bran, wheat bran, wheat flour, gram flour, rice flour, and cornflour (Abakari et al., 2021). Comparative studies have found that glucose and molasses outperform starch-based sources during *L. vannamei* grow-out (Huang et al., 2022), while by-products such as tapioca waste and wheat-milling residues have supported strong growth and survival in shrimp and tilapia culture, respectively (Mansour & Esteban, 2017).

Using low-cost agricultural by-products as carbon sources is attractive precisely because it avoids competing with human food supplies, while cutting production costs, supporting circular bioeconomy principles, and improving shrimp survival, digestive enzyme activity, gut microbial balance, and hepatopancreas health.

That said, this approach is not without its challenges. Agricultural by-products are not always available in consistent quantity or quality supply can be seasonal, and transport costs may offset the savings gained from using a low-value residue in the first place. Nutrient composition also varies considerably between batches and sources, even within the same crop residue, which complicates the precise C:N ratio management that biofloc systems depend on. Farmers adopting by-product-based carbon sources therefore need reliable local supply chains and some capacity for on-farm testing or standardisation before these inputs can be used reliably at scale.

Table 1 summarises an experimental comparison of sugarcane bagasse and rice bran as biofloc carbon sources against a clearwater control (Mansour & Esteban, 2017). Both by-product-based treatments produced comparable biofloc volumes while eliminating the need for water exchange and commercial feed inputs.

Table 1. Experimental design and rearing conditions for Pacific white shrimp, *L. vannamei* (adapted from Mansour & Esteban, 2017).

Treatment	Culture System	Biofloc Volume (ml L^{-1})	Management Conditions
Control	Clearwater	0	C/N 0 | 100% exchange, twice weekly | Feed reduced gradually from 10% to 3%
Sugarcane bagasse (SB)	Biofloc (SB)	21.50 ± 1.25	C/N 16:1 | Zero water exchange | No commercial feed
Rice bran (RB)	Biofloc (RB)	22.20 ± 0.75	C/N 16:1 | Zero water exchange | No commercial feed

Conclusion

Biofloc technology already offers a more water-efficient, environmentally responsible alternative to conventional intensive shrimp farming, recycling waste nutrients into a natural microbial feed and lowering operational costs. On its own, though, it can struggle with nutrient balance and system stability at high stocking densities. Bringing microalgae into the system species such as *Haematococcus, Dunaliella, Chlorella, Nannochloropsis,* and *Spirulina* among them measurably improves floc nutritional quality, nitrogen removal, and shrimp disease resistance. Layering in low-cost agricultural by-products as a carbon source adds a further economic and environmental dividend, provided farmers can manage the supply and quality challenges these materials bring.

Looking ahead, the next step for this approach is moving from small-scale trials to commercial-scale validation. Future research should prioritise field trials on larger farms, cost-benefit comparisons of agricultural by-product sourcing against conventional carbon sources at scale, and simple on-farm protocols for selecting and dosing microalgae species suited to local conditions. Done well, a combined strategy of biofloc technology, microalgae integration, and

agricultural waste-derived carbon could become a genuinely scalable model for sustainable, low-cost shrimp aquaculture one that Indian farmers, in particular, are well placed to adopt given the country's large base of agricultural residues.

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EMPOWERING RURAL YOUTH THROUGH NURSERY BUSINESS UNDER THE ARYA PROJECT A SUSTAINABLE PATHWAY FOR EMPLOYMENT AND ENTREPRENEURSHIP

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Abstract

Rural youth play a crucial role in the development of the agricultural sector, yet limited employment opportunities often lead to migration from villages to urban areas (FAO, 2021; Kumar *et al*., 2019). The ARYA (Attracting and Retaining Youth in Agriculture) Project aims to address this challenge by promoting agriculture-based entrepreneurship among rural youth (ICAR, 2023). In Gujarat, the project is implemented through Krishi Vigyan Kendra (KVK) of Navsari Agricultural University (NAU), Navsari, Gujarat. Nursery business has emerged as a promising enterprise under the project due to its low investment requirements, high demand for quality planting materials, and potential for generating sustainable income (Choudhary *et al*., 2020). Through capacity-building programmes, hands-on training, technical guidance, and entrepreneurial support, rural youth are equipped with the knowledge and skills required for scientific nursery management. The initiative encourages the production of healthy seedlings, fruit plants, ornamental plants and vegetable saplings, thereby creating self-employment opportunities and strengthening local agricultural systems (NHB, 2023). This article highlights the role of the ARYA Project in empowering rural youth through nursery-based entrepreneurship, showcasing its impact on skill development, employment generation and rural economic growth.

Keywords: ARYA Project, Rural Youth, Nursery Business, Entrepreneurship, Employment Generation, Sustainable Agriculture, Skill Development, Livelihood Enhancement.

Introduction

A nursery is a place where seedlings, saplings, ornamental plants, fruit plants, vegetable seedlings, medicinal plants and forestry species are propagated and raised for sale or transplantation. Quality planting material is the foundation of successful crop production. The increasing demand for improved varieties of fruit crops, vegetables, flowers, medicinal plants, and ornamental species has created vast opportunities for nursery entrepreneurs.

Nursery enterprises require comparatively small land areas, moderate investment and provide year-round income. They are particularly suitable for educated rural youth seeking self-employment opportunities in agriculture.



Role of ARYA Project in Promoting Nursery Enterprises

The ARYA Project focuses on developing entrepreneurial skills among rural youth through capacity building, hands-on training, demonstrations, exposure visits and technical guidance. Under the nursery enterprise component, participating youth receive support in:

- Scientific nursery management practices
- Selection of suitable crops and plant species
- Propagation techniques
- Infrastructure development
- Plant protection measures
- Marketing strategies
- Business planning and record keeping

The project encourages youth to establish commercial nurseries and become suppliers of quality planting material within their local regions.

Opportunities in Nursery Business

1. Fruit Plant Nursery

Demand for grafted and budded fruit plants such as mango, guava, sapota, lemon, pomegranate, and custard apple continues to increase. Farmers prefer certified and healthy planting material, creating a profitable market for nursery owners.

2. Vegetable Seedling Production

The adoption of hybrid vegetable cultivation has significantly increased the demand for healthy seedlings of tomato, chilli, brinjal, cabbage, cauliflower, and cucurbits. Pro-tray seedling production under protected conditions provides excellent business opportunities.

3. Ornamental and Landscaping Plants

Urbanization, landscaping projects, parks, institutions, and household gardening have boosted the demand for ornamental plants, flowering species, indoor plants, and decorative shrubs.

4. Medicinal and Aromatic Plants

Growing awareness regarding herbal medicine and natural products has increased the market demand for medicinal plants such as tulsi, aloe vera, ashwagandha, and lemongrass.

5. Forestry and Agroforestry Saplings

Government plantation programmes, environmental campaigns, and agroforestry initiatives create regular demand for forestry species and shade trees.

Scientific Nursery Management Practices

Success in nursery business depends on scientific management and quality production. Important aspects include:

Site Selection

- Well-drained fertile soil
- Availability of irrigation water
- Easy accessibility to markets and transportation
- Protection from strong winds and livestock

Propagation Methods

- Seed propagation
- Cutting
- Grafting
- Budding

- Layering
- Tissue culture-based hardening

Growing Media

A suitable potting mixture consisting of soil, sand, vermicompost, cocopeat, and organic manures ensures healthy root development and seedling growth.

Nursery Infrastructure

- Shade net houses
- Polyhouses
- Mist chambers
- Seedling trays
- Irrigation systems
- Hardening units

Plant Protection

Regular monitoring and integrated pest and disease management practices help maintain the quality and health of planting material.

Economic Benefits to Rural Youth

The nursery business offers several economic advantages:

- Regular and year-round income generation
- Low land requirement
- Employment opportunities for family members
- Quick returns compared to many field crops
- Scope for enterprise expansion
- Opportunities for value addition and diversification

A well-managed nursery can generate substantial profits through the sale of seedlings, grafted plants, ornamental species, potting mixtures, and gardening accessories.

Social and Environmental Impact

Beyond economic benefits, nursery enterprises contribute significantly to rural development and environmental sustainability:

- Reduction in rural unemployment
- Prevention of migration to urban areas
- Promotion of entrepreneurship among youth

- Increased availability of quality planting material
- Support for horticulture and agroforestry expansion
- Enhancement of green cover and biodiversity conservation

The active participation of youth in nursery enterprises also strengthens local agricultural systems and promotes climate-resilient farming practices.

Success Through Skill Development

Training programmes organized under the ARYA Project equip rural youth with practical skills and confidence to establish successful enterprises. Exposure to modern nursery technologies, business management principles and market linkages enables young entrepreneurs to transform nursery raising from a traditional activity into a profitable agribusiness venture.

Many rural youths associated with the project have successfully established commercial nurseries, generating employment for themselves and others while supplying quality planting material to farmers and institutions.





Success Story: Mango Grafting Enterprise under the ARYA Project

Name	Rajeshbhai Mandubhai Birari
Address	At. Po.: Limzar Ta: Vansda Dist: Navsari
Mobile No	9428019482
Age	46
Education	B.A.
Land Holding	3 acre

Situation Before KVK Intervention

Before receiving technical guidance from Krishi Vigyan Kendra (KVK), Rajeshbhai faced several challenges in mango graft production:

- Limited knowledge regarding the establishment and maintenance of a healthy mother block for scion collection.
- Lack of technical skills in performing multiple grafting techniques on a single mango plant.
- No awareness of the high-yielding hybrid mango variety **Sonpari**.
- Limited knowledge of scientific nursery management and plant protection practices.

KVK Intervention

Under the **ARYA (Attracting and Retaining Youth in Agriculture) Project**, KVK, Navsari organized hands-on training, demonstrations and continuous technical guidance on scientific mango graft production. The intervention included:

- Training on mother block establishment and maintenance.
- Demonstration of scientific softwood and multiple grafting techniques.
- Introduction and promotion of the Sonpari hybrid mango variety.
- Guidance on nursery hygiene, sanitation and plant protection measures.
- Technical support for quality graft production and marketing.

Impact of the Intervention

- Farmers' confidence in scientific mango graft production increased significantly.
- Adoption of multiple grafting techniques improved the quality and productivity of grafts.
- Greater awareness and adoption of nursery hygiene, cleanliness and safety measures.
- Scientific use of plant protection chemicals and Novel Banana Sap was adopted as per recommended doses and crop requirements.
- Improved technical knowledge has enhanced the scope for sustainable nursery entrepreneurship and increased income opportunities under the ARYA Project.

Economics		
1	Produce (grafts)	10000
2	Price (Rs)	80/-
3	Income (Rs)	8,00,000

4	Cost (Rs)	4,00,000
5	Profit (Rs)	4,00,000

Conclusion

The nursery business represents a highly viable agri-enterprise capable of transforming the livelihoods of rural youth. Through skill development, technical support and entrepreneurial guidance, the ARYA Project is playing a crucial role in attracting and retaining young people in agriculture. By promoting nursery enterprises, the project not only creates sustainable employment opportunities but also strengthens agricultural productivity, environmental conservation, and rural economic development.

Empowering rural youth through nursery entrepreneurship is not merely an employment strategy; it is an investment in the future of sustainable agriculture and rural prosperity.

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DIGITAL AGRICULTURE FOR STRENGTHENING AGRICULTURAL EXTENSION SERVICES: FROM ADVISORY TO EMPOWERMENT

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Abstract

Agricultural extension services are evolving from traditional one-way communication to interactive, data-driven platforms due to advances in digital technology. Key technologies include mobile apps, AI, IoT, GIS, drones, and big data analytics, all aimed at enhancing productivity and sustainability. These tools facilitate real-time weather updates, pest monitoring, market intelligence, and personalized advice. In India, initiatives like e-NAM and Kisan Call Centers have improved service reach and effectiveness, promoting inclusivity for smallholder farmers and rural youth. Despite hurdles like digital illiteracy and connectivity issues, digital agriculture holds significant promise for empowering farmers and fostering sustainable agricultural practices.

Keyword: Digital Agriculture, Extension Services, Empowerment

Introduction

Agriculture is one of the world's oldest and largest sectors of India's economy, contributing significantly to economic growth, food security, and livelihoods for nearly two-thirds of the population. However, increasing global food demand and labour pressures have exposed the limitations of traditional farming methods, highlighting the need for modern, technology-driven approaches. Shrinking landholdings from 2.28 ha in 1970–71 to 0.77 ha due to urbanization, industrialization, and land fragmentation (Shahajahan et al 2026; Akter et al, 2026). Over the years, agricultural extension services have played an important role in transmitting knowledge, technologies, and best approaches to farmers. Traditionally, extension depended on face-to-face discussions, field demonstrations, training programs, and printed

materials. While these techniques have made a substantial contribution to the development of agriculture, they frequently have disadvantages such as restricted outreach, delayed information delivery, and adequate personalisation.

In recent years, the rapid growth of digital technology has created new opportunities for agricultural extension. The rise of digital agriculture, which involves the use of mobile phones, internet connectivity, data analytics, and artificial intelligence, has radically altered how information is transferred and used in farming. This change represents a move from a traditional advisory-based strategy to a more inclusive and participatory approach that focuses on farmer empowerment.

The primary concern is no longer how to give farmers with information, but how to help them make educated, timely, and context-specific decisions. This transition from "advisory to empowerment" reflects a paradigm shift in global agricultural extension systems (FAO, 2017; World Bank, 2019).

Evolution of Agricultural Extension in the Digital Era

Agricultural extension has seen tremendous evolution throughout the decades. Initially, extension programs depended heavily on interpersonal communication techniques including farm visits, demonstrations, farmer field schools, and community gatherings. These strategies emphasised direct engagement between extension workers and farmers, but they were constrained by geographical boundaries and insufficient human resources.

The development of mass media technologies like radio and television broadened the scope of agricultural communication. Farm radio and television broadcasts aided in the dissemination of agricultural information to a larger audience. However, these technologies remained mostly one-way communication systems, with no opportunities for feedback or personalisation.

The rapid advancement of mobile phones, internet access, and digital technology began a new era in agricultural extension. ICT-enabled extension systems now allow for real-time communication, personalised advising services, and interactive learning experiences. Farmers may use digital platforms to communicate directly with scientists, extension experts, markets, and government bodies.

The COVID-19 project has increased the digital transformation of extension services. Physical movement restrictions emphasised the significance of virtual extension systems, online

training, and mobile advisory services. Many extension organisations used internet communication technologies to continue to assist farmers during the crisis.

Digital agriculture is the application of current information and communication technologies (ICTs) to improve agricultural production, sustainability, and profitability. It encompasses mobile apps, SMS-based advisory services, remote sensing, geographic information systems (GIS), big data analytics, and artificial intelligence (AI). At its foundation, digital agriculture seeks to close the knowledge gap between research institutions and farmers. Unlike traditional extension approaches, which frequently give broad suggestions, digital technologies may provide location-specific, real-time, and personalised information to particular farmer requirements (Aker, 2011). For example, a farmer may now receive weather predictions, pest warnings, market pricing, and crop management information immediately to their cell phone. This immediate and relevant information considerably improves decision-making and reduces agricultural hazards.

From Advisory to Empowerment: A Paradigm Shift

Agricultural extension is currently transforming from a traditional model of expert-driven advice to a farmer empowerment approach that emphasizes informed decision-making. Traditionally, this system operated on a top-down basis, leading to a lack of consideration for the diverse farming contexts and the necessity for personalized support (Rogers, 2003). Today, with the rise of digital agriculture technologies, farmers are becoming active participants in their learning, utilizing tools like mobile advisories and AI platforms for location-specific information, including weather updates and market prices (FAO, 2025; Beach et al., 2025).

This transformation also signifies a shift from one-way communication to interactive, participatory systems that promote two-way dialogue among farmers. Such approaches enhance trust and accelerate innovation adoption (Mukherjee et al., 2025). Furthermore, empowerment encompasses capacity building, where extension professionals play the role of facilitators, guiding farmers in utilizing digital tools while integrating local knowledge (Acharya et al., 2024).

An essential aspect of this paradigm shift is promoting inclusivity through digital platforms that reach underserved communities, reducing information gaps (FAO, 2023; Mukherjee et al., 2025). Nevertheless, achieving empowerment necessitates overcoming challenges such as the digital divide and low digital literacy, requiring strategic investments in

rural infrastructure and training (FAO, 2023; Finger, 2023). Finally, integrating behavioral insights into digital systems can enhance the responsiveness and effectiveness of extension services (Chakraborty et al., 2026).

Major Digital Tools Strengthening Agricultural Extension

1. Mobile-Based Advisory Services

Mobile phones are essential for agricultural extension services, providing critical information on crop management, weather, pest control, fertilizer use, irrigation, and market prices. In India, platforms like the mKisan portal deliver SMS advisories in regional languages about weather, crop technologies, and government schemes, while the Kisan Call Center connects farmers with experts through toll-free calls. Mobile apps also allow farmers to diagnose crop diseases by uploading images for AI-driven advice, enhancing problem-solving efficiency and reducing the need for physical agent visits.

2. Artificial Intelligence and Data Analytics

Artificial intelligence is enhancing digital agricultural extension by analyzing large datasets to provide location-specific recommendations for farmers. AI systems aid in crop planning, disease diagnosis, irrigation management, yield prediction, and risk assessment. AI based image recognition technologies detect pest infestations and nutrient deficiencies in crops, while chatbots improve farmer accessibility by responding in local languages. Machine learning algorithms utilize weather and soil data for predictive analytics, promoting climate-smart agriculture and sustainable resource management (Rajasri, 2025).

3. Remote Sensing and GIS Technologies

Geographic Information Systems (GIS) and remote sensing are increasingly vital in digital agriculture, enhancing agricultural extension services through real-time data. GIS involves storing and analyzing spatial data, while remote sensing employs satellites and drones to collect information on agriculture and natural resources. Together, they improve precision farming and evidence-based decision-making. In India, agencies like the Indian Space Research Organisation leverage these technologies for crop acreage estimation and drought assessment, improving agricultural planning and policy implementation. The integration of GIS with digital advising platforms allows for more timely, accurate, and farmer-focused services (Meera et al., 2023).

4. Internet of Things (IoT)

The Internet of Things (IoT) is pivotal in digital agriculture, enhancing extension services via real-time data collection and precision farming. This technology involves interconnected sensors and devices that monitor key agricultural conditions like soil moisture and crop health through internet connectivity. IoT systems empower farmers to make accurate decisions about irrigation, fertilizer use, and pest management, optimizing resource efficiency, especially during climate change and water scarcity (Birthal et al., 2022). Additionally, IoT aids in early detection of nutrient deficiencies and diseases, providing farmers with timely alerts through digital platforms.

Digital learning and video-based Extension

Digital learning and video-based extension are revolutionizing agricultural services by leveraging smartphones, apps, and social media for knowledge sharing among farmers. Platforms like YouTube and WhatsApp facilitate interactive training on topics such as crop production and pest management. The COVID-19 pandemic heightened the importance of virtual training and e-extension services for efficient outreach. Moreover, farmer-to-farmer video models promote community empowerment and participatory learning, enhancing the adoption of improved agricultural practices.

Indian Initiatives in Digital Agricultural Extension

1. Agri-stack

Agri-stack is a centralized digital farmer register integrating land records, cropping patterns, input consumption, and market behavior into a unified digital identity. Launched in pilot programs in Madhya Pradesh, Uttar Pradesh, and Maharashtra in 2023, it aims to support over 5 million farmers by enabling targeted subsidy distribution and financial services. While it offers customized recommendations and improved credit ratings, concerns regarding data privacy and ownership highlight issues of digital sovereignty (aktar 2026).

2. Digital Green

Digital Green is an ICT-enabled initiative in partnership with the Government of India to enhance smallholder farmers' livelihoods through video-based learning and mobile technology. It collaborates with organizations like the National Rural Livelihoods Mission to improve the skills of extension workers and market connectivity using digital tools. This approach has shown

greater effectiveness than traditional methods, leading to increased adoption, productivity, and income for farmers (aktar 2026).

3. mKisan Portal

The mKisan Portal, launched by the Government of India on July 16, 2013, offers mobile-based agricultural advisory services to farmers. It allows agricultural experts and government officials to send tailored SMS and voice messages in local languages, focusing on farmers' specific needs and locations. This service is part of broader Digital Agriculture and e-Governance initiatives, providing timely information on weather, pest management, crop practices, market prices, and government schemes, and operates on basic mobile phones to ensure accessibility for rural farmers (aktar, 2026).

4. Kisan Call Centres (KCC)

Kisan Call Centers (KCC), launched on January 21, 2004, by the Ministry of Agriculture & Farmers Welfare, India, serve as an essential ICT-based agricultural extension initiative. They aim to assist farmers by answering queries via phone in their local languages. Operating across 21 sites nationwide, KCC provides a toll-free number, 1800-180-1551, accessible from all telecom networks. Services are available seven days a week, from 6 a.m. to 10 p.m., in 22 local languages (aktar, 2026).

5. The Soil Health Card (SHC) Scheme

The Soil Health Card (SHC) Scheme, initiated by the Indian Government in 2015, focuses on scientific soil management and enhanced agricultural extension services. It provides farmers with thorough insights into their soil's nutrient status, encouraging tailored fertilizer application for crops. Soil samples are analyzed for various parameters, leading to personalized Soil Health Cards. The scheme leverages digital technologies, allowing efficient access to soil data and advisories via online platforms and GIS. The SHC Scheme promotes sustainable agriculture by minimizing fertilizer use, cutting costs, boosting productivity, and maintaining soil fertility while reducing environmental impacts (Aktar, F., & Shahajahan, M., 2026).

6. e-NAM (National Agriculture Market)

The e-NAM (National Agriculture Market) is a digital platform established in 2016 by the Indian government to unify agricultural markets and enhance extension services. It connects farmers, traders, buyers, and Agricultural Produce Market Committees (APMCs) through an online trading system, promoting transparency and efficiency in the marketing of agricultural

goods. Farmers benefit from real-time market prices, online bidding, quality testing, and digital payment options, helping them make informed decisions and reducing reliance on middlemen. e-NAM also strengthens extension services with market intelligence and price forecasting, encourages competitive pricing, and broadens market access, leading to enhanced economic empowerment for farmers.

7. PM-KISAN Digital Integration

Digital learning and video-based extension are revolutionizing agricultural services by leveraging smartphones, apps, and social media for knowledge sharing among farmers. Platforms like YouTube and WhatsApp facilitate interactive training on topics such as crop production and pest management. The COVID-19 pandemic heightened the importance of virtual training and e-extension services for efficient outreach. Moreover, farmer-to-farmer video models promote community empowerment and participatory learning, enhancing the adoption of improved agricultural practices.

8. Krishak Bandhu

The Krishak Bandhu scheme by the West Bengal Government offers financial support and social security to farmers, enhancing agricultural development and reducing financial risks. Eligible farmers receive direct aid for crop production and death benefits for their families. The scheme utilizes digital integration for effective management and transparency through Direct Benefit Transfer. Overall, it aims to improve financial inclusion, agricultural investment, and rural livelihoods in West Bengal.

Role of Extension Workers in the Digital Era

The function of extension workers is changing in the digital era. Instead of simply providing information, they are becoming facilitators, consultants, and knowledge brokers. Their responsibilities include:

- ✓ Training farmers to use digital technologies.
- ✓ Transforming data into usable insights.
- ✓ Closing the gap between technology developers and farmers.
- ✓ Promoting inclusion by assisting marginalised and digitally disadvantaged farmers.

This transformation needs extension personnel to build capacity and learn on a constant basis.

Challenges in Digital Agricultural Extension

Despite its potential, digital agriculture faces several challenges:

- ✓ Not all farmers have access to smartphones, internet connectivity, or digital infrastructure.
- ✓ Many farmers lack the skills required to effectively use digital tools.
- ✓ Most digital content is not available in local languages, limiting its accessibility.
- ✓ Farmers may be hesitant to rely on digital information without verification.
- ✓ The increasing use of data raises concerns about privacy and misuse.

Addressing these challenges is critical for ensuring inclusive and equitable access to digital extension services.

Strategies for Effective Digital Extension

To fully realize the potential of digital agriculture in strengthening extension services, several steps are necessary:

- **Promoting Digital Literacy:** Training programs should be conducted to enhance farmers' digital skills.
- **Developing Localized Content:** Information should be available in local languages and tailored to regional conditions.
- **Strengthening Infrastructure:** Investments in rural internet connectivity and digital infrastructure are essential.
- **Public-Private Partnerships:** Collaboration between government, private sector, and research institutions can accelerate innovation.
- **Integrating Traditional and Digital Approaches:** A hybrid model combining field-based extension with digital tools can maximize impact.

Conclusion

Digital agriculture is reshaping the future of agricultural extension by transforming traditional advisory systems into farmer empowerment. Key technologies, including AI, IoT, GIS, drones, and mobile applications, enhance information access and sustainability while improving productivity and market integration. In India and other developing countries, digital extension systems have the potential to bridge knowledge gaps and improve climate resilience, thereby fostering sustainable agricultural development. However, the effectiveness of these technologies hinges on their ability to meet farmers' needs and overcome their constraints. A successful digital extension strategy requires a balanced combination of technological advancements, human support, and institutional development. This shift from advisory to

empowerment signifies a broader transformation in perspective, viewing farmers as active decision-makers, and promotes a more inclusive and sustainable agricultural future.

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NATURE WALKS: A HEALING PATH FOR ANXIETY AND DEPRESSION

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Introduction

In an age dominated by speed, screens, and constant connectivity, mental health challenges such as anxiety and depression are becoming increasingly common. Modern lifestyles often leave little room for rest, reflection, or meaningful connection with the natural world. Amid this growing crisis, one simple and powerful practice that is gaining renewed attention is nature walk. A nature walk is more than just walking outdoors. It is an intentional act of spending time in natural surroundings such as parks, forests, gardens, beaches, hills, or even quiet tree-lined streets. This simple activity has a profound impact on mental well-being, particularly in reducing anxiety and depression. As science and lived experience increasingly show, nature has an extraordinary ability to heal the human mind. Anxiety and depression are not just individual struggles; they reflect the pressures of modern society. Anxiety often manifests as constant worry, restlessness, fear of the future, racing thoughts, and physical symptoms such as rapid heartbeat and shallow breathing. Depression, on the other hand, is characterized by persistent sadness, loss of interest, fatigue, low self-worth, and emotional numbness.

Several lifestyle factors contribute to these conditions:

- Excessive screen time and digital overload
- Reduced physical activity
- Social isolation
- Urban living with limited green spaces
- Constant exposure to stressful information

As humans, we evolved in close connection with nature. For thousands of years, natural environment shaped our bodies, minds, and emotional responses. The sudden shift to enclosed, artificial, and highly stimulating environments has disrupted this natural balance. Nature walks combine three essential elements for mental health- physical movement, exposure to natural environments and mental relaxation

Unlike intense exercise routines, nature walks are gentle and accessible. They do not demand performance, speed, or competition. Instead, they invite the individual to slow down, breathe, observe, and simply exist. Walking itself stimulates blood circulation, releases endorphins, and reduces muscle tension. When combined with nature, these benefits multiply. Green spaces calm the nervous system, reduce sensory overload, and offer a sense of safety and openness that urban environments often lack.

How Nature Walks Reduce Anxiety

Anxiety thrives on overstimulation and constant mental noise. Nature walks counter this by engaging the senses in a soothing and non-threatening way.

Calming the Nervous System: Natural environments help shift the body from a "fight-or-flight" state to a "rest-and-digest" state. The sound of birds, flowing water, rustling leaves, and gentle wind signals safety to the brain. This reduces the production of stress hormones such as cortisol and adrenaline. As the body relaxes, breathing becomes deeper and more regular. Heart rate slows down, muscles loosen, and the mind begins to quieten.

Grounding the Mind: Anxiety often pulls the mind into the future- imagining, worst-case scenarios and uncertainties. Nature walks naturally bring attention back to the present moment. Watching clouds move, noticing the texture of tree bark, or feeling the earth beneath one's feet creates a grounding effect. This grounding helps interrupt anxious thought loops and builds a sense of emotional stability.

Nature Walks and Depression:

Restoring Light and Movement: Depression often drains energy, motivation, and joy. Even small tasks can feel overwhelming. Nature walks offer a gentle and non-pressuring way to reintroduce movement and engagement into daily life.

The Role of Sunlight: Sunlight exposure during outdoor walks helps regulate circadian rhythms and improves sleep quality. It also boosts the production of vitamin D and serotonin-both crucial for mood regulation. Low levels of these are commonly associated with depression.

Breaking Isolation: Depression can make individuals feel disconnected from the world. Nature provides a sense of belonging without judgment or expectation. Walking in a park or forest can remind individuals that life continues around them, offering comfort and perspective. Even solitary walks can reduce loneliness, while group walks or walking with a friend can rebuild social connection.

Research from psychology, neuroscience, and environmental health strongly supports the mental health benefits of nature exposure.

Studies have found that:

- People who walk in natural settings experience lower levels of rumination (repetitive negative thinking).
- Green spaces reduce symptoms of anxiety and depression more effectively than indoor or urban environments.
- Regular exposure to nature improves attention, memory, and emotional regulation.

What can be done

Digital Detox: Escaping the Pressure of Constant Connectivity

Modern anxiety and depression are often intensified by constant digital engagement. Notifications, news updates, social media comparisons, and online conflicts keep the mind in a state of alertness. Nature walks provide a natural digital detox. Stepping away from screens even for a short time gives the brain a chance to recover from information overload. Without constant input, the mind can process emotions, reflect, and regain clarity.

Mindfulness Through Movement: Nature walks naturally encourage mindfulness. Unlike structured meditation, they do not require special techniques. Mindfulness emerges organically when attention is drawn to sensory experiences.

- Feeling the rhythm of footsteps
- Noticing changes in light and shadow
- Listening to natural sounds

Making Nature Walks a Daily Habit

- Walk regularly, even if only for 15–30 minutes
- Choose quiet, green spaces when possible
- Walk without headphones or phones occasionally
- Focus on sensory experiences

- Be patient healing is gradual

Conclusion

Nature walks remind us that healing does not always require complexity. Sometimes, it begins with a simple step outside. In a world overwhelmed by noise, speed, and stress, nature offers stillness, rhythm, and reassurance. By reconnecting with the natural world through regular walks, individuals can reduce anxiety, ease depression, and restore emotional balance. Nature does not judge, rush, or demand it simply invites us to walk, breathe, and be. In embracing nature walks, we rediscover not only the healing power of the earth but also the quiet strength within ourselves.

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SOCIAL JETLAG: A GROWING PUBLIC HEALTH CONCERN IN MODERN SOCIETY

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Introduction

Social jetlag is an emerging health concern in modern society, reflecting the growing imbalance between biological needs and socially imposed schedules. In today's fast-paced world, individuals often adjust their daily routines to meet work, school, and social demands, which leads to irregular sleep patterns. Unlike traditional jetlag caused by travel across time zones, social jetlag occurs within everyday life and affects a large proportion of the population. With increasing urbanization, digitalization, and changing lifestyles, the problem of disturbed sleep cycles has become more common, making it an important public health issue.

Social jetlag is defined as the mismatch between an individual's internal biological clock, also known as the circadian rhythm, and their external social schedule. It is typically observed as the difference in sleep timing between weekdays and weekends. For instance, a person may wake up early during working days but sleep late and wake up much later on weekends. This variation creates a disruption similar to traveling across time zones, leading to fatigue and reduced functioning. The circadian rhythm plays a crucial role in regulating sleep, hormone release, metabolism, and overall physiological processes, and any disruption to this rhythm can negatively affect health.

Causes:

The primary causes of social jetlag are rooted in lifestyle and societal demands. Fixed work and school schedules often force individuals to wake up earlier than their natural sleep preference, leading to sleep deprivation during weekdays. Many people attempt to compensate

for this sleep loss by oversleeping on weekends, which further disrupts their biological clock. Additionally, the widespread use of digital devices such as smartphones and laptops has significantly delayed sleep onset due to exposure to blue light and increased mental stimulation. Urban lifestyles, late-night social activities, and shift work patterns further contribute to irregular sleep cycles and increased prevalence of social jetlag.

Statistics:

Recent statistical evidence highlights the widespread nature of social jetlag across different populations. Studies suggest that nearly 70 per cent of individuals experience at least one hour of social jetlag, while about half of the population experiences two or more hours of mismatch between biological and social time. Adolescents and young adults are particularly vulnerable due to late sleeping habits and early school timings. Research has also shown that individuals experiencing more than two hours of social jetlag are at a higher risk of developing mental health issues such as anxiety and depression. Furthermore, social jetlag has been associated with physical health problems including obesity, metabolic disorders, and cardiovascular diseases, indicating its serious impact on overall well-being.

Effects:

The effects of social jetlag are multidimensional, affecting both mental and physical health. Psychologically, individuals may experience mood disturbances, irritability, stress, and decreased emotional stability. Physically, irregular sleep patterns can disrupt metabolism, weaken the immune system, and increase the risk of chronic diseases. Social jetlag also impacts cognitive functioning, leading to poor concentration, reduced memory, and decreased productivity. Students and working professionals often report difficulty in maintaining focus and efficiency due to inconsistent sleep patterns. Over time, chronic sleep disruption can significantly reduce quality of life.

Certain population groups are more affected by social jetlag than others. Adolescents are highly vulnerable due to biological tendencies for late sleep combined with early school schedules. Working adults, especially those engaged in shift work or irregular job timings, also experience significant disruption in their sleep-wake cycles. Urban populations are at greater risk due to exposure to artificial lighting, digital devices, and demanding lifestyles. These factors collectively contribute to increasing levels of sleep disturbance and associated health problems in modern society.

Managing social jetlag requires conscious efforts at both individual and societal levels. Individuals can reduce its effects by maintaining a consistent sleep schedule throughout the week, limiting screen time before bedtime, and ensuring adequate sleep duration. Healthy lifestyle practices such as regular physical activity, balanced diet, and stress management also play a vital role in regulating the biological clock. At the societal level, introducing flexible work schedules, delaying school start times, and promoting awareness about sleep health can help align social demands with biological needs.

Conclusion

Social jetlag is a significant yet often overlooked consequence of modern lifestyle patterns. It arises from the misalignment between biological rhythms and social obligations, leading to various physical, mental, and cognitive health issues. Recent statistics indicate that a large proportion of the population is affected, making it a growing public health concern. Addressing social jetlag requires a combined approach involving lifestyle modifications and supportive societal policies. By prioritizing regular sleep patterns and raising awareness about the importance of circadian health, individuals can improve their overall well-being and lead healthier, more balanced lives.

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RIGHT VARIETY, RIGHT PLACE: WHY SELECTING CROP VARIETIES ACCORDING TO LOCAL AGRO-CLIMATIC CONDITIONS DETERMINES FARMERS' PROFIT

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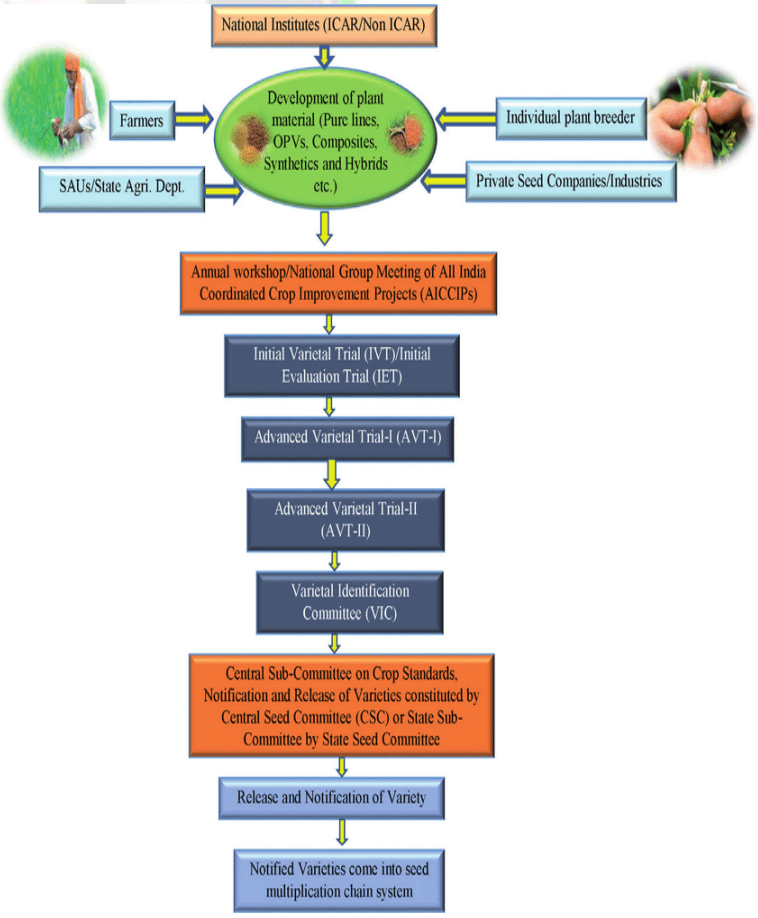
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Introduction

Introduction: Why Variety Selection is the First Step to Successful Farming

Crop variety selection is one of the most important decisions a farmer makes before sowing because it determines the genetic potential of the crop for yield, stability, quality and resilience throughout the growing season. Unlike crop management practices that can be modified after planting, the genetic makeup of a variety remains fixed. Consequently, selecting an appropriate variety directly influences productivity, resource-use efficiency, tolerance to biotic and abiotic stresses, and



ultimately the profitability of farming. Since varietal performance is largely governed by genotype × environment (G × E) interactions, a cultivar that performs exceptionally well in one agro-climatic region may not produce similar results under different environmental conditions.

This principle is well illustrated by several ICAR-developed varieties. For instance, **HD 3385**, a wheat variety developed by ICAR–Indian Agricultural Research Institute (IARI), was specifically released for the timely sown irrigated conditions of the **North Western Plains Zone (NWPZ)**, where it consistently expresses high yield potential, heat tolerance and resistance to major rust diseases. Similarly, **Pusa Basmati 1509** was developed for the Basmati-growing regions of Punjab, Haryana, Delhi, Western Uttar Pradesh, Uttarakhand and Jammu & Kashmir. Under these recommended environments, it combines premium grain quality with early maturity (115–120 days), non-lodging plant type and the ability to save approximately **3–6 irrigations (about 33% irrigation water)** compared with traditional Basmati cultivars, while also enabling timely sowing of the succeeding wheat crop. However, these advantages may not be fully realized when the same varieties are cultivated outside their recommended agro-climatic zones, where differences in temperature, photoperiod, soil properties, disease prevalence and crop management practices can restrict the expression of their genetic potential.

These examples reinforce the fundamental principle of **"Right Variety for the Right Place."** Results from multi-location and multi-year evaluation trials have consistently shown that matching varieties with their target production environments improves yield stability, resource-use efficiency and farm profitability. Recognizing the importance of scientifically evaluated cultivars, India has established a robust varietal evaluation, release and notification system under the **Seeds Act, 1966**, through which only varieties demonstrating superior performance, stability and adaptability across representative testing environments are recommended for cultivation in specific agro-climatic regions.

Despite remarkable advances in plant breeding, the adoption of improved varieties remains suboptimal in many parts of the country because of limited farmer awareness, inadequate access to quality seed and weak extension support. In recent years, **Participatory Variety Selection (PVS)** has emerged as an effective approach to address these challenges by involving farmers in the evaluation of advanced breeding lines under their own field conditions. This approach not only helps identify varieties that best meet farmers' production needs and local environmental conditions but also accelerates varietal adoption and strengthens the linkage

between researchers, extension agencies and farming communities. Thus, selecting the right variety should be viewed not merely as a routine pre-sowing activity but as a strategic investment that lays the foundation for higher productivity, greater resilience and improved farm profitability. yield stability, resource-use efficiency and profitability by matching the genetic potential of a variety with the prevailing climate, soil characteristics and production environment. Recognizing the importance of scientifically evaluated

Factors Affecting Variety Performance

Crop variety performance is governed by the interaction between **genotype, environment and management**. The suitability and productivity of a variety under a specific location depend on **agro-climatic conditions** (temperature, rainfall, humidity, photoperiod, solar radiation and length of growing season), **soil characteristics** (soil type, fertility, pH, drainage, salinity and water-holding capacity), **water availability** (irrigated or rainfed conditions and water quality), **genetic attributes** (yield potential, maturity duration, plant architecture, lodging resistance, grain quality and yield stability), **biotic stress resistance** (diseases, insect pests and nematodes), **abiotic stress tolerance** (drought, heat, cold, flooding and salinity), **cropping system compatibility** (cropping sequence, sowing window and mechanization), **crop management** (fertilizer responsiveness, irrigation and input use), **market and economic factors** (consumer preference, processing quality and profitability), and **institutional factors** such as the availability of quality seed, region-specific recommendations and extension services. Therefore, optimum varietal selection should integrate these factors to maximize productivity, stability and farmers' profitability under local agro-climatic conditions.

Scientific Criteria for Selecting Crop Varieties

Selection Criterion	Representative ICAR Example
Adaptation to the target agro-climatic zone	**HD 3385** (Wheat, ICAR-IARI) – Recommended for timely sown irrigated conditions of the **North Western Plains Zone (NWPZ)**.
High and stable yield potential	**HD 3226** (Wheat, ICAR-IARI) and **Pusa Basmati 1847** (Rice, ICAR-IARI) are known for consistently high productivity under recommended environments.

Suitable maturity duration	**Pusa Basmati 1509** (Rice, ICAR-IARI) matures in approximately **115–120 days**, making it ideal for the rice–wheat cropping system.
Resistance to major diseases and insect pests	**HD 3385** possesses resistance to stripe, leaf and stem rusts, while **Pusa Mustard 30 (NPJ 93)** is tolerant to white rust.
Tolerance to abiotic stresses	**Swarna-Sub1** (Rice) for flood-prone areas, **Pusa Basmati 1885** for saline soils, and **HHB 67 Improved** (Pearl millet) for drought-prone regions.
Yield stability under variable environments (G × E interaction)	Varieties such as **HD 3385** are released only after successful evaluation in **AICRP multi-location and multi-year trials**, ensuring stable performance.
Superior produce quality	**Pusa Basmati 1121** is internationally recognized for premium grain quality, while **Pusa Mustard 31** is valued for its high oil content.
Efficient water- and nutrient-use efficiency	**Pusa Basmati 1509** requires **3–6 fewer irrigations (≈33% water saving)** than traditional Basmati cultivars while maintaining high productivity.
Compatibility with existing cropping systems	**Pusa Basmati 1509** fits well into the **rice–wheat cropping system** by allowing timely sowing of wheat.
Suitability for mechanized cultivation and harvesting	Semi-dwarf and lodging-tolerant varieties such as **HD 3385** and **Pusa Basmati 1885** are suitable for combine harvesting.
High input responsiveness	**HD 2967** (Wheat) and **Pusa Mustard 32** respond efficiently to recommended fertilizer and irrigation management.
Consumer and market acceptability	**Pusa Basmati 1121** commands premium export prices, whereas **Arka Rakshak** (Tomato, ICAR-IIHR) is preferred because of superior fruit quality.
Availability of quality seed	Certified seed is produced through **ICAR Institutes, National Seeds Corporation (NSC), State Seed Corporations (SSC) and State Agricultural Universities (SAUs)**.

Performance in multi-location and multi-year trials	All recommended varieties undergo rigorous testing under the **All India Coordinated Research Project (AICRP)** before release.
Official release and notification	Only varieties officially notified by the **Central Sub-Committee on Crop Standards, Notification and Release of Varieties (Government of India)** are recommended for commercial cultivation.

Selection of Crop Varieties Based on Farming Conditions

Farming condition	Characteristics of the ideal variety	Representative ICAR/SAU varieties
Irrigated farming	High-yielding, fertilizer-responsive, lodging-resistant and suitable for intensive cultivation	**HD 3385**, **HD 3226**, **HD 2967** (Wheat, ICAR-IARI); **Pusa Basmati 1847**, **Pusa Basmati 1885**, **Pusa Basmati 1985**
Rainfed farming	Early maturing, drought-tolerant, efficient water-use and stable under moisture stress	**Pusa JG 16** (Chickpea, ICAR-IARI), **HHB 67 Improved** (Pearl millet), **Pusa Mustard 30** (Mustard)
Drought-prone areas	Deep root system, early maturity, efficient water-use and heat tolerance	**Pusa JG 16** (Chickpea), **HHB 67 Improved** (Pearl millet), **KRL 210** (Wheat)
Flood-prone / waterlogged areas	Submergence tolerance, rapid recovery and stable yield after flooding	**Swarna-Sub1**, **CR Dhan 801 (Swarna-Sub1)** (Rice, ICAR-NRRI)
Saline and alkaline soils	Salt tolerance, better nutrient uptake and stable productivity	**CSR 30**, **CSR 36**, **CSR 43** (Rice); **KRL 283** (Wheat); **CS 58** (Indian mustard
Organic / low-input farming	Disease-resistant, nutrient-use efficient, vigorous early growth and competitive against weeds	Region-specific open-pollinated varieties recommended by **ICAR, SAUs and Package of Practices**; avoid highly

Farming condition	Characteristics of the ideal variety	Representative ICAR/SAU varieties
		input-responsive hybrids.
Rice–wheat cropping system	Early maturity allowing timely sowing of wheat	**Pusa Basmati 1509**, **Pusa Basmati 1847**, **Pusa Basmati 1692**
Direct Seeded Rice (DSR)	Early vigour, lodging resistance and herbicide tolerance	**Pusa Basmati 1509**, **Pusa Sugandh 5**, **Pusa Basmati 1985** (Herbicide tolerant)
Mechanized farming	Semi-dwarf stature, lodging resistance, uniform maturity and suitability for combine harvesting	**HD 3385** (Wheat); **Pusa Basmati 1885**, **Pusa Basmati 1509** (Rice)
High-value export production	Premium grain quality, export acceptance and high market value	**Pusa Basmati 1121**, **Pusa Basmati 1718**, **Pusa Basmati 1885**
Disease-prone regions	Multiple disease resistance with stable yield	**Pusa Basmati 1847** (Blast & bacterial blight resistant), **Improved Pusa Basmati 1** (Bacterial blight resistant), **HD 3385** (Rust resistant)

Climate-Resilient Variety Selection

Climate change has become a major challenge to agricultural production, exposing crops to rising temperatures, erratic rainfall, prolonged droughts, floods, salinity and unseasonal frost. These changing weather patterns not only reduce crop yields but also increase the uncertainty associated with farming. Under such conditions, selecting a climate-resilient variety is as important as adopting appropriate irrigation, nutrient management and other agronomic practices. Climate-resilient varieties are developed through conventional and modern breeding approaches to withstand specific environmental stresses while maintaining stable yield and produce quality. Instead of choosing varieties solely for their high yield potential, farmers should select cultivars that are recommended for the major climatic challenges of their region, such as

drought, heat, flooding or salinity. Such varieties are better adapted to local conditions, reduce the risk of crop failure, make more efficient use of water and nutrients, and provide more stable returns under variable weather conditions. Therefore, choosing the right climate-resilient variety for the local production environment is a practical and effective strategy for climate-smart agriculture, ensuring sustainable productivity and improved farmer livelihoods.

Climate stress	Desired variety traits	Representative variety
Heat stress	Heat tolerance, stable grain filling, stay-green character	HD 3385, HD 3298 (Wheat)
Drought	Deep root system, early maturity, efficient water-use	Pusa JG 16 (Chickpea), HHB 67 Improved (Pearl millet)
Flood/Submergence	Rapid recovery after flooding, SUB1-mediated tolerance	Swarna-Sub1, CR Dhan 801 (Rice)
Salinity	Salt tolerance and efficient ion regulation	CSR 36, CSR 43 (Rice); Pusa Basmati 1885
Waterlogging	Tolerance to temporary water stagnation	CR Dhan 505 (Rice)
Cold/Frost	Cold tolerance during vegetative and reproductive stages	VL wheat varieties
Lodging-prone areas	Strong stem, semi-dwarf plant type	HD 3385, Pusa Basmati 1885

Selecting Resistant Varieties

Genetic resistance is one of the most economical, environmentally safe and sustainable approaches for protecting crops against diseases, insect pests and abiotic stresses. Resistant varieties reduce dependence on chemical pesticides, lower cultivation costs and minimize yield losses while contributing to environmental conservation. Since resistance is an inherent genetic trait, it provides season-long protection without additional investment by farmers. Before purchasing seed, farmers should verify whether the variety possesses resistance to the major diseases, insect pests and environmental stresses prevalent in their locality. Selecting resistant

varieties is particularly important under climate change because increasing temperatures and altered rainfall patterns often favour the emergence and spread of new pests and diseases

Resistance trait	Representative variety	Major advantage
Rust resistance	HD 3385 (Wheat)	Reduces yield losses caused by stripe, leaf and stem rust
Bacterial blight resistance	Improved Pusa Basmati 1	Lower disease incidence and improved grain quality
Blast resistance	Pusa Basmati 1847	Stable yield in blast-prone areas
White rust resistance	Pusa Mustard 30 (NPJ 93)	Higher productivity in mustard-growing regions
Fusarium wilt resistance	Pusa JG 16 (Chickpea)	Improved plant survival and yield stability
Flood tolerance	Swarna-Sub1	Suitable for flood-prone ecosystems
Lodging resistance	HD 3385, Pusa Basmati 1885	Reduced lodging and improved harvestability

Market-Oriented Variety Selection

Modern agriculture is increasingly market-driven, where profitability depends not only on yield but also on grain quality, consumer preference and market demand. A high-yielding variety may not necessarily provide maximum economic returns if it lacks desirable quality attributes such as grain size, aroma, processing quality or nutritional value. Therefore, farmers should select varieties according to the intended market, whether for household consumption, local markets, food processing industries or export. Market-oriented variety selection enables farmers to obtain premium prices, improve market competitiveness and increase overall farm income.

Target market	Preferred variety traits	Representative variety
Premium export rice	Extra-long slender grains, aroma	Pusa Basmati 1121
Domestic premium rice	Excellent cooking and milling quality	Pusa Basmati 1509

Target market	Preferred variety traits	Representative variety
Bread wheat industry	High protein and superior chapati quality	HD 3385
Edible oil industry	High oil content	Pusa Mustard 31
Processing tomato	Firm fruits, high TSS and disease resistance	Arka Rakshak
Pulse market	Bold seed size and attractive seed colour	Pusa JG 16
Biofortified food market	High zinc, iron or protein content	Pusa Biofortified Wheat, Pusa Biofortified Maize

Sources of Authentic Seeds

The productivity of any crop depends not only on the variety selected but also on the genetic purity and quality of the seed. Even the best variety may fail to perform if poor-quality or spurious seed is used. Farmers should always purchase certified seed from reliable and authorized sources to ensure varietal purity, high germination and freedom from seed-borne diseases. Purchasing seed from unverified local markets without certification may lead to varietal mixtures, poor crop establishment and substantial economic losses. Farmers are advised to verify the seed tag, certification label, germination percentage, lot number and validity before purchase.

Source	Examples
ICAR Institutes	ICAR-IARI, ICAR-IIPR, ICAR-NRRI, ICAR-IIMR
State Agricultural Universities (SAUs)	CCS HAU, PAU, GBPUAT, TNAU, UAS and others
Krishi Vigyan Kendras (KVKs)	District-level seed distribution and demonstrations
National Seed Corporation (NSC)	Certified seed of notified varieties
State Seed Corporations	Haryana Seeds Development Corporation, Punjab Seeds Corporation, etc.
Registered Private Seed Companies	Companies registered under the Seeds Act and Seed Certification Agencies

Source	Examples
Farmer Producer Organizations (FPOs)	Certified seed produced under supervision

Common Mistakes Made by Farmers While Selecting Varieties

One of the most frequent errors is the continued cultivation of obsolete varieties, despite the availability of newly released cultivars with superior yield potential, enhanced resistance to diseases and insect pests, and greater tolerance to climatic stresses. Many farmers also purchase seed from unauthorized or unverified sources without checking certification, resulting in poor germination, varietal impurity and reduced crop performance. Variety selection based solely on neighbouring farmers' preferences, local popularity or advertised high yield, without considering local recommendations, often leads to poor adaptation because of genotype × environment interactions. Farmers also tend to overlook important traits such as maturity duration, lodging resistance, grain quality, resistance to major pests and diseases, and tolerance to drought, heat, flooding or salinity. In addition, repeated use of farm-saved seed without periodic replacement gradually reduces genetic purity and vigour, leading to declining productivity over time. Ignoring market demand and consumer preferences further reduces economic returns even when yields are satisfactory. Therefore, farmers should select officially released and region-specific varieties recommended by ICAR, State Agricultural Universities (SAUs), Krishi Vigyan Kendras (KVKs) and the All India Coordinated Research Project (AICRP), while purchasing only certified seed from authorized agencies. Scientific variety selection, combined with quality seed and recommended crop management practices, remains one of the most effective strategies for achieving higher productivity, climate resilience and sustainable farm profitability.

Digital Agriculture and Future Variety Selection

Digital technologies are transforming variety selection by providing farmers with real-time weather forecasts, soil information, pest advisories and location-specific varietal recommendations. Artificial intelligence (AI), remote sensing, precision agriculture and mobile-based advisory services enable farmers to make informed decisions regarding crop and variety selection. In addition, biofortified and climate-smart varieties developed through genomics-assisted breeding are expected to play an increasingly important role in ensuring food and nutritional security under changing climatic conditions.

Platform	Purpose
Kisan Suvidha	Weather, advisory and market information
Meghdoot	Weather-based agro-advisory
Pusa Krishi	ICAR-IARI technologies and varieties
SeedNet India Portal	Seed availability
mKisan Portal	SMS-based advisory
e-NAM	Agricultural marketing
CHAMAN	Horticultural monitoring
Agrisnet	State agricultural information systems

Conclusion

Selecting the right crop variety for the right agro-climatic conditions is one of the most profitable and cost-effective decisions a farmer can make before sowing. A scientifically selected variety enhances yield stability, improves resistance to biotic and abiotic stresses, increases resource-use efficiency and ensures better market returns. As climate variability intensifies, farmers should move beyond traditional variety choices and adopt newly released, region-specific, climate-resilient cultivars recommended by ICAR, State Agricultural Universities and the All India Coordinated Research Project. Combined with certified seed, appropriate crop management and informed decision-making, variety selection serves as the foundation of sustainable, resilient and profitable agriculture.

Choose varieties recommended for your agro-climatic zone.

- Use certified seed from authorized sources.
- Prefer newly released varieties over obsolete cultivars.
- Match the variety with soil type and irrigation availability.
- Consider maturity duration and cropping system.
- select varieties resistant to major diseases and insect pests.
- Adopt climate-resilient cultivars in stress-prone areas.
- Choose varieties according to market demand.
- Follow the recommended package of practices.
- Seek technical guidance from ICAR, SAUs and KVKs before purchasing seed

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BIOFERTILIZERS AND BIOPESTICIDES: THE BACKBONE OF ORGANIC FARMING

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Abstract

Organic farming is acquiring a significant priority area worldwide due to the growing demand for safe and healthy food and long-term sustainability. Along with this, it focuses on reduction of environmental pollution by avoiding utilization of chemical fertilizers, pesticides, herbicides etc. Biofertilizers and biopesticides are significant components of this system, offering eco-friendly alternatives to synthetic fertilisers and pesticides. Biofertilizers improve nutrient availability to the plant through beneficial microorganisms, while biopesticides protect crops from pests and diseases using naturally occurring organisms and plant-based products. Together, they improve soil fertility, support biodiversity, reduce chemical residues in food and soil, and contribute to resilient agricultural systems. Although difficulties such as limited shelf life, uneven field performance, and farmer knowledge still persist, ongoing research and technical developments are boosting their effectiveness and uptake. This article highlights the importance of biofertilizers and biopesticides in strengthening organic farming and promoting environmentally sustainable agriculture.

Key Words: Biofertilizers, biopesticides, Organic farming, sustainable agriculture

Introduction

Modern agriculture has significantly increased food production through the widespread use of chemical pesticides and fertilisers, but their indiscriminate and excessive applications have led to different negative impacts like soil degradation, environmental pollution, declining biodiversity, negative effects on animal and human health etc. These challenges have transformed global interest towards organic production, in which the farming that completely avoid use of synthetic fertilisers, pesticides, herbicides, etc, and mostly depend on utilization of biological inputes to maintain soil fertility and crop health, which minimises environmental impacts. Though the use of chemical inputs in agriculture is inescapable to fill the need of the expanding demand for food in the world, there are chances in chosen crops and niche regions where organic production can be pushed to capture the domestic export market (Mishra et al, 2013).

Among the various inputs used in organic farming, biofertilizers and biopesticides play an important role. They provide sustainable alternatives to chemical fertilizers and pesticides by utilizing naturally occurring microorganisms and biological compounds. Their use not only enhances crop productivity but also improves soil quality, conserves beneficial microorganisms, and supports ecosystem balance. With appropriate support of policy, education, and innovation, biofertilizers and biopesticides have the potential to become the fulcrum of a greener and more sustainable agriculture in the years to come.

Biofertilizers: Nature's Nutrient Provider

Biofertilizers are products carrying living microorganisms, which, when given to seeds, seedling surfaces, or soil, infect the rhizosphere or the plant interior and increase nutrient supply by different biological processes like nitrogen fixation , phosphate solubilization, potassium mobilization, and inducing plant hormones. These microorganisms colonize the rhizosphere or plant tissues, where they improve nutrient uptake and stimulate root development.

Classification Of Biofertilizers:

1. **Nitrogen Fixing Biofertilizer (NBF)**

Different types of biofertilizers play specific roles in improving plant growth and soil fertility. Nitrogen-fixing biofertilizers, such as Rhizobium, Azotobacter, and Azospirillum, convert atmospheric nitrogen into forms that plants can readily absorb and use. Rhizobium forms a symbiotic relationship with leguminous crops, making it especially

effective for these plants. In contrast, Azotobacter and Azospirillum are commonly used for non-leguminous crops, where they enhance nitrogen availability and support healthy plant development.

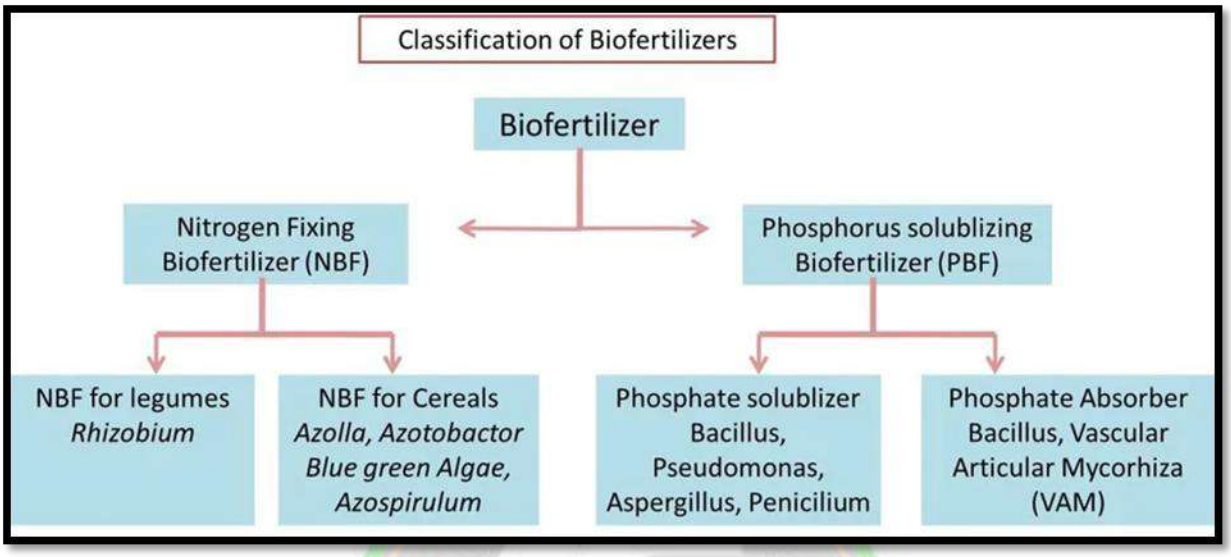


Figure 1: Classification of biofertilizers based on microorganisms.

Characteristics zobia**of Bio-fertilizers: -Nitrogen fixers**

- **Rhizobium:** It belongs to the family Rhizobiaceae, symbiotic in nature, fix nitrogen 50- 100 kg/ ha. with legumes. It colonises the roots of specific legumes to form tumour like growths called root nodules. It has the capacity to fix atmospheric nitrogen (Unavailable to plant) in symbiotic association with legumes and certain non-legumes like Parasponia.
- **Azospirillum** is a heterotrophic, associative nitrogen-fixing bacterium belonging to the family Spirillaceae. It can fix about 20–40 kg of nitrogen per hectare and also produces plant growth-promoting substances. It mainly associates with C4 crops such as maize, sugarcane, sorghum, and pearl millet, where it uses organic acids like malic and aspartic acid for growth and nitrogen fixation (Arun, 2007).
- **Azotobacter**: It is a free-living, aerobic, heterotrophic nitrogen-fixing bacterium belonging to the family Azotobacteriaceae. It is commonly found in neutral to alkaline soils, with *A. chroococcum* being the most prevalent species in cultivated fields. Besides fixing nitrogen, it produces antifungal substances that help suppress soil-borne pathogens and promote healthy plant growth. It is commonly associated with crops

such as rice, maize, sugarcane, pearl millet, vegetables, and plantation crops (Rao Subba, 2001; Arun, 2007).

2. **Phosphate-solubilizing/ Phosphorus Solubilizing Biofertilizer (PBF)**

Phosphate-solubilizing microorganisms (PSMs) like Bacillus and Pseudomonas excrete organic acids and enzymes that transform insoluble phosphorus forms to soluble forms, which are made available to the plant. while arbuscular mycorrhizal fungi improve the uptake of phosphorus, zinc, and water by forming symbiotic associations with plant roots.

Advantages of Biofertilizers:

- **Improve soil fertility:** Biofertilizers improve soil fertility by enriching the soil with beneficial microorganisms and organic matter, which enhances crop growth, yield attributes, and overall productivity (Subashini et al., 2007; Son et al., 2007). They also increase soil microbial activity and help reduce the dependence on chemical fertilizers (Subashini et al., 2007).
- **Reduce chemical fertilizer use:** They decrease the need for synthetic fertilizers, helping to lower cultivation costs and minimize environmental pollution.
- **Enhance nutrient availability:** Biofertilizers promote natural nutrient cycling, making essential nutrients more accessible and efficiently utilized by plants.
- **Support plant growth:** They encourage healthy root and shoot development, resulting in improved crop growth, vigor, and productivity.
- **Produce natural growth-promoting substances:** Many biofertilizers release plant hormones such as **auxins, gibberellins,** and **cytokinins**, which stimulate root growth and overall plant development.
- **Increase soil microbial activity:** Regular application enhances the diversity and activity of beneficial soil microorganisms, creating a balanced soil ecosystem.
- **Improve organic matter decomposition:** Biofertilizers accelerate the breakdown of organic residues, releasing nutrients that are readily available for plant uptake.
- **Promote sustainable agriculture:** Their eco-friendly nature helps conserve soil health, reduce environmental impacts, and support long-term agricultural sustainability.
- **Provide an economical alternative:** Biofertilizers are a cost-effective option for improving crop productivity while maintaining soil quality over time.

Biopesticides: Eco-Friendly Pest Management

Biopesticides are biological agents or naturally occurring products used in to control insects, pathogens, nematodes, and weeds. Unlike conventional pesticides, they are generally target-specific, biodegradable, and environmentally safe.

The products are derived from microorganisms, plant extracts, or naturally occurring biochemical compounds that reduce the development or action of unwanted organisms without damaging useful species or the environment. Biopesticides manage plant pests through mechanisms such as parasitism, antibiosis, or competition. Examples are *Bacillus thuringiensis (Bt), Trichoderma spp., Pseudomonas fluorescens,* and neem products.

Types of Biopesticides

Microbial biopesticides include bacteria, fungi, and viruses that suppress pests and diseases. *Bacillus thuringiensis* effectively controls many insect pests, while *Trichoderma* species suppress several soil-borne fungal pathogens through competition, parasitism, and production of antifungal compounds. Plant-based products such as neem extracts also provide effective pest control by disrupting insect feeding and reproduction.

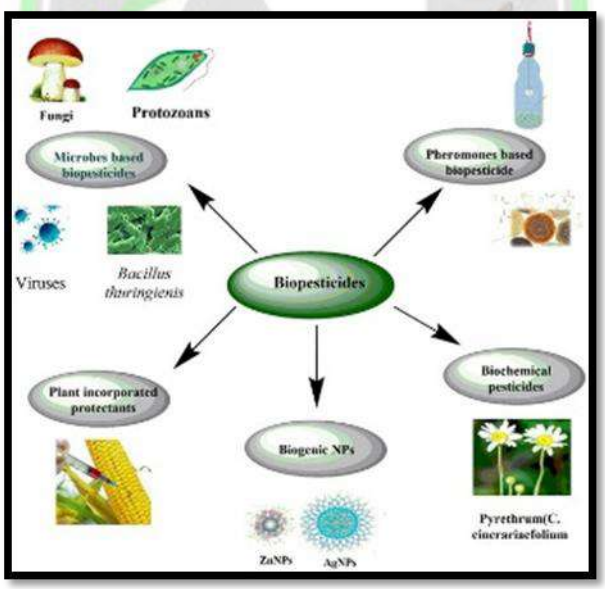


Figure 2. Types of biopesticides. This figure was uploaded by Muhammad Summer

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The selective nature of biopesticides helps conserve pollinators, natural enemies, and beneficial soil organisms, making them highly compatible with integrated pest management and organic production systems.

Types of biopesticides

Microbial insecticides employ living microorganisms like bacteria (*Bacillus thuringiensis*), fungi (*Trichoderma*, *Beauveria bassiana*), and viruses (nucleopolyhedroviruses - NPVs) to infect and kill pest organisms. The microbes produce toxins or compete with the pathogens to manage diseases.

Plant pesticides are derived from plants that have pesticidal characteristics. Some examples are neem (*Azadirachta indica*), pyrethrum (chrysanthemum flowers), and garlic extracts. These compounds work as repellents, feeding inhibitors, or growth regulators for the pest.

Biochemical pesticides consist of naturally occurring substances like insect pheromones and plant growth regulators which disrupt the pests' mating, feeding, or growth activity without producing direct mortality.

Advantages of Biopesticides

- Target-specific action: Biopesticides mainly affect the intended pests while causing little or no harm to beneficial organisms such as pollinators, predators, and other natural enemies.
- Environmentally friendly: Since they are biodegradable, biopesticides break down naturally and do not leave harmful chemical residues in the soil, water, or harvested crops.
- Lower risk of resistance: Regular use of biopesticides helps slow the development of pest resistance, making them a sustainable alternative to conventional chemical pesticides.
- Supports ecosystem health: By protecting beneficial organisms and maintaining natural ecological processes, biopesticides contribute to improved biodiversity and a balanced farm ecosystem.
- Safer for people and food: Their reduced toxicity helps produce safer food while minimizing health risks for farmers, consumers, and nearby communities.

Role in Organic Farming

The combined use of biofertilizers and biopesticides plays a vital role in the success of

organic farming. Biofertilizers improve soil fertility by increasing nutrient availability, while biopesticides protect crops from pests and diseases in an environmentally friendly way. Together, they support healthy plant growth, enhance soil microbial activity, and reduce the need for synthetic fertilizers and pesticides.

Healthy soils rich in beneficial microorganisms are better able to withstand environmental stresses such as drought, nutrient shortages, and disease outbreaks. In addition, the use of these biological inputs promotes carbon storage in the soil, lowers greenhouse gas emissions, and supports biodiversity, making agriculture more sustainable and resilient to climate change.

As consumer preference for organic and chemical-free food continues to grow, biofertilizers and biopesticides have become increasingly important. They help produce safe, high-quality crops while preserving soil health, protecting natural resources, and maintaining environmental sustainability.

Challenges and Future Perspectives

Despite the significant potential of biofertilizers and biopesticides in promoting sustainable agriculture, several challenges still hinder their widespread adoption. Their effectiveness can vary considerably depending on soil properties, climatic conditions, crop species, and agricultural management practices. Unlike synthetic agrochemicals, biological inputs often require specific environmental conditions to achieve optimal performance, which can affect their reliability under different field conditions.

Other major limitations include shorter shelf life, difficulties in storage and transportation, inadequate availability of quality products, and a lack of awareness among farmers regarding their proper application and benefits. Variations in product quality and inconsistent results in field conditions also reduce farmers' confidence and limit their large-scale use.

To overcome these challenges, future research should focus on developing more stable and efficient microbial formulations, advanced microbial consortia, nano-based delivery systems, and precision application technologies. Strengthening quality control measures, improving farmer training and extension services, and implementing supportive policies will be essential for increasing the acceptance and adoption of biofertilizers and biopesticides. These efforts will

contribute significantly to the development of sustainable, productive, and environmentally friendly agricultural systems.

Conclusion

Biofertilizers and biopesticides signify more than alternatives to synthetic agricultural inputs—they are essential tools for achieving sustainable food production. By enhancing soil fertility, protecting crops naturally, and preserving ecological balance, these biological products strengthen the principles of organic farming. As agriculture seeks solutions to climate change, soil degradation, and environmental pollution, wider adoption of biofertilizers and biopesticides will be crucial for developing productive, resilient, and environmentally responsible farming systems. Their continued advancement through scientific research, innovation, and effective extension services will play a vital role in ensuring food security while safeguarding natural resources for future generations.

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THE INVISIBLE FARMERS: BENEFICIAL MICROBES THAT FEED THE WORLD

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Abstract

Beneficial soil microorganisms play a key role in farming, even though we often cannot see them. They help with important tasks like fixing nitrogen, making phosphate available, recycling nutrients, fighting diseases, and helping plants handle environmental stress. This article examines how these beneficial microbes serve as natural biofertilizers and biocontrol agents. It also explains how biotechnology helps us find, grow, and use them in sustainable agriculture. Finally, the article covers how India is relying more on chemical fertilizers, how this affects soil health, and why there is a growing need for biological alternatives. Government programs that support bio-inputs, together with field study results, show that microbial technologies can help reduce fertilizer use, cut production costs, and boost soil fertility over time. While there are still issues such as quality control, storage, and uneven field results, using beneficial microbes offers a practical and eco-friendly way to support sustainable, climate-resilient farming. Relying on these invisible helpers will play a key role in keeping our food supply secure and protecting natural resources for the future.

Keywords

Biofertilizers, Soil Microbiome, Nitrogen Fixation, Phosphate Solubilisation, Sustainable Agriculture, Biotechnology

Introduction

When you visit a farm, you might notice the crops, the color of the soil, the irrigation channels, and the farmer working. But there is also a hidden workforce underground. Each gram of soil contains billions of bacteria, fungi, and other microorganisms. They all play important roles that would otherwise need a lot of fertilizer, pesticides, or manual work. These tiny

organisms take nitrogen from the air, help release phosphorus in the soil, protect plants from disease, and turn organic matter into nutrients that plants need. They have been doing this since before people began farming. Now that science understands their abilities, Indian agriculture could benefit greatly if we take advantage of this opportunity.

Keywords: Biofertilizers, Soil Microbiome, Nitrogen Fixation, Phosphate Solubilisation, Sustainable Agriculture, Biotechnology

Who Are These Invisible Farmers?

" The term 'beneficial microbes' refers to many different organisms, each having its own role.

Nitrogen-fixing bacteria, including Rhizobium, Azotobacter, and Azospirillum, facilitate plant growth by converting atmospheric nitrogen, which is unavailable to plants, into ammonia, a form that plants can readily absorb.

Rhizobium functions within the root nodules of legumes, whereas Azotobacter and Azospirillum operate in the soil adjacent to the roots of cereals and vegetables.

- Phosphate-solubilizing microbes like Pseudomonas, Bacillus, and certain fungi help release phosphorus from minerals, making it easier for plants to take it up through their roots.
- Mycorrhizal fungi interact symbiotically with plant roots to establish a network that extends beyond the reach of roots alone. The plant supplies the fungi with sugars, while the fungi facilitate increased absorption of water and nutrients, particularly phosphorus and zinc.
- Biocontrol agents such as Trichoderma, Bacillus subtilis, and Pseudomonas fluorescens control soil-borne pathogens by outcompeting these pathogens, producing antifungal compounds, or enhancing the plant immune response.
- Decomposers, such as bacteria and fungi, break down crop residue, manure, and other organic matter into humus and nutrients that plants can use. These nutrients are essential for healthy soil.

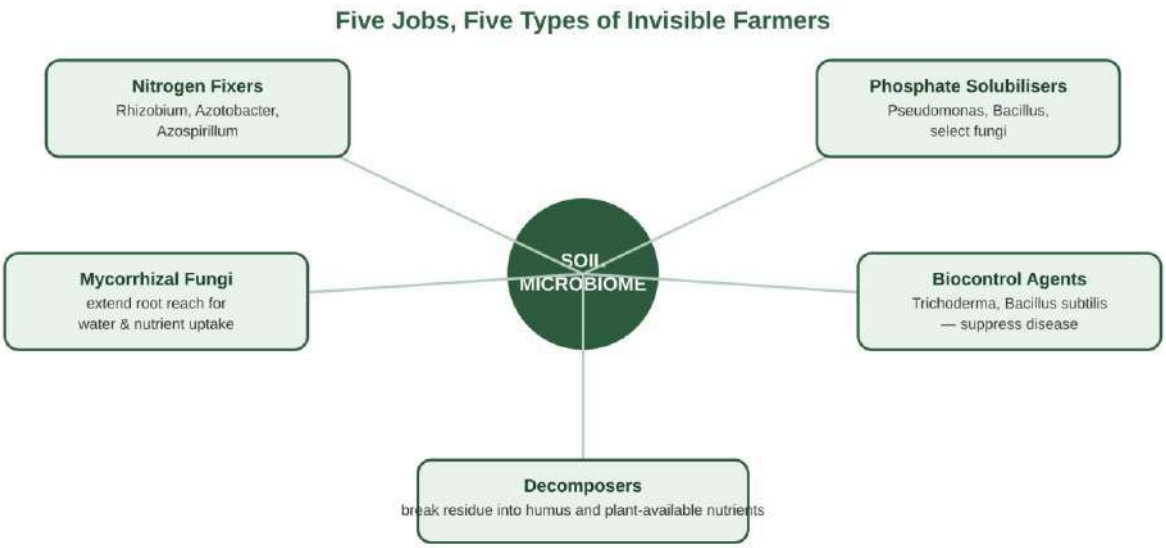


Figure 1: Five functional groups of soil microbes, each solving a different problem in the root zone.

This isn't a rare laboratory science. These organisms are already found in most farm soils. Biotechnology lets us choose the best strains, grow more of them, produce stable products, and deliver them to farmers in ways that work better and more reliably than nature alone.

This difference is important because it affects what farmers and decision-makers can expect from these products. Chemical fertilizers only work when they are applied, and their effects end once they are used up. Microbial inoculants are different since they are living. These organisms can multiply in the root zone and sometimes last throughout the season, which means you may not need to apply them as often. However, because they are living, their behaviour is less predictable. Living systems react to things like soil temperature, moisture, other microbes, and how you manage the soil, while a bag of urea stays the same no matter what.

How a Biofertilizer Is Actually Made

Knowing how these products are made helps explain why they work and why their quality can vary widely between manufacturers. It all begins by finding a promising strain, usually from soil near the roots of a strong, high-yield plant. The underlying hypothesis is that a thriving plant is likely associated with a robust microbial partner. Subsequently, each microbial strain is evaluated for specific traits, including nitrogen-fixation capacity, phosphorus-release efficiency, or pathogen-control effectiveness. Only a limited number of strains demonstrate sufficient and consistent performance for commercial application.

Once the strain is selected, it is grown in large amounts using fermentation. Then, it is combined with a carrier material. In the past, lignite or peat was used, but today liquid polymer mixtures are often chosen to extend its lifespan. The carrier protects the organism and ensures its survival during transport from the factory to the field. This stage is particularly sensitive, as exposure to heat, prolonged storage, or inadequate storage conditions may cause the organism to die before it is introduced into agricultural soil. Unlike chemical fertilizers, the activity of a biofertilizer cannot be determined through visual inspection or Odor. Even when batch numbers and expiry dates are provided on the packaging, it remains difficult to ascertain whether the microbial contents are viable.

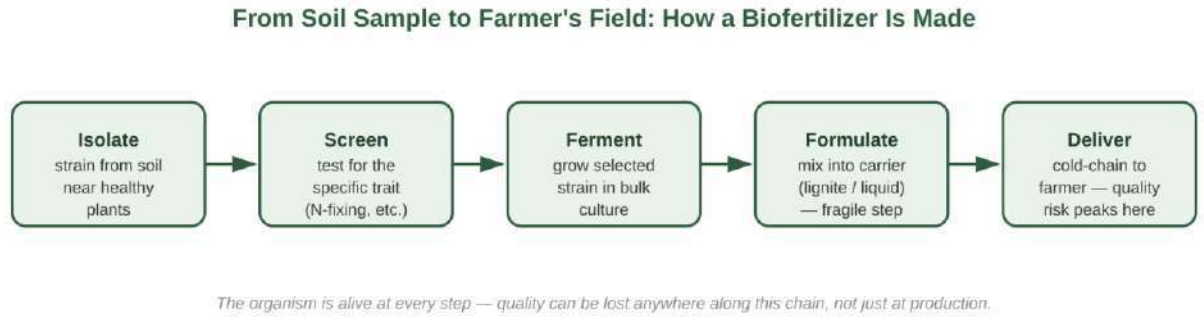


Figure 2: The production chain from soil sample to field application — viability can be lost at any link.

Beyond Nutrients: Microbes and Stress Tolerance

Recently, researchers have started to pay more attention to stress tolerance in plants, not just nutrition. Some bacteria and fungi, known as endophytes, live inside plant tissue and can help crops cope with drought, salty soil, and heat. These issues are occurring more often across many areas of India as rainfall patterns shift and groundwater levels decline. Some endophytes help by activating the plant's stress-response genes earlier and more strongly than the plant would on its own. Others produce compounds that help roots keep water or block extra salt from entering the cell membrane.

This matters more than a slight boost in soil fertility because it addresses a risk that chemical fertilizers cannot solve. Even with extra nitrogen or phosphorus, crops cannot survive three weeks without rain. Intentional enhancement of the soil microbiome to enhance stress tolerance serves as an intrinsic form of insurance within the root zone. However, this application

remains more experimental than nitrogen fixation or phosphate solubilization, and fewer large-scale, multi-season field results are currently available.

Why This Matters More Than It Used To

India's fertilizer economics are straightforward. The Union government expects to spend ₹1.7-1.9 lakh crore on fertilizer subsidies in 2025-26, making it one of the biggest items in the Union Budget. Most of this money goes to urea, which has been sold at ₹242 for a 45-kg bag since 2018. This price is much lower than the cost of production or import.

Chemical fertilizer use per hectare rose from about 136 kg in 2015-16 to around 141 kg in 2022-23. However, the benefits of using more fertilizer are going down. This situation is called an input trap. Farmers end up buying more fertilizer each year just to maintain the same yields, since the soil's ability to recycle nutrients has been reduced by the fertilizers that were supposed to help.

The fertilizer subsidy has increased affordability but has also altered farmers' application patterns. Nationally, the ratio of nitrogen, phosphorus, and potassium applied is approximately 10.9:4.4:1, whereas the recommended ratio is closer to 4:2:1. As a result, excessive nitrogen is applied relative to other nutrients. This imbalance is reflected in the data, as nutrient use efficiency in Indian agriculture remains low.

The subsidy has lowered fertilizer costs, but it has also affected how farmers use it. In India, the current ratio of nitrogen, phosphorus, and potassium applied is about 10.9:4.4:1, while the ideal ratio is closer to 4:2:1. Many farmers use too much nitrogen, which is cheaper, and not enough of the other nutrients. As a result, nutrient use efficiency in Indian fields is only around 35-40 percent.

More than half of the fertilizer does not get absorbed by crops. Instead, it is lost through runoff or evaporation, or it becomes trapped in forms that plants cannot use. The amount of grain produced per tonne of fertilizer has dropped from about 1:10 in the 1970s to around 1:2.7 today. This decline continues partly due to decades of dependence on chemical fertilizers, which have damaged the soil biology that once helped make nutrients available to plants.

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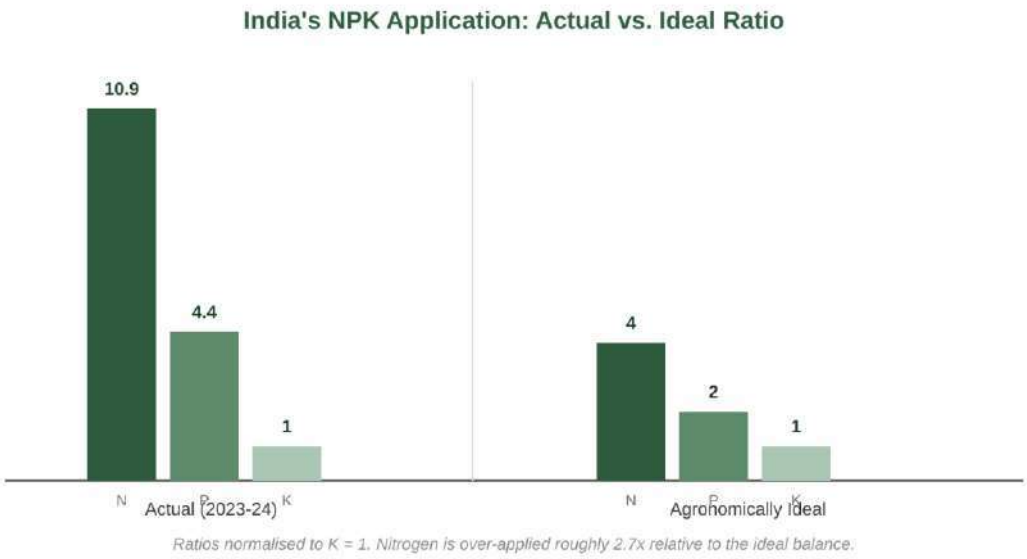


Figure 3: Actual nitrogen-phosphorus-potassium application versus the agronomically balanced ratio.

This issue goes beyond efficiency. Using too much nitrogen fertilizer leads to higher nitrous oxide emissions. This greenhouse gas is about 273 times as potent as carbon dioxide by weight. Now, the costs of fertilizer, soil health, and climate are all closely connected

What Biotechnology Actually Adds

Biofertilizers and microbial biopesticides cannot replace all chemical inputs, and no credible scientist says they can. Still, they do something chemical fertilizers cannot. They help restore the soil's natural nutrient-cycling ability rather than merely serving as a substitute each year.

If legume crops are inoculated with the right Rhizobium strains, they can get most of the nitrogen they need, and farmers can use less urea fertilizer. Phosphate-solubilizing bacteria and mycorrhizal inoculants help plants tap into phosphorus reserves that have built up in many Indian soils after years of fertilizer use, but which plants could not use before. Biocontrol agents such as Trichoderma help manage major soil-borne diseases, allowing farmers to rely less on chemical fungicides and reduce their environmental impact.

These inputs offer real economic benefits. When used correctly, studies show that fertilizer costs can fall by 15 to 25 percent for the treated crop, without reducing yields. Sometimes, yields even increase because the crop's roots become healthier, not just better fed.

India's Policy Push — and Its Gap

Government support for this change has shifted from scattered efforts to a more organized strategy. The PM-PRANAM program rewards states financially for reducing chemical fertilizer use and allocates much of that funding to building facilities for bio-inputs. The National Mission on Natural Farming is opening thousands of Bio-Input Resource Centers. These centers will produce and supply ready-to-use biofertilizers and biopesticides locally, so farmers do not have to rely on products imported from distant places. Established producers such as NAFED's biofertilizer units and ICAR-linked labs continue to supply Rhizobium, Azotobacter, and phosphate-solubilizing cultures to distribution networks nationwide.

Biofertilizer production has grown steadily in recent years. National carrier-based biofertilizer output rose from about 1.21 lakh tonnes in 2017-18 to over 3.25 lakh tonnes by 2022-23. Liquid formulations, which are newer and have a longer shelf life, saw even faster growth during this period. India's bio-inputs sector is also benefiting from the global agricultural biologicals market, which industry estimates put at around USD 15 billion in 2024 and projects will nearly triple by the early 2030s.

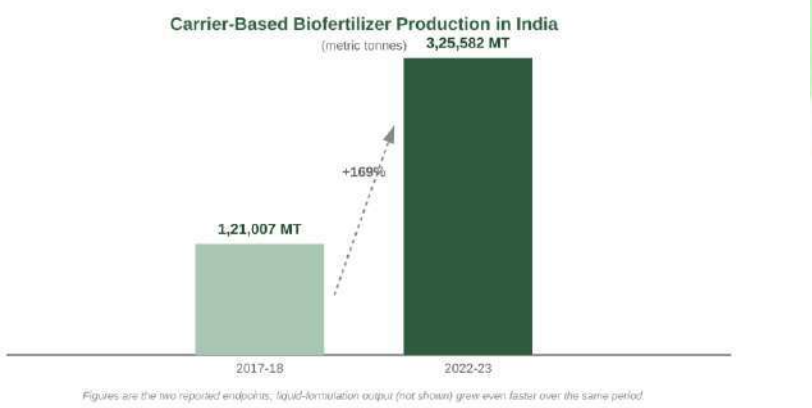


Figure 4: Growth in carrier-based biofertilizer production, the two reported endpoints.

The real problem is not with policy or how much is produced, but with how things are handled at the final step. Biofertilizers are living products, so they need to be kept cold, have expiry dates, and must be handled with care. Most rural supply chains are not set up for this. If a farmer buys a packet with dead or weak cultures for the same price as a good one, it damages trust more than not having the product at all. Just one bad experience can spread quickly through a village, much faster than any awareness campaign can repair. Ensuring quality control during production and keeping products cold during distribution are just as important as the science behind them.

Researchers have also noted that new Bio-Input Resource Centers lack sufficient funding to support reliable local production and storage

What the Field Trials Actually Show

Looking at specific numbers can be more helpful than just discussing theory. In a rice-legume cropping study in West Bengal, researchers found that when farmers treated pulse crops like lentil, gram, and lathyrus with Rhizobium, they could use 43 to 48 kilograms less nitrogen fertilizer per hectare without reducing yields. The treated crops were able to get much of their nitrogen from the air. In another study on mungbean, using only one microbial strain had little effect. But when Rhizobium was combined with a phosphate-solubilizing bacterium and a potassium-mobilizing organism, the yield improved noticeably. This improvement did not occur when any single organism was used alone.

The second finding matters more than it might seem. It shows these products are valuable not because of a single microbe, but because they bring together different organisms, each solving a separate problem, such as making nitrogen, phosphorus, and potassium available at once. Rather than relying on a single inoculant to do everything a chemical fertilizer does, the combination is what makes the difference.

The Honest Limitations

- Field results are not always the same. A microbial strain that thrives in one type of soil, pH level, or climate may not perform as well in a different setting. Unlike chemical fertilizers, biofertilizers are living organisms that adapt to their environment rather than supplying fixed amounts of nutrients.
- These products do not last as long as chemical inputs, and their quality can fall quickly if they are not stored properly. This becomes a real problem in places where cold-chain systems are unreliable.
- Improvements in soil health tend to happen slowly, not overnight, and it often takes more than one season to notice real changes. This is because these methods focus on rebuilding the soil's biological system rather than just giving it a quick nutrient boost.

Farmers who hear that these products will completely replace urea or double their yield in just one season are being given marketing promises, not scientific facts. The real benefit is more modest but lasting: when used properly, alongside balanced chemical fertilization rather than

replacing it, these microbes can lower input costs, help restore soil health over time, and reduce the environmental impact of the fertilizers India already uses.

Reframing the Soil

The biggest change this technology brings to Indian farming is not only about new tools, but about how we comprehend things. Soil is not just dead material we add fertilizer to. It is full of tiny living things, most of which are too small to see, that have quietly helped every harvest since farming began. Years of depending solely on chemicals have decreased these helpful organisms, and most farmers never even knew they were there. Biotechnology does not create something new; instead, it finds, supports, and brings back the natural team that has always been in the soil, working unnoticed.

The image of a farmer working in the field is still the most familiar symbol of Indian agriculture. But now, the harvest depends increasingly on another group of workers who often go unnoticed. The future sustainability of Indian agriculture will depend on how much is invested in these workers, whether through better crop varieties, improved storage, or sharing reliable information.

Conclusion

Sustainable agriculture relies not just on better crop varieties and modern farming methods, but also on accepting the important role of microorganisms in the soil. These helpful microbes work with plants to make nutrients more available, defend crops from disease, and help them cope with environmental stress. While they cannot fully replace chemical fertilizers, they can greatly reduce the need for them and help restore soil health and environmental balance. Thanks to biotechnology, we now have effective microbial inoculants that make farming more productive and environmentally friendly. For these efforts to succeed, there must be reliable quality control, good storage, better agricultural education, and encouraging policies. When India treats soil as a living ecosystem rather than merely a place for crops to grow, the country moves closer to an agricultural system that supports both production and environmental stewardship. Supporting these often-overlooked farmers is an investment in food security, healthy soil, and an increasingly sustainable future for everyone.

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BIOCHEMICAL CHARACTERIZATION OF ANTHOCYANIN FROM RED TAMARIND (*TAMARINDUS INDICA* VAR. RHODOCARPA): ANTIOXIDANT ACTIVITY, FUNCTIONAL PROPERTIES, AND NUTRACEUTICAL POTENTIAL

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Abstract

Red Tamarind is a rare anthocyanin-rich mutant with remarkable antioxidant and therapeutic potential. This article highlights its phytochemical importance, extraction, qualitative and quantitative analysis, and antioxidant evaluation. Anthocyanins were extracted using soxhlet extraction and confirmed through standard phytochemical tests, while their content and antioxidant activity were determined using the pH differential and DPPH assays, respectively. The high anthocyanin concentration imparts superior free radical scavenging activity, natural pigmentation, and diverse health benefits, including anti-inflammatory, cardioprotective, neuroprotective, antidiabetic, anti-obesity, and anticancer effects. With its excellent functional properties and broad applications in food, nutraceutical, pharmaceutical, and cosmetic industries, red Tamarind represents a promising, sustainable, and underutilized natural resource for value-added product development.

Red Tamarind: Rich in Anthocyanin

Tamarind (*Tamarindus indica* L.), a multipurpose tree belonging to the family Fabaceae, is widely cultivated across tropical and subtropical regions for its nutritional, medicinal, and economic value. Among its naturally occurring variants, red Tamarind is a

rare mutant found predominantly in the southern parts of India described by Senthilkumar *et al*., (2021). Unlike the common brown-pulped type, red Tamarind is distinguished by its striking reddish colour during the unripe stage, which is attributed to its exceptionally high anthocyanin content. Anthocyanins are natural plant pigments responsible for the red, purple, and blue colours of many fruits and vegetables. Beyond their colouring properties, these compounds are recognized for their powerful antioxidant activity and wide range of health-promoting effects, including anti-inflammatory, cardioprotective, neuroprotective, anti-diabetic, anti-obesity, and anticancer potential. Owing to these functional attributes, anthocyanins are increasingly being explored as natural alternatives to synthetic food colourants and as valuable ingredients in functional foods, nutraceuticals, and cosmetic formulations. Red tamarind is considered an exceptionally rich source of anthocyanins, with unripe red Tamarind fruits containing approximately 180–360 mg/g, a level considerably higher than that reported in several well-known anthocyanin-rich fruits such as grapes, cherries, and jamun. In addition to imparting an attractive natural red colour, these bioactive compounds enhance the body's antioxidant defence system by supporting key antioxidant enzymes that protect cells from oxidative stress. The unique combination of vibrant pigmentation, high anthocyanin concentration, and health-promoting properties makes red Tamarind a promising yet underutilized resource with significant potential for value addition and future applications in the food and health sectors.

Anthocyanin as Natural Antioxidant in Red Tamarind

Anthocyanins are water-soluble flavonoid pigments that not only impart the characteristic red coloration but also serve as potent natural antioxidants. Mamathashree *et al* ., (2022) stated that their antioxidant activity is primarily attributed to their ability to donate hydrogen atoms or electrons to neutralize reactive oxygen species (ROS) and other free radicals, thereby minimizing oxidative stress and protecting cellular components from oxidative damage. In addition, anthocyanins can chelate pro-oxidant metal ions and inhibit lipid peroxidation, further enhancing their antioxidant efficacy. The elevated anthocyanin concentration in red Tamarind is considered one of the major factors contributing to its strong antioxidant potential. Consequently, a higher total anthocyanin content is generally associated with greater free radical scavenging activity, making red Tamarind a promising functional fruit with considerable nutraceutical value. Owing to this close relationship, the

determination of total anthocyanin content, together with antioxidant activity, provides a reliable assessment of the bioactive potential and health-promoting properties of red Tamarind. These attributes highlight its potential as a valuable source of natural antioxidants for functional foods, nutraceuticals, and natural food colourants.

Extraction for Anthocyanin

- **Sample Collection:** Fresh unripe red Tamarind (*Tamarindus indica* var rhodocarpa) fruits were collected.
- **Sample Preparation:** The fruits were thoroughly washed to remove contaminants, shade-dried, pulverized into a fine powder, and sieved for extraction.
- **Soxhlet Extraction:** The powdered sample was successively extracted using methanol (65°C) in a Soxhlet apparatus for 5 hours with each solvent.
- **Filtration and Concentration:** Each extract was filtered through Whatman filter paper, re-extracted twice to maximize recovery, pooled, and concentrated using a rotary evaporator to remove the extraction solvents.
- **Storage and Phytochemical Analysis:** The concentrated extracts were dried in a desiccator and preserved at 4°C for subsequent qualitative and quantitative phytochemical analysis.

Qualitative Analysis of Anthocyanin

The presence of anthocyanin in the red Tamarind extract was determined by Rampriya *et al* ., (2019) for standard phytochemical screening. The extract was subjected to acid and alkaline tests to evaluate the characteristic colour changes of anthocyanin pigments. The appearance of a red colour under acidic conditions and its conversion to bluish-green or colourless under alkaline conditions confirmed the presence of anthocyanin.

Method	Procedure	Reagents	Result
Acid–Alkali Test	Treat the extract separately with acid and alkali.	HCl and NaOH	Red in acidic medium; blue/green or colourless in alkaline medium, indicating the presence of anthocyanins.
Ferric Chloride	Add ferric	1% $FeCl_3$	Greenish or bluish colour

Test	chloride solution to the extract.	solution	indicates the presence of phenolic compounds.
Lead Acetate Test	Add lead acetate solution to the extract.	10% Lead acetate solution	Bluish or purplish precipitate indicates the presence of anthocyanins.
Thin Layer Chromatography (TLC)	Apply the extract on a TLC plate and develop in a suitable solvent system.	Silica gel TLC plate and solvent system	Distinct coloured spots with characteristic Rf values confirm anthocyanins.

Estimation of Total Anthocyanin Content

The total monomeric anthocyanin content was determined using the pH differential method validated by Lee *et al.*, (2005). The extract was diluted separately with 0.025 M potassium chloride buffer (pH 1.0) and
0.4 M sodium acetate buffer (pH 4.5). After equilibration for 15 min at room temperature, the absorbance of each solution was measured at 520 nm and 700 nm using a UV–Visible spectrophotometer, with the corresponding buffer using as the blank.

Method	Procedure	Reagents	Results
pH Differential Method	Measure absorbance of the extract at pH 1.0 and pH 4.5 using a UV–Vis spectrophotometer.	Potassium chloride buffer, Sodium acetate buffer	Total anthocyanin content (mg C3G/g)
Single pH Method	Measure the absorbance of the extract at the maximum wavelength.	Acidified solvent	Anthocyanin content (mg C3G/g)
HPLC-DAD	Separate and quantify anthocyanins using HPLC.	HPLC solvent	Individual anthocyanins (mg/g)

		s, Anthocyanin standards	
LC–MS/MS	Identify and quantify anthocyanins using LC–MS/MS.	LC–MS solvent s, Anthocyanin standards	Individual anthocyanins (mg/g)

Determination of Antioxidant Activity

The antioxidant potential of the anthocyanin-rich extracts was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay. The decrease in absorbance following reaction with DPPH solution was measured spectrophotometrically, and the antioxidant activity was expressed as percentage radical scavenging activity (% inhibition) (Swathi *et al*., 2025).

$$\text{DPPH scavenging activity (\%)} = \frac{\text{Absorption (DPPH)} - \text{Absorption sample}}{\text{Absorption DPPH}} \times 100$$

Functional Attributes of Anthocyanin

- **Natural Red Pigment:** Imparts an attractive red to purple colour, making it a potential natural alternative to synthetic food colourants.
- **Powerful Antioxidant Activity:** Effectively scavenges free radicals and protects cells from oxidative stress.
- **Water Solubility:** Easily dissolves in aqueous solutions, facilitating its incorporation into food, beverage, and pharmaceutical formulations.
- **pH-Sensitive Colour Stability:** Exhibits characteristic colour changes under different pH conditions, making it useful as a natural pH indicator.
- **Anti-inflammatory Potential:** Helps reduce inflammation by modulating oxidative stress and inflammatory pathways.
- **Antimicrobial Activity:** Exhibits inhibitory effects against selected foodborne and pathogenic microorganisms.
- **Health-Promoting Properties:** Associated with cardioprotective, neuroprotective, anti-diabetic, anti-obesity, and anticancer activities owing to its high antioxidant capacity.

- **Functional Food Ingredient:** Serves as a valuable bioactive compound for the development of functional foods and nutraceutical products.
- **Cosmetic Applications:** Used as a natural colourant and antioxidant ingredient in cosmetic and personal care formulations.
- **Sustainable Natural Resource:** Represents a promising plant-based source of eco-friendly, biodegradable natural pigments with high commercial potential.

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NANO FERTILIZERS: THE FUTURE OF INDIAN AGRICULTURE

Article ID: AG-V06-I07-50

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Abstract

Indian agriculture has made remarkable progress in achieving food security through the widespread adoption of chemical fertilizers. However, the indiscriminate and imbalanced use of conventional fertilizers has resulted in declining nutrient use efficiency, soil degradation, environmental pollution, and rising production costs. Nanotechnology has emerged as a transformative approach to address these challenges through the development of nano fertilizers. Nano fertilizers contain nutrients in particles ranging from 1 to 100 nanometres, enabling controlled nutrient release, targeted delivery, and enhanced nutrient absorption by plants. Among these, nano urea and nano diammonium phosphate (nano DAP) have gained significant attention in India due to their potential to improve crop productivity while reducing fertilizer consumption and environmental losses. Field demonstrations across diverse agro-climatic regions have reported improvements in crop growth, nutrient use efficiency, yield, and profitability when nano fertilizers are integrated with recommended fertilizer practices. Besides improving agricultural productivity, nano fertilizers contribute to environmental sustainability by minimizing nutrient losses, reducing greenhouse gas emissions, and protecting soil and water resources. Nevertheless, their successful adoption depends on scientific application, crop-specific recommendations, and integration with conventional fertilizers and biofertilizers under integrated nutrient management systems. This article discusses the concept, types, advantages, field performance, economic and environmental benefits, limitations, and future prospects of nano

fertilizers, highlighting their potential role in achieving sustainable and climate-resilient agriculture in India.

Keywords: Nano fertilizers, Nano urea, Nano DAP, Nutrient use efficiency, Sustainable agriculture, Precision nutrient management, Indian agriculture, Nanotechnology.

1. Introduction

Agriculture remains the backbone of the Indian economy, providing livelihood to nearly half of the country's population while ensuring national food and nutritional security. Since the Green Revolution, the extensive use of chemical fertilizers such as urea and diammonium phosphate (DAP) has played a crucial role in enhancing agricultural productivity. However, the continuous and indiscriminate application of conventional fertilizers has created several challenges, including declining soil fertility, nutrient imbalance, groundwater contamination, greenhouse gas emissions, and increasing production costs.

One of the major concerns associated with conventional fertilizers is their poor nutrient use efficiency. Studies indicate that crops utilize only about 30–50% of applied nitrogen, while phosphorus use efficiency often remains below 20%, with the remaining nutrients being lost through leaching, volatilization, runoff, or fixation in the soil. These losses not only reduce fertilizer efficiency but also contribute significantly to environmental pollution and economic losses for farmers.

The growing demand for higher agricultural productivity, coupled with increasing concerns regarding environmental sustainability, has created the need for innovative nutrient management strategies. In this context, nanotechnology has emerged as one of the most promising scientific advancements in modern agriculture. Nano fertilizers represent a new generation of fertilizers designed to improve nutrient delivery and maximize nutrient utilization while minimizing losses to the environment.

Nano fertilizers consist of nutrients encapsulated or formulated into particles ranging between 1 and 100 nanometres. Owing to their extremely small particle size, large surface area, and unique physicochemical properties, they provide controlled nutrient release and targeted nutrient delivery. Consequently, crops are able to absorb nutrients more efficiently, resulting in improved growth, higher productivity, enhanced fertilizer use efficiency, and reduced environmental impact.

Recognizing their immense potential, India has become one of the pioneering countries in promoting nano fertilizers, particularly nano urea and nano DAP, for sustainable agriculture. These products have been developed to supplement conventional fertilizers rather than completely replace them, thereby supporting integrated nutrient management practices. Their adoption is expected to play a significant role in improving resource-use efficiency, reducing cultivation costs, enhancing farmers' income, and promoting climate-resilient agricultural systems.

This article provides a comprehensive overview of nano fertilizers, including their principles, advantages, applications, field performance, economic and environmental benefits, limitations, and future prospects for Indian agriculture.

2. What are Nano Fertilizers?

Nano fertilizers are advanced nutrient formulations developed using nanotechnology in which essential plant nutrients are delivered in the form of particles measuring between 1 and 100 nanometres. At this nanoscale, materials exhibit unique physical, chemical, and biological properties that differ considerably from their conventional forms.

Unlike traditional fertilizers that release nutrients rapidly after soil application, nano fertilizers are designed to provide controlled and site-specific nutrient release, thereby enhancing nutrient use efficiency and minimizing nutrient losses. Their exceptionally high surface area, greater reactivity, and improved mobility enable rapid absorption by plants through leaf stomata, cuticular pores, and root tissues.

Nano fertilizers may be applied as foliar sprays, soil applications, or seed treatments, depending on the crop and nutrient requirement. Among these methods, foliar application has proved particularly effective because nutrients are directly absorbed through leaves, bypassing several soil-related constraints such as nutrient fixation and leaching.

The development of nano fertilizers represents a paradigm shift from bulk fertilizer application towards precision nutrient management, where nutrients are supplied in the right quantity, at the right time, and at the right place.

Major characteristics of nano fertilizers

- Particle size ranges between 1 and 100 nanometres.
- Possess extremely high surface area and reactivity.
- Provide slow and controlled nutrient release.

- Improve nutrient absorption efficiency.
- Reduce nutrient losses through leaching and volatilization.
- Require smaller quantities than conventional fertilizers.
- Enhance fertilizer use efficiency and crop productivity.

Nano fertilizers therefore offer an environmentally friendly and resource-efficient alternative for sustainable crop nutrition.

Table 1. Comparison between Conventional Fertilizers and Nano Fertilizers

Parameter	Conventional Fertilizers	Nano Fertilizers
Particle size	Micrometre scale	1–100 nm
Nutrient release	Rapid and uncontrolled	Slow and controlled
Nutrient use efficiency	Relatively low	High
Nutrient losses	High through leaching, volatilization and fixation	Significantly reduced
Mode of application	Mainly soil application	Foliar, soil and seed treatment
Quantity required	High	Low
Environmental impact	Comparatively higher	Lower
Crop response	Moderate	Better growth and higher productivity

3. Why Do We Need Nano Fertilizers?

The increasing demand for food production, coupled with shrinking natural resources and climate change, has intensified the need for more efficient nutrient management practices. Conventional fertilizers have undoubtedly contributed to remarkable gains in agricultural productivity; however, their efficiency remains relatively poor due to significant nutrient losses after application.

Nitrogen fertilizers, particularly urea, suffer substantial losses through ammonia volatilization, nitrate leaching, denitrification, and surface runoff. Similarly, phosphorus fertilizers become fixed in the soil shortly after application, rendering a large proportion

unavailable to crops. Consequently, farmers often apply fertilizers in excess to compensate for these losses, which further aggravates environmental degradation and increases cultivation costs. Nano fertilizers have been developed specifically to overcome these limitations. Their controlled nutrient release and targeted delivery mechanisms substantially improve nutrient availability to plants while reducing losses to the environment. Because nutrients are supplied in nano-sized particles, plants can absorb them more efficiently, resulting in higher nutrient use efficiency, improved crop growth, and better yield.

The adoption of nano fertilizers also aligns with the principles of precision agriculture, where inputs are optimized to maximize productivity while conserving natural resources. This makes nano fertilizers an important component of sustainable and climate-smart agricultural systems.

The major reasons for adopting nano fertilizers include:

- Enhanced nutrient use efficiency.
- Reduced fertilizer consumption.
- Lower production costs.
- Improved crop growth and productivity.
- Reduced environmental pollution.
- Better soil health.
- Higher profitability for farmers.
- Promotion of sustainable agricultural development.

4. Nano Urea: A Breakthrough in Nitrogen Management

Nitrogen is the most important macronutrient required for plant growth and development. It is a major constituent of chlorophyll, amino acids, proteins, nucleic acids, and enzymes that regulate various physiological and biochemical processes in plants. Adequate nitrogen nutrition promotes vigorous vegetative growth, enhances photosynthesis, improves biomass production, and ultimately increases crop yield. However, despite its importance, nitrogen use efficiency (NUE) from conventional urea remains low, generally ranging from **30–50%**, because a substantial proportion of the applied nitrogen is lost through volatilization, leaching, runoff, and denitrification (FAO, 2022; ICAR, 2023).

To address these limitations, nano urea has emerged as an innovative fertilizer technology capable of improving nitrogen use efficiency while reducing environmental losses.

Nano urea is a liquid fertilizer containing nitrogen in nano-sized particles that are readily absorbed through leaf stomata and cuticular pores. Unlike conventional urea, which is primarily applied to the soil, nano urea is applied as a foliar spray, ensuring rapid absorption and efficient utilization by plants.

The Government of India and the Indian Farmers Fertiliser Cooperative Limited (IFFCO) have promoted nano urea as a supplementary source of nitrogen to improve fertilizer efficiency and reduce dependence on conventional urea. It is intended to supplement recommended fertilizer doses rather than completely replace soil-applied nitrogen fertilizers.

4.1 Advantages of Nano Urea

Nano urea offers several agronomic, economic, and environmental advantages over conventional nitrogen fertilizers:

- Enhances nitrogen use efficiency through targeted nutrient delivery.
- Provides rapid absorption by leaves.
- Improves chlorophyll synthesis and photosynthetic activity.
- Promotes vigorous vegetative growth and better crop vigour.
- Reduces nitrogen losses through volatilization and leaching.
- Lowers fertilizer requirement and transportation costs.
- Reduces greenhouse gas emissions associated with excessive nitrogen application.
- Improves grain quality and overall crop productivity.
- Supports sustainable and climate-resilient agriculture.

4.2 Field Performance of Nano Urea

Extensive multilocational field demonstrations conducted across India have confirmed the effectiveness of nano urea under diverse agro-climatic conditions. Demonstrations conducted on cereals, pulses, oilseeds, vegetables, and horticultural crops have consistently reported improvements in crop growth, nutrient uptake, and productivity.

Important findings from these demonstrations include:

- More than **75,000 field demonstrations** have been conducted across different crops in India.
- Average yield improvement of approximately **5–6%** has been reported under recommended application practices.

- Yield enhancement ranging from **4–7%** has been observed under several state-level demonstrations, including eastern India.
- Farmers have reported improved crop vigour, greener foliage, better grain filling, and superior produce quality.
- Nano urea has shown the best performance when integrated with recommended fertilizer doses rather than used as a complete substitute.

These findings indicate that nano urea can significantly improve nitrogen use efficiency while reducing the quantity of conventional urea required in crop production systems.

5. Nano DAP: Improving Phosphorus Use Efficiency

Phosphorus is the second major nutrient required by crops after nitrogen. It plays a vital role in root growth, energy transfer, flowering, seed formation, and early crop establishment. However, phosphorus availability in soils is generally limited because a large proportion of applied phosphorus becomes chemically fixed into insoluble compounds shortly after fertilizer application. Consequently, phosphorus use efficiency from conventional DAP often remains below **20%**, resulting in substantial nutrient losses and increased fertilizer requirements.

Nano diammonium phosphate (Nano DAP) has been developed to improve phosphorus availability and utilization by crops. Nano DAP is a liquid fertilizer containing nitrogen and phosphorus in nano form. Due to its nano-sized particles, nutrients are readily absorbed by plant tissues when applied as a foliar spray, thereby improving nutrient availability during critical growth stages.

Nano DAP supplements conventional phosphorus fertilizers by enhancing nutrient uptake efficiency and improving crop growth while reducing phosphorus losses.

5.1 Benefits of Nano DAP

The major advantages of nano DAP include:

- Promotes rapid root development and seedling establishment.
- Improves flowering, fruiting, and seed development.
- Enhances phosphorus uptake efficiency.
- Improves nitrogen utilization simultaneously.
- Increases nutrient availability during critical crop growth stages.
- Reduces dependence on conventional DAP fertilizers.
- Supports balanced nutrient management.

5.2 Field Evidence of Nano DAP

Recent research conducted under different cropping systems has demonstrated that nano DAP performs effectively when integrated with recommended fertilizer practices and beneficial microorganisms.

Several studies have reported that the application of **75% recommended dose of fertilizers (RDF)** together with nano urea, nano DAP, and biofertilizers such as **Azospirillum** and phosphate-solubilizing bacteria (PSB) resulted in:

- Higher biomass production.
- Increased nutrient uptake.
- Improved nutrient use efficiency.
- Enhanced crop productivity.
- Greater economic returns.
- Better fertilizer use efficiency compared with conventional fertilization alone.

These findings indicate that nano DAP is particularly effective as a component of integrated nutrient management rather than as a complete replacement for conventional phosphorus fertilizers.

Table 2. Major Nano Fertilizers and Their Agricultural Benefits

Nano Fertilizer	**Major Nutrient**	**Principal Benefits**
Nano Urea	Nitrogen (N)	Higher nitrogen use efficiency, improved chlorophyll synthesis, enhanced vegetative growth
Nano DAP	Nitrogen and Phosphorus	Better root development, flowering, nutrient uptake and seed formation
Nano Zinc	Zinc	Corrects zinc deficiency, improves enzyme activity and crop quality
Nano Iron	Iron	Enhances chlorophyll synthesis and prevents iron chlorosis
Nano Copper	Copper	Improves disease resistance and physiological activities
Nano Boron	Boron	Improves flowering, pollen viability and fruit set

6. Importance of Nano Fertilizers in Sustainable Agriculture

The importance of nano fertilizers extends beyond improving crop productivity. They represent a significant advancement in precision nutrient management and sustainable agriculture by ensuring that nutrients are delivered efficiently to plants while minimizing adverse environmental impacts. The major contributions of nano fertilizers include:

6.1 Improved Nutrient Use Efficiency: Nano fertilizers increase nutrient absorption because their extremely small particle size allows efficient penetration into plant tissues. Controlled nutrient release ensures continuous nutrient availability during crop growth, thereby improving fertilizer use efficiency.

6.2 Higher Crop Productivity: Enhanced nutrient availability promotes vigorous plant growth, improved photosynthesis, greater biomass accumulation, and higher yields. Many field demonstrations have shown consistent improvements in crop performance following the adoption of nano fertilizers.

6.3 Reduced Fertilizer Requirement: Because nutrients are utilized more efficiently, lower quantities of fertilizers are required to achieve comparable or higher yields. This contributes to reduced fertilizer consumption and lower production costs.

6.4 Environmental Protection: Nano fertilizers reduce nutrient losses through leaching, volatilization, and runoff, thereby minimizing groundwater contamination, eutrophication of water bodies, and greenhouse gas emissions.

6.5 Improved Soil Health: Balanced nutrient application helps maintain soil fertility, encourages beneficial microbial activity, and reduces nutrient imbalance associated with excessive fertilizer use.

6.6 Climate-Resilient Agriculture: Efficient nutrient management contributes to climate-smart agriculture by lowering the carbon footprint associated with fertilizer production and application while improving resource-use efficiency under changing climatic conditions.

7. Economic Benefits of Nano Fertilizers: The adoption of nano fertilizers offers significant economic advantages to farmers by improving nutrient use efficiency and reducing fertilizer consumption. Conventional fertilizers often require repeated applications because of substantial nutrient losses through leaching, volatilization, runoff, and soil fixation. Nano fertilizers, owing to their controlled-release properties and higher absorption efficiency, enable crops to utilize nutrients more effectively, thereby reducing input costs.

Field demonstrations conducted across different agro-climatic regions of India have shown that the combined application of nano fertilizers with recommended fertilizer doses can increase crop yield by approximately **3–8%**, while reducing the requirement for conventional fertilizers. In several farmer demonstrations, higher profitability has been attributed to lower fertilizer consumption, improved crop quality, and increased marketable yield.

The major economic benefits include:

- Reduced expenditure on chemical fertilizers.
- Improved fertilizer use efficiency.
- Increased crop productivity.
- Better quality produce and enhanced market value.
- Higher net returns through improved yield and reduced input costs.
- Improved benefit–cost ratio under integrated nutrient management.

As the adoption of nano fertilizers expands, they are expected to contribute substantially to improving farmers' income while ensuring sustainable agricultural production.

8. Environmental Benefits

Environmental sustainability has become a major concern in modern agriculture because excessive fertilizer use contributes to soil degradation, groundwater contamination, eutrophication of water bodies, and greenhouse gas emissions. Nano fertilizers offer an environmentally friendly alternative by improving nutrient utilization and reducing nutrient losses.

The controlled-release characteristics of nano fertilizers ensure that nutrients remain available to crops for a longer duration, thereby minimizing leaching, volatilization, and runoff. Consequently, lower quantities of fertilizers are required to achieve similar or higher crop yields.

Major environmental benefits include:

- Reduced nitrate leaching into groundwater.
- Lower emission of ammonia and nitrous oxide.
- Reduced contamination of rivers, lakes, and reservoirs.
- Improved soil biological activity.
- Better maintenance of soil fertility.
- Conservation of natural resources through efficient nutrient utilization.
- Reduced carbon footprint associated with fertilizer production and transportation.

Thus, nano fertilizers support environmentally sustainable and climate-smart agriculture by improving resource-use efficiency while minimizing adverse ecological impacts.

9. Limitations and Challenges

Despite their enormous potential, nano fertilizers are not free from limitations. Their effectiveness depends on crop species, soil properties, climatic conditions, and management practices. Scientific recommendations are therefore essential for obtaining consistent benefits.

The major limitations include:

- Nano fertilizers should supplement and not completely replace conventional fertilizers.
- Their performance varies among crops and agro-climatic regions.
- Long-term studies on environmental and soil health impacts are still limited.
- Farmers require proper training regarding dosage, timing, and method of application.
- Commercial availability is currently limited compared with conventional fertilizers.
- Additional research is needed to develop crop-specific recommendations and evaluate long-term safety.

Therefore, a balanced and evidence-based approach is necessary to maximize the benefits of nano fertilizer technology.

10. Government Initiatives in India

Recognizing the importance of nanotechnology in agriculture, the Government of India has taken several initiatives to promote the adoption of nano fertilizers. Nano Urea (Liquid) and Nano DAP have been notified under the Fertilizer Control Order (FCO) following bio-efficacy and safety evaluations. Government agencies, research institutions, fertilizer companies, and State Agricultural Universities are actively conducting demonstrations and awareness programmes to promote their scientific use.

Key initiatives include:

- Promotion of Nano Urea and Nano DAP under the Fertilizer Control Order.
- Large-scale field demonstrations across different agro-climatic zones.
- Training programmes through Krishi Vigyan Kendras (KVKs).
- Collaboration among ICAR institutes, State Agricultural Universities, and fertilizer industries.
- Promotion of balanced and integrated nutrient management.

These initiatives are expected to accelerate the adoption of nano fertilizers and contribute to sustainable agricultural development in India.

11. Future Prospects

Nano fertilizers are expected to play a pivotal role in the future of Indian agriculture. Continuous advancements in nanotechnology, precision agriculture, and smart farming are likely to improve the efficiency, affordability, and accessibility of nano-based nutrient formulations.

Future research should focus on:

- Developing crop-specific nano fertilizer formulations.
- Improving controlled nutrient-release technologies.
- Integrating nano fertilizers with precision agriculture tools.
- Studying long-term impacts on soil microorganisms and ecosystem health.
- Enhancing compatibility with biofertilizers and organic nutrient sources.
- Developing multi-nutrient nano formulations for balanced crop nutrition.

With continued research, policy support, and farmer awareness, nano fertilizers have the potential to transform nutrient management while contributing to higher productivity, improved profitability, and sustainable agricultural development.

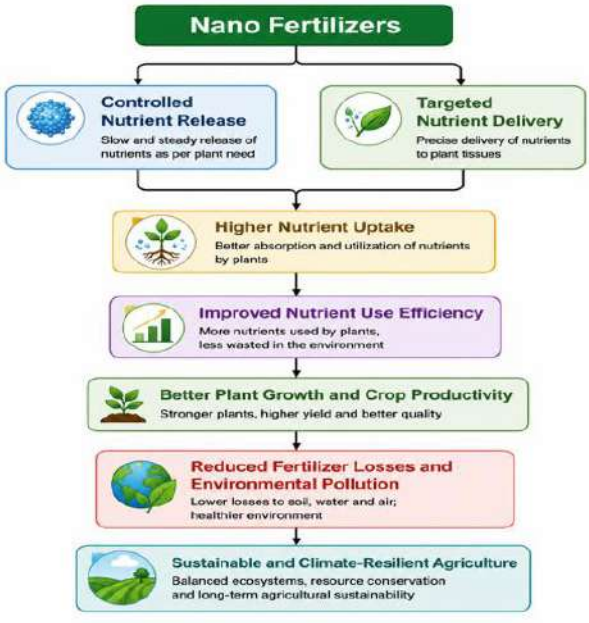


Figure 1. Conceptual mechanism of nano fertilizer action for improving nutrient use efficiency and sustainable agriculture.

Conclusion

Nano fertilizers represent one of the most promising innovations in plant nutrient management and sustainable agriculture. Their ability to enhance nutrient use efficiency, improve crop productivity, reduce fertilizer losses, and minimize environmental pollution makes them an attractive alternative to conventional fertilizer practices. Products such as nano urea and nano DAP have demonstrated encouraging results under diverse agro-climatic conditions, particularly when integrated with recommended fertilizer doses and other components of integrated nutrient management.

Although additional long-term research is required to optimize crop-specific recommendations and evaluate ecological impacts, current evidence suggests that nano fertilizers can significantly contribute to improving agricultural productivity while conserving natural resources. Their adoption will support precision farming, climate-resilient agriculture, and sustainable intensification of crop production. With continued scientific research, government support, and farmer awareness, nano fertilizers are expected to play a crucial role in ensuring food security, enhancing farmers' income, and promoting environmentally sustainable agriculture in India.

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FROM AN ORDINARY FARMER TO A NATIONAL AWARD WINNER: THE INSPIRING JOURNEY OF SANJIV KUMAR OF BIHAR

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Introduction

India's agricultural sector has witnessed remarkable contributions from progressive farmers who have transformed traditional farming into profitable and sustainable enterprises through innovation. Among these inspiring individuals is **Sanjiv Kumar**, a progressive farmer from **Chakwara village in Vaishali district, Bihar**. Despite having only school-level education and limited resources, he became one of India's most respected farmer-innovators by developing an improved cauliflower variety and promoting scientific seed production.

His journey demonstrates that dedication, practical knowledge, and continuous experimentation can bring national recognition while improving the lives of hundreds of farming families.

Early Life and Challenges

Sanjiv Kumar was born into a farming family in Chakwara village. Like most farmers in Bihar, his family depended on agriculture for their livelihood. Traditional cultivation methods generated only modest income, and many young people from the village migrated to cities in search of employment.Although he did not receive formal agricultural education, Sanjiv possessed a deep interest in crop improvement. Instead of accepting low farm productivity as inevitable, he believed that farmers themselves could innovate through careful observation and field experimentation.

The early years were difficult. Financial constraints, limited access to quality seed, and skepticism from fellow farmers tested his determination. Rather than giving up, he invested his time in learning improved cultivation techniques through training programmes conducted by agricultural institutions and by experimenting in his own fields.

Innovation in Cauliflower Seed Production

Around **2005**, Sanjiv Kumar began improving local cauliflower germplasm through continuous selection of healthy, vigorous, early-maturing plants with compact white curds. After several years of field trials and selection, he developed an improved cauliflower line known as **"Sanjiv Selection (SS)."**

The variety became popular because it offered:

- Early maturity (about 60–70 days)
- Large, compact white curds
- High yield
- Better seed vigour
- Good adaptability across different climatic regions

Field evaluations conducted with support from agricultural institutions confirmed that the variety produced excellent yields and quality. Its germplasm also contributed to the development of the **'Sabour Agrim'** cauliflower variety by Bihar Agricultural University.

Formation of Annadata Krishak Club

Recognizing that individual success alone would not transform rural communities, Sanjiv established the **Annadata Krishak Club** in 2005 with support from NABARD and the Bank of India.

Initially, only a small group of farmers joined the initiative. Through regular training, demonstrations, and sharing of improved production techniques, Sanjiv encouraged farmers to adopt scientific cauliflower seed cultivation.

Within a few years:

- More than **100 farmers** adopted commercial cauliflower seed production.
- Farmers began marketing branded seeds across India.
- Many unemployed rural youth chose agriculture instead of migrating for work.
- Women's participation and local employment also increased significantly.

Transforming Chakwara Village

Before the introduction of commercial seed production, Chakwara was an economically struggling village. Today, it is widely recognized for its successful cauliflower seed industry.

Farmers from the village supply seeds to states including:

- Uttar Pradesh

- Punjab
- Haryana
- Jharkhand
- West Bengal
- Madhya Pradesh
- Chhattisgarh

The village has become an example of how scientific agriculture and entrepreneurship can generate prosperity. The success attracted visits from senior policymakers, including Bihar Chief Minister **Nitish Kumar**, who observed the transformation firsthand.

Major Awards and Achievements

Sanjiv Kumar's contributions have earned recognition from national institutions and the Government of India.

1. National Grassroots Innovation Award (2019)

The highest recognition in his career came when he received the **National Grassroots Innovation Award** from the President of India, **Ram Nath Kovind**, for developing the innovative cauliflower variety **Sanjiv Selection**. He became the **first farmer from Bihar** to receive this prestigious honour.

2. Plant Genome Saviour Farmer Reward (2015)

He received the **Plant Genome Saviour Farmer Reward** from the Government of India for conserving valuable cauliflower genetic resources and sharing germplasm that supported the development of improved varieties. The award included recognition from the National Gene Fund.

3. Jagjivan Ram Innovative Farmer Award (2016)

The **Indian Council of Agricultural Research (ICAR)** honoured Sanjiv Kumar with the **Jagjivan Ram Innovative Farmer Award** for promoting commercial vegetable seed production, greenhouse cultivation, entrepreneurship, and employment generation.

4. Progressive Farmer Award (2010)

The **Indian Agricultural Research Institute (IARI), New Delhi**, honoured him with the **Progressive Farmer Award** for his outstanding work in vegetable seed production and technology dissemination.

5. Udyan Ratna Award (2011)

He received the **Udyan Ratna Award** for innovation and outstanding contributions to horticulture and rural prosperity through scientific vegetable seed production.

Other Recognitions

- National Silver Medal from the Indian Institute of Vegetable Research (2009).
- Invited speaker at the **India International Science Festival (2019)** to share his experience in cauliflower seed production and grassroots innovation.

Impact on Farmers and Society

Sanjiv Kumar's work extends far beyond his own farm.

His initiatives have:

- Created employment opportunities for hundreds of rural youth and women.
- Reduced migration by making agriculture more profitable.
- Improved farmers' incomes through branded seed production.
- Promoted scientific farming and entrepreneurship.
- Inspired farmers across Bihar to adopt modern agricultural practices.

His efforts transformed cauliflower seed cultivation into a successful rural enterprise and demonstrated that innovation at the farm level can strengthen the entire agricultural economy.

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TISSUE CULTURE IN BANANA CULTIVATION: A REVIEW OF ITS IMPACT ON DISEASE MANAGEMENT, YIELD IMPROVEMENT AND SUSTAINABLE PRODUCTION

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Abstract

and crop losses, supporting more environmentally friendly farming methods. In several tropical and subtropical areas, bananas (*Musa* spp.) are an important food source and commercial crop. Disease transmission and production uncertainty are common problems with traditional propagation techniques such as suckers. By supplying consistent, high-quality, and disease-free planting material, tissue culture, known as micro propagation, represents a potential alternative. The application of tissue culture has greatly enhanced disease management in banana cultivation. Reducing the incidence of ailments like Fusarium wilt, bacterial wilt, and Banana Bunchy Top Virus (BBTV), pathogen-free plantlets are grown in controlled conditions. This strategy lessens the demand for artificial fertilizers while also promoting healthier crops and lessening the impact on the environment. Micro propagated banana plants demonstrated consistent growth, early fruiting, and increased yield in contrast to conventionally propagated plants. Tissue-cultured plants exhibit strong development and genetic uniformity, which contribute to these advantages and more consistent and dependable harvests. By promoting efficient land use and reducing the need for chemical inputs, tissue culture enhances sustainability in the production of bananas. The growing demand for bananas

may be met without requiring the increase of agricultural land thanks to tissue culture techniques, which enable the large-scale production of enhanced banana cultivars at a quick rate. Furthermore, using planting material free of disease lowers input costs

Keywords: Tissue culture, micropropagation, disease resistance and genetic transformation.

Introduction

Banana (Musa spp.) is a herbaceous perennial monocot belonging to the Musaceae family and is cultivated in more than 130 tropical and subtropical countries. It is the world's fourth most important food crop after rice, wheat, and maize, serving as a major source of nutrition and income. Banana fruits are rich in carbohydrates, vitamins A, C, and B6, proteins, and essential minerals such as potassium, calcium, magnesium, and manganese. Besides the fruit, other plant parts, including the pseudo stem, peel, leaves, rhizome, and flowers, have significant industrial and value-added applications. Conventional propagation through suckers often results in non-uniform plants and disease transmission. Therefore, tissue culture has emerged as an effective technique for rapid multiplication of disease-free, true-to-type planting material with uniform growth and higher productivity. Successful micropropagation has been achieved using shoot tips, male flower apices, and somatic embryogenesis. Banana cultivation requires balanced nutrition, with nitrogen promoting vegetative growth, phosphorus supporting root development, and potassium playing a critical role in fruit development and yield. Secondary and micronutrients, including calcium, magnesium, sulfur, zinc, manganese, boron, iron, and copper, are also essential for healthy growth and optimum productivity.

Micropropagation (Shoot Tip Culture)

Berg and Bustamante were the first authors to publish on the application of banana tissue culture. They found that using thermotherapy in conjunction with banana meristem stem culture could produce virus-free plants. To quickly increase planting material free of Fusarium wilt, Ma and Shi used Cavendish (AAA) shoot tips that had been dissected from suckers. Since then, several features of banana tissue culture have been studied as a catalyst for optimizing banana production, and banana micro propagation has been used in a wide range of cultivars. Earlier in the 1980s, tissue culture banana plantlets were planted in large fields for the first time in Taiwan and Jamaica.

Source and Selection of an Explant

Small plant fragments, known as explants are used to initiate plant tissue cultures.

Explants may be effectively obtained from almost any plant section. Many explants have been used to induce banana micropropagation, such as meristems, corm tissue, leaf bases, immature zygotic embryos, and immature male and female flowers. Nonetheless, Mayawati and Kariyana state that the most often utilized explants for banana micropropagation are the tips of the banana shoots.Young suckers' shoot tips, which should range in height from 40 to 100 cm, are used as explants for rapidly reproducing bananas in vitro. The apical meristem-containing tissue, ranging in volume from 1 to 2 cubic centimeters, is separated from the banana suckers in these shoots. Any plant portion that has a shoot meristem that is, the horizontal, small suckers, paternal pseudo stem, and peepers will usually be the starting point for the creation of shoot cultures.

Surface Sterilization of an Explant

One of the most significant challenges in establishing and keeping an in vitro culture functional is microbial contamination. Microorganisms may contaminate field-grown plants; thus, before explants are moved to an in vitro setting, they must be cleane. Goswami and Handique describe surface sterilization of alterations made to the subterranean stem. Many studies conducted in vitro have suggested various methods of sterilizing and chemical disinfectants. In vitro, surface sterilization of banana explants is most usually achieved using sodium hypochlorite as the disinfectant. A low concentration of mercuric chloride replaced with sodium hypochlorite is reported by Molla; Titov and Goswami. According to Goswami and Handique, the maximum percentage of a contamination-free healthy culture is obtained using 1% sodium hypochlorite for 15 minutes and 0.1% mercuric chloride for 7 minutes. Jafari used the double-disinfection approach, using mercuric chloride followed by Clorox. Ten-day old suckers of the banana variety "Williams" were considerably less contaminated following double sterilization with NaOCl (3.5%) and Tween 80 first for 15 minutes, followed by five water rinses, and a second time for 5 minutes.

Media Preparation and Composition

Murashige and Skoog (MS) medium is the most commonly used medium for banana tissue culture. The medium is sterilized by autoclaving at 121°C for 30 minutes and supplemented with 3-5 g/L agar as a gelling agent and 30-40 g/L sucrose as a carbon source. Plant growth regulators, mainly auxins and cytokinins, regulate shoot development and morphogenesis. After preparation, the medium is dispensed into sterile culture vessels and inoculated with explants. Phenolic exudation from damaged tissues may cause browning and

inhibit culture growth. To minimize this problem, explants are periodically transferred to fresh medium during the initial culture period and may be incubated in darkness for a few days. Antioxidants such as ascorbic acid (10-140 mg/L) or cysteine (50 mg/L) are commonly used to reduce tissue browning and improve culture establishment.

Stages of Micropropagation

Stage 1: Shoot Culture Initiation

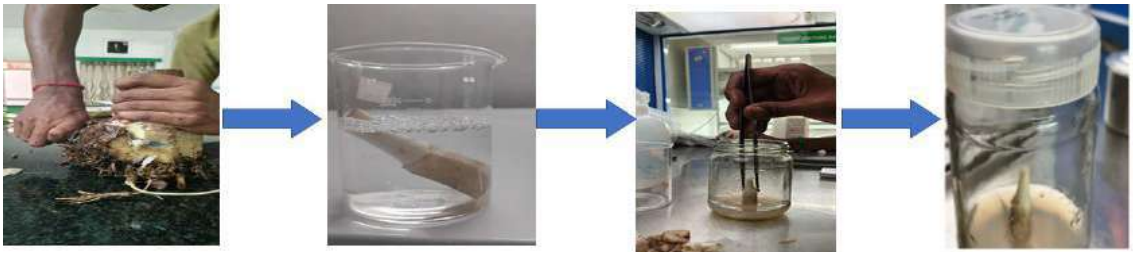
Stage 2: Multiplication of Shoot Cultures

Stage 3: Rooting of Regenerated Plants

Stage 4: Hardening of *In-vitro* Plantlets

Control of Microbial Contamination During In- vitro Culture

One of the main obstacles to plant micro propagation is microbial contamination. Fungi and bacteria are the primary microbial agents that proliferate in plant tissue cultures. The main bacterial contaminants in plant tissue cultures have been characterized as Pseudomonas syringae, Bacillus licheniformis, Bacillus subtilis, Corynebacterium spp., and Erwinia spp. whereas the most frequently detected fungal contaminants are Alterneria tenius, Aspergillus niger, Aspergillus fumigatus, and Fusarium culmorum. These organisms result in significant losses both during the initial phase of the culture and during subcultures, with each subculture accounting for 5-15% of the total losses. Even with the adoption of reliable aseptic methods, the overall losses in bananas and plantains due to microbial contamination are estimated to be between 40 and 60 percent. This means that microbial contamination causes a substantial number of explants to be lost during culture**.**



Conclusion

Banana tissue culture has emerged as an effective biotechnology tool for producing disease-free, genetically uniform, and high-quality planting materials. Micropropagation enables rapid multiplication of elite cultivars, improves crop productivity, and minimizes the spread of major diseases such as Fusarium wilt and Black Sigatoka. The success of tissue culture largely

depends on the optimization of nutrient media, including appropriate concentrations of vitamins, sugars, amino acids, minerals, and plant growth regulators, which support shoot proliferation, rooting, and plantlet development. Proper acclimatization further enhances the survival and field performance of tissue culture-raised plants. The integration of tissue culture into banana cultivation contributes to sustainable production by reducing dependence on chemical disease control, improving planting material quality, and increasing yield. Continued research on media optimization, contamination control, and genetic improvement will further strengthen the commercial application of tissue culture and support sustainable banana production to meet the growing global demand.

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BEACH PEA [*VIGNA MARINA* (BURM.) MERRILL.,]: A POTENTIAL GENE SOURCE OF SALT-TOLERANCE FOR CULTIVATED *VIGNA* SPECIES

Article ID: AG-VO6-I07-53

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Introduction

The genus *Vigna* is an agriculturally important pan-tropical taxon comprising several economically significant food legumes, including cowpea (*V. unguiculata*), bambara groundnut (*V. subterranea*), mungbean (*V. radiata*), and blackgram (*V. mungo*). The genus consists of approximately 104 species distributed across tropical and subtropical regions worldwide. Soil is considered saline when its electrical conductivity (EC) exceeds 4 dS m^{-1} (approximately equivalent to 40 mM NaCl at 25°C) and the exchangeable sodium percentage (ESP) exceeds 15%. According to the Food and Agriculture Organization (FAO, 2024), nearly 1.4 billion hectares of land, representing about 10% of the world's land area, are affected by salinity. Soil salinization is expected to intensify due to climatic and anthropogenic factors such as reduced precipitation, increased surface evaporation, irrigation with saline water, and unsustainable agricultural practices. By 2050, salinity is projected to become one of the major constraints to global food production, reducing both crop yield and quality and affecting more than 50% of the world's arable land.

Vigna marina (Burm.) Merr., commonly known as beach pea, nanea, or notched cowpea, belongs to the family, Fabaceae. It is a perennial, prostrate, creeping vine that is widely distributed along tropical and subtropical sandy seashores worldwide. The genus *Vigna* was

named in honor of the Italian physician and botanist Domenico Vigna, a professor at the University of Pisa, while the species epithet *marina*, derived from the Latin word meaning "of the sea," reflects its natural coastal habitat. The species has been described under several synonyms, including *Dolichos luteus* Sw., *Phaseolus marinus*, *Scytalis anomala*, *S. retusa* E. Mey., *V. anomala* Walp., *V. lutea* (Sw.) A. Gray, *V. repens* var. *lutea* (Sw.) Kuntze, and *V. retusa* (E. Mey.) Walp. Two subspecies are currently recognized: *V. marina* subsp. marina and *V. marina* subsp. *oblonga*. As a true halophyte, *V. marina* is considered an excellent source of genes associated with salinity tolerance. Its seeds can remain viable after prolonged immersion in seawater for several years, and young plants are capable of surviving for at least one month when submerged in a 400 mM NaCl solution. Owing to its natural adaptation to coastal sandy habitats, *V. marina* is regarded as a promising donor of genes conferring both salinity and drought tolerance, making it a valuable genetic resource for developing climate-resilient legume crops.

Botanical description

V. marina is a perennial, prostrate, creeping herb with stems that grow up to 3 m long and often display purplish stripes (Fig. 1). The leaves are trifoliate, light green, and arranged alternately along the stems. Each leaf is borne on a petiole measuring 2–5 cm in length. Small, triangular, leaf-like stipules are present at the junction of the petiole and stem.

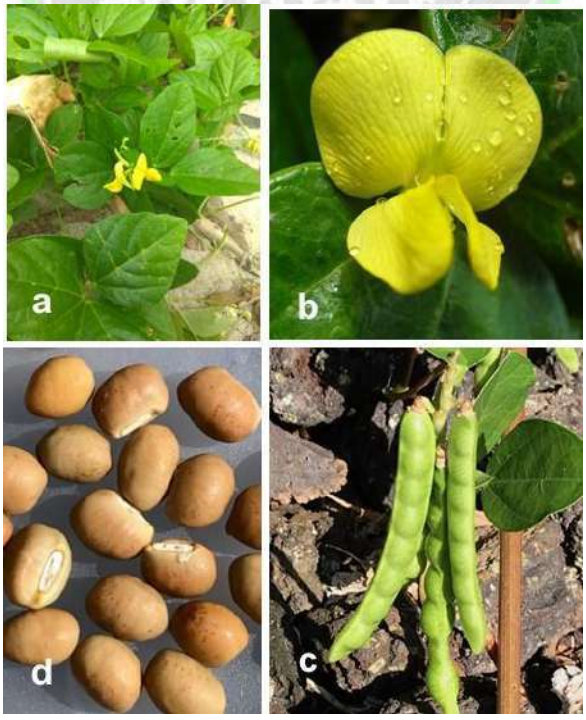


Fig. 1 Beach pea (*Vigna marina*): a) Plant, b) Flower, c) Pod and d) Seed

Each leaf consists of three prominently triple-nerved leaflets that are broadly ovate to oblong, with smooth margins and an acute apex. The leaflets measure 4–10 cm in length and 2–5 cm in width. The flowers are yellow, papilionaceous (pea-shaped), and borne in clusters at the tips of peduncles that are up to 10 cm long. Individual flowers are 15–18 mm in length and are produced throughout the year, with peak flowering occurring during autumn and early winter. The flowers are odourless. The fruits are elongated, rounded pods measuring up to 8 cm in length and approximately 6 mm in width. Each pod contains 4–9 seeds that are circular to oblong and greyish-brown in colour. Upon maturity, the pods split open and twist, releasing the ripe seeds.

Distribution and habitat

Generally, it occurs throughout the tropical and subtropical seashore beaches of the world viz., Hawaii and islands in the Pacific Ocean, the Caribbean, along the Atlantic and Indian Ocean coasts of Africa, India and Sri Lanka, Australian coasts. It grows at the vegetation line on sandy beaches, frontal dunes, and beach ridges close to the seashore. Occasionally, it occurs on inland sea cliffs and dry slopes amongst shrubs up to around 395 feet above mean sea level.

Gene pool, cross-compatibility and genetic diversity

The genus *Vigna* is classified into four major gene pools (GPs). Gene Pool A (GP A) comprises taxa belonging to the subgenus *Ceratotropis*, including *V. radiata*, *V. mungo*, *V. angularis*, *V. umbellata*, *V. reflexo-pilosa* var. *glabra*, and *V. aconitifolia*. Gene Pool B (GP B) includes taxa of the subgenus *Plectotropis*, consisting of domesticated *V. vexillata* and its wild relatives. Gene Pool C (GP C) comprises species from the sections *Catiang*, *Macrodontae*, and *Reticulatae* of the subgenus *Vigna*. Gene Pool D (GP D) includes domesticated *V. subterranea* along with other taxa belonging to the section *Vigna* of the subgenus *Vigna*. Among these, GP D, to which *V. marina* belongs, remains the least explored. Many taxa within this gene pool have not yet been utilized in interspecific hybridization or breeding programs, raising questions regarding the cross-compatibility of *V. marina* with cultivated *Vigna* species. However, a phylogenetic study based on 28 isozyme loci involving 58 *Vigna* accessions representing the *V. luteola*, *V. ambacensis*, and *V. racemosa* groups demonstrated considerable genetic diversity within GP D.

The study revealed a close genetic relationship among *V. marina*, *V. oblongifolia*, and *V. luteola*, indicating strong cross-compatibility between *V. marina* and *V. luteola*. Exploiting this compatibility, Chankaew *et al.* (2014) identified three quantitative trait loci (QTLs) associated

with salt tolerance by analyzing an F_2 population derived from the interspecific cross *V. luteola* × *V. marina* subsp. *oblonga*.

Beach pea germplasm collected from diverse habitats of the Andaman and Nicobar Islands by ICAR–CIARI, Port Blair, was evaluated for agronomic performance. Among the collected accessions, ANBp-14-03, ANBp-14-05, and ANBp-15-02 exhibited superior yield attributes, producing 5–8 seeds per pod and recording a 100-seed weight of 8.26 g. Molecular characterization using inter-simple sequence repeat (ISSR) markers demonstrated the genetic relationship between beach pea, mungbean, and urdbean. In a separate study employing simple sequence repeat (SSR) markers, all beach pea genotypes formed a distinct cluster from green gram and black gram genotypes. Principal Coordinate Analysis (PCoA) further revealed that 85.93% of the total genetic variation was explained by the first few principal coordinates, highlighting the substantial genetic divergence of beach pea from cultivated *Vigna* species. Additionally, approximately 50 accessions collected from the coastlines of Australia and neighbouring islands have been conserved as part of the Australian Native *Vigna* Collection, providing valuable genetic resources for future breeding and conservation efforts.

Economic utilization

It is used as human food and cover crop under cultivation in Maldives. In Australia, the Aboriginal population used its root as edible food and is also used to stabilize coastal sand dunes/ restoration of beach vegetation. The early Hawaiians ground the leaves, stalks, midribs, and stems of the plant to treat heal wounds such as boils, running sore, or ulcers; as they applied the softened materials directly onto the affected area. *V. marina* is also able to fix nitrogen obtained from the air around its roots, where the rhizobium species present on the nodules of the roots fixes it. The resultant nitrogen is used by the plant, and also increases the nitrogen content in the surrounding sand. It has some medicinal importance's such as: Fractured bone, food poisoning, weakness after child birth, headache, stomach-ache, asthma, poultice, mouth infections and abscesses. Its chemical/ mineral composition of dry seeds as follows: protein (18.91 – 30.26 %), iron (1.8 – 2.53 mg), calcium (5.38 – 14.54 mg), magnesium (8.10 – 9.22 mg), zinc (0.60 – 1.46 mg) and cobalt (0.01 – 0.06 mg).

Characteristic features of Beach pea - As Halophytic (salt-tolerant) species

Based on its habitats, distribution pattern, occurrence/ frequency and salt tolerance capability, *V. marina* could be treated as a halophytic species.

1) ***Habitat environment***: Beach pea naturally grows on sandy beaches and saline soils of the Andaman and Nicobar Islands (Fig. 2) and many tropical and subtropical coastal regions. The soils where it grows have high salt content (high electrical conductivity, EC), showing that the plant is well adapted to saline conditions.



Fig. 2 Vegetation of *V. marina* in natural condition across Andaman and Nicobar Islands A) Chidya Tapu, B) Manjery, C) Wandoor, D) Lamia bay of Diglipur, E) Harminder bay of Little Andaman and F) Radhanagar beach of Havelock Island (**Source**: Prithivi et al., 2021).

2) ***Survival of seedlings at high EC***: Young Beach pea plants can survive in soils with an EC of about 13 dS m^{-1}, while cultivated mungbean (*V. radiata*) dies at around 6 dS m^{-1}. Its seedlings can also remain alive for at least one month in a solution containing 400 mM NaCl.

3) ***Associated Rhizobium at root zone***: The roots of Beach pea contain Rhizobium bacteria that fix atmospheric nitrogen. These bacteria continue to function even under high salt conditions. They also tolerate several antibiotics and survive in laboratory conditions with up to 1000 mM NaCl.

4) ***Large seed size and hard seed coat***: Beach pea has relatively large seeds protected by a thick, hard seed coat. This hard covering protects the seed but also prevents water from entering easily. Scratching the seed coat (scarification) helps improve germination.

5) ***Seed buoyancy and viability in sea water***: The term 'seed buoyancy' refers to the ability or tendency of a seed to float in water. Beach pea seeds are buoyant and can float on seawater. They can remain alive and capable of germination even after 25 years of immersion because of their low density and hard seed coat.
6) ***Pattern of Na^+ accumulation***: Unlike some plants that prevent salt from entering their tissues, Beach pea allows sodium (Na^+) to enter and stores it safely in its roots, stems, and leaves. Therefore, it is known as a "Na^+ includer" type.
7) ***Presence of tissue tolerance type of salt-stress mechanism***: Beach pea shows tissue tolerance, meaning it continues normal physiological processes such as photosynthesis even when large amounts of salt accumulate inside its tissues.
8) ***Unique type of stomatal regulation***: Most plants reduce the opening of their stomata under salt stress to conserve water, which also reduces photosynthesis. In contrast, Beach pea keeps relatively high stomatal conductance and transpiration, allowing it to maintain photosynthesis even in saline conditions.
9) ***QTL for salt tolerance related traits***: Researchers have identified several **Quantitative Trait Loci (QTLs)** related to salt tolerance in Beach pea. These include:
    - **Saltol1.1** – associated with seedling survival.
    - **Saltol1.2** – associated with reduced leaf wilting.
    - **Saltol1.3** – associated with better plant recovery after salt stress.

These genes help the plant survive, grow, and recover under highly saline conditions.

Future prospects

In general, wide hybridization often faces challenges due to reproductive barriers or genetic incompatibility issues, which is also the true in case of cultivated *Vigna* species and *V. marina* being different gene pools. The way forward to harness the salt tolerance of *V. marina*, we suggest the following research gaps or areas need to be focused: 1) In-depth cross-compatibility studies (include both pre- and post-fertilization barriers along with techniques to overcoming them), 2) Bridging crosses, 3) Genetic engineering along with transformation techniques, 4) De-novo domestication – which directly utilizes the naturally adapted wild species as a new crop and 5) Whole genome sequence – Information will be useful for comparative genomic analysis and other approaches

Conclusion

Beach pea (*Vigna marina*) is an excellent example of a halophytic plant because it: 1) Naturally grows on saline coastal soils, 2) Survives very high salt concentrations, 3) Forms associations with salt-tolerant nitrogen-fixing bacteria, 4) Has large, hard-coated seeds that float and remain viable in seawater for many years, 5) Safely accumulates sodium in its tissues, 6) Maintains photosynthesis under salt stress through tissue tolerance and unique stomatal regulation, 7) Possesses genetic regions (QTLs) responsible for strong salt tolerance. These characteristics make Vigna marina an important genetic resource for improving salt tolerance in cultivated legume crops.

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CISSUS QUADRANGULARIS - NATURE'S GIFT FOR BONE HEALTH: INDIA'S ANCIENT MEDICINAL VINE WITH MODERN RELEVANCE

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Introduction

For centuries, rural communities across India have relied on medicinal plants for treating common ailments. Among these plants, *Cissus quadrangularis* L. occupies a unique position because of its remarkable reputation as a natural bone-healing herb. Popularly known as Pirandai, Hadjod, Harjor, Asthisamharaka, Nalleru, and Veldt Grape, this medicinal climber belongs to the grape family (Vitaceae). The Sanskrit name "Asthisamharaka" means "protector of bones" or "that which joins broken bones," reflecting its traditional use in healing fractures. Even today, many traditional healers and Ayurvedic practitioners prescribe preparations made from this plant to aid recovery from fractures, sprains, and joint disorders. Today, scientific studies are increasingly validating many of its traditional medicinal claims, making it a plant of growing commercial and therapeutic importance.

Botanical Characteristics: *C. quadrangularis* is a succulent, climbing shrub characterized by its distinctive fleshy, quadrangular (four-angled) stems. The stems are green, jointed, and capable of storing water, enabling the plant to survive under drought conditions. Leaves are simple, small, and heart-shaped, while tendrils arise opposite the leaves, helping the plant climb nearby supports. Small greenish-white flowers are produced in clusters, followed by globose berries that turn reddish-purple upon maturity.

Habitat and distribution: The plant thrives in warm climates and is commonly found growing on hedges, rocky terrains, wastelands, and dry regions across India. It is widely distributed in Rajasthan, Gujarat, Maharashtra, Tamil Nadu, Karnataka, Kerala, Andhra Pradesh, Telangana,

Madhya Pradesh, and several other states. It adapts well to tropical and semi-arid conditions and grows successfully in poor soils with minimal management.

Genetic variation and diversity: The plant exhibits substantial variation in morphology, growth habit, yield attributes, phytochemical composition, and medicinal properties. The greatest practical significance lies in the variation of calcium, ketosteroids, phenolics, and antioxidant compounds, which determine its effectiveness in bone healing and other therapeutic applications. In plant genetic resource point of view, systematic collection, characterization, and evaluation of germplasm from diverse agro-climatic regions are essential for developing elite medicinal cultivars and promoting commercial cultivation.

Huge variations available in this species on basis of leaf shape, leaf margin, stem ridges and stem and internode length. In our exploration trip to state of Tamil nadu, we found variations in stem (shape, colour, number of ridges) and leaf (size, shape, margin) and petiole length (Fig. 1). Few collections are conserved and maintained at ICAR-NBPGR, Regional Station, Thrissur.

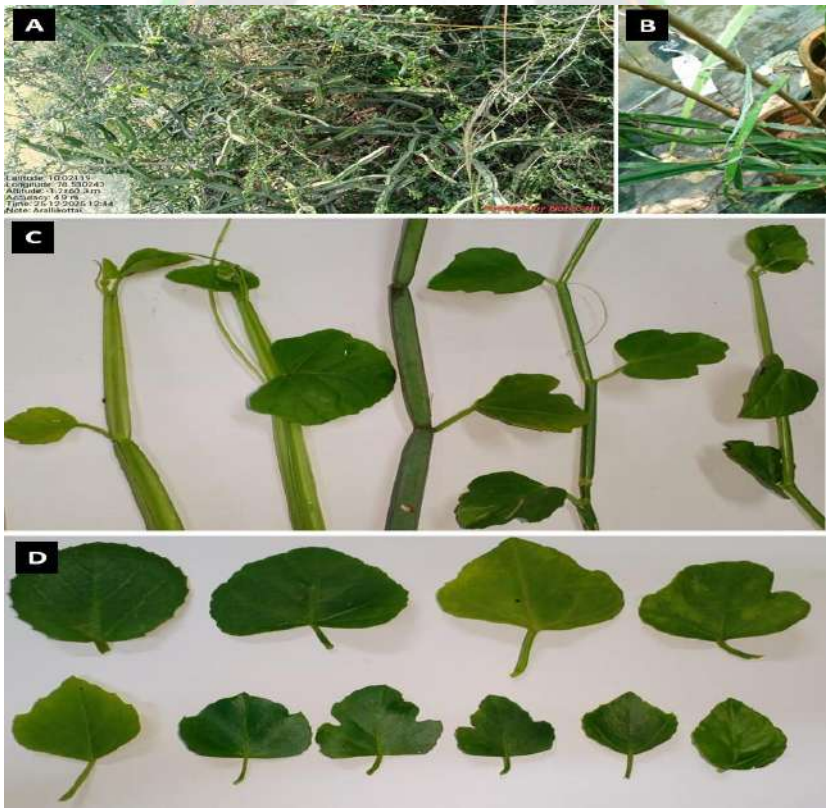


Fig. 1 Pirandai (*Cissus quadrangularis*) A) Plant at natural habitat, B) Plant at Pot in ICAR-NBPGR, Regional Station, Thrissur, C) Stem variations with leaf and D) Leaf variations including size, shape and margin

Economic plant part/s: Primary - Succulent Stem; Secondary - Roots, leaves

Cultivation: It is mainly through stem cuttings. Healthy stem segments of 20–30 cm length are planted during the onset of monsoon. The crop requires well-drained sandy loam soils and moderate irrigation. Being a hardy species, it tolerates drought and requires comparatively fewer inputs than many commercial crops. The first harvest can be obtained within 6–8 months after planting, and subsequent harvests may be taken periodically. Under good management, the crop can provide substantial biomass suitable for medicinal processing.

As a drought-tolerant species requiring minimal inputs, *Cissus quadrangularis* is well suited for cultivation in marginal and rainfed areas. Farmers can integrate it into medicinal plant farming systems, fence lines, and agroforestry models. Its resilience to harsh environmental conditions makes it a promising crop under changing climatic scenarios.

Biochemical composition: Its proximate profile contains approximately 53% carbohydrates, 14% crude protein, and high calcium, phosphorus, ascorbic acid and others.

Medicinal value: The medicinal value of *C. quadrangularis* arises from its rich array of phytochemicals. The plant contains, ascorbic acid (vitamin C), carotenoids, flavonoids, triterpenoids, stilbenes, β-sitosterol, ketosteroids, calcium and phosphorus compounds, phenolic compounds. These bioactive constituents contribute to its antioxidant, anti-inflammatory, antimicrobial, and bone-healing properties.

Traditional Medicinal Uses: For centuries, traditional healers across India have utilized *C. quadrangularis* for various ailments. Important uses include:

- Bone Fracture Healing - The plant is most renowned for accelerating the healing of fractured bones. Stem extracts are traditionally administered internally or applied externally to promote callus formation and strengthen bones.
- Joint and Musculoskeletal Disorders - It is widely used in Ayurveda for treating osteoporosis, arthritis, joint pain, back pain, and sports injuries.
- Digestive Health - Traditional practitioners recommend the plant for indigestion, hemorrhoids, gastric ulcers, and constipation.
- Women's Health - In some regions, preparations from the plant are used to regulate menstrual disorders and support post-partum recovery.
- Wound Healing - The anti-inflammatory and antimicrobial properties of the plant aid in the healing of wounds and damaged tissues.

Scientific Validation of Medicinal Properties: Modern pharmacological research has revealed multiple biological activities of *Cissus quadrangularis*:

- Osteogenic Activity - Research demonstrates that extracts stimulate osteoblast activity, enhance mineralization, and accelerate fracture repair. The high calcium content and anabolic phytochemicals contribute significantly to bone regeneration.
- Anti-inflammatory Effects - Plant extracts reduce inflammation by modulating inflammatory mediators, making them useful for managing arthritis and musculoskeletal disorders.
- Antioxidant Activity - The presence of phenolics and flavonoids helps neutralize free radicals, protecting cells from oxidative damage.
- Anti-obesity Potential - Several studies suggest that standardized extracts may aid weight management by influencing lipid metabolism and reducing body fat accumulation.
- Antidiabetic and Cardioprotective Effects - Emerging evidence indicates beneficial effects on blood glucose regulation and cardiovascular health, although further clinical studies are needed.

Economic Importance:

The growing demand for herbal medicines and nutraceutical products has increased the commercial value of *Cissus quadrangularis*. The plant is used in Ayurvedic formulations, Herbal supplements, Nutraceutical products, Bone health capsules, functional foods, cosmetic and wellness products. The pharmaceutical industry utilizes standardized extracts in formulations aimed at bone strengthening and joint health. The expanding global herbal market offers significant opportunities for cultivation and value addition.

Culinary Dishes Prepared from Pirandai Stem:

The tender stems of *C. quadrangularis* (pirandai) are widely used in traditional Indian cuisine, particularly in South India. Before cooking, the fibrous ridges and outer edges of the stem are removed to improve texture and palatability. The processed stems are then incorporated into a variety of culinary preparations, including chutneys, curries, soups, and herbal foods with recognized nutritional and medicinal value. Among these, pirandai thuvaiyal (pirandai chutney) is the most popular and widely consumed preparation. Other traditional dishes include pirandai rasam, a medicinal soup-like preparation; pirandai dosa and pirandai adai, in which stem paste is incorporated into fermented or pulse-based batters; pirandai pickle (porugai), valued for its

extended shelf life; pirandai soup; and pirandai powder (pirandai podi), a dried and powdered condiment commonly mixed with rice. These preparations are consumed in different regions of India not only for their distinctive flavor but also for their traditional health benefits, particularly in promoting digestive health, bone strength, and overall well-being.

Conclusion

Cissus quadrangularis represents a remarkable example of India's traditional medicinal heritage. From ancient Ayurvedic texts to modern pharmaceutical applications, this versatile plant continues to demonstrate immense value. Its proven role in bone healing, diverse medicinal properties, adaptability to challenging environments, and growing market demand make it a promising medicinal crop for farmers, researchers, and healthcare industries alike. Conserving and promoting this valuable indigenous resource can contribute significantly to sustainable agriculture, rural livelihoods, and human health. Increasing public interest in natural healthcare products and scientifically validated herbal medicines is likely to enhance the importance of *Cissus quadrangularis*. Future research focusing on genetic improvement, standardized cultivation practices, quality planting materials, and advanced phytochemical studies will further strengthen its commercial potential.

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BAHEDA: THE HEALING TREE BEHIND TRIPHALA

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Abstract

Terminalia bellirica (Gaertn.) Roxb. is a cornerstone of traditional Ayurvedic medicine and a key constituent of the renowned formulation Triphala. Triphala, one of the most celebrated polyherbal formulations in Ayurveda, combines the fruits of *Terminalia chebula* (Harad/Haritaki), *Terminalia bellirica* (Baheda/Vibhitaki), and *Emblica officinalis* (Amla/Amalaki) in equal proportions to promote holistic health. Beyond its therapeutic significance, it supports the livelihoods of forest-dependent communities through its valuable non-timber forest products. Rich in bioactive compounds such as tannins, gallic acid, and ellagic acid, *T. bellirica* exhibits antioxidant, antimicrobial, antidiabetic, hepatoprotective, anti-inflammatory, and cardioprotective properties. This review highlights its ethnomedicinal, pharmacological, ecological, and socioeconomic importance, emphasizing its potential in modern healthcare while underscoring the need for sustainable harvesting and conservation to ensure long-term benefits.

Introduction

Terminalia bellirica (Baheda) belongs to the family Combretaceae, is a large deciduous tree with the height of 50m and diameter of 30m with a rounded crown. It is branchless up to 20m. It is perennial and requires cold climate. The outer bark is bluish or ashy-grey whereas inner-bark is yellow in color. The bark contains number of longitudinal cracks. Young leaves are

copper red in color which turn into parrot green and later they become dark green. Leaves are large, alternate, glabrous, mostly clustered at the twig ends.

Flowers are greenish white in color usually appear along with new leaves having an offensive odor or strong honey like smell. Flowers are simple, solitary and sessile. Inflorescence is axillary spikes generally 3-15cm long. Upper flowers of the spike are male. Lower flowers are bisexual. Fruits are light yellow in color. It is drupe, globose or ovoid, densely velutinous or sericeous. It is slightly 5 ridged, 3cm across. It is one seeded and covered with minute pale pubescence. Parts Used: Fruit rind, seed, seed kernel (Easy Ayurveda, 2025). It grows wild at an elevation of up to 2000m in wide variety of ecologies. It is native to Sri Lanka, India, Bangladesh, Bhutan, Thailand, China, Indonesia, Pakistan, Malaysia, Nepal, Cambodia and Vietnam. In India, it is commonly found in Madhya Pradesh, Uttarakhand, Uttar Pradesh, Punjab and Maharashtra (Planet Ayurveda, 2025). Major chemical constituents present in Baheda are tannins, gallic acid, ellagic acid, ethyl gallate, chebulinic acid (Sharma *et al*., 2005).



Whole Tree, Flowering and Fruiting of Baheda

The Power Behind Triphala

Terminalia bellirica (Baheda) is one of the major components of Triphala Churna. Triphala (*triphalā*, "three fruits") is a polyherbal Ayurvedic formulation, specifically a churna or powder, a kwatha or decoction (Chen, 2021). The annual demand of fruits of this species is approximately 2000-5000 metric tonnes (NMPB). In terms of composition, Triphaladi Churna derives its therapeutic strength from the synergistic action of its constituent herbs. Haritaki is valued for its mild laxative and detoxifying properties, aiding in the elimination of accumulated metabolic wastes. Vibhitaki contributes to respiratory and digestive equilibrium while supporting lipid metabolism, and Amalaki acts as a powerful antioxidant due to its high vitamin C content and cooling nature. These three fruits are used in equal proportion to make Triphala Churna (Mehta *et al*., 2026).

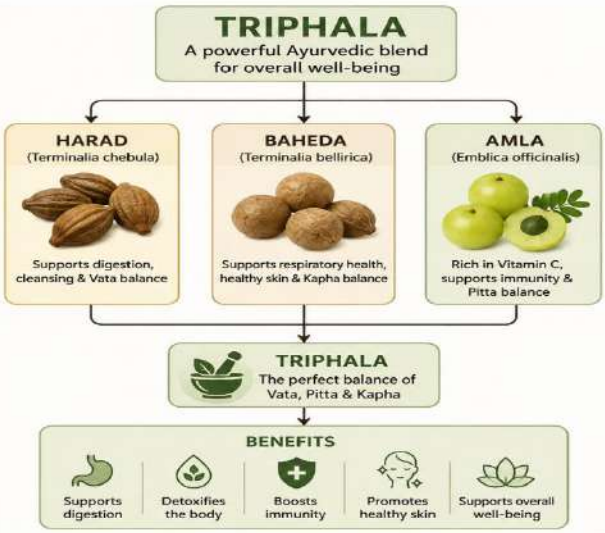
Ethnomedicinal Importance of *Terminalia* in Ayurveda:

In Ayurveda, Baheda is known as **Bibhitaki**, meaning "the one that keeps away disease." It is considered:

- **Rasa (Taste):** Kashaya (Astringent)
- **Virya (Potency):** Ushna (Warm)
- **Vipaka:** Madhura (Sweet)

It is mainly used to balance **Kapha** and **Vata** doshas and is a key ingredient in: Triphala, Chyawanprash, Various Ayurvedic cough formulations, Digestive tonics and Rasayana preparations. (Peterson *et al*., 2017)

Several indigenous communities in India, including those in the Himalayan region, Central India, and tribal belts of Odisha, Chhattisgarh, Madhya Pradesh, and Uttarakhand, traditionally use Baheda for treating livestock diseases, Snake bites (folk medicine), Fever, Digestive ailments, Wound healing and Respiratory infections.



Flow chat of Triphala and its uses

Products made From *Terminalia bellirica*:

Throughout the Indian sub-continent, Terminalias are valued as sources of an array of non-wood forest products (Srivastav *et al*., 1993). *Terminalia bellirica* yield indigenous drug preparations, tannins, gums, oils, fodder and certain organic compounds from their leaves, trunk, bark or fruits. Industries such as pharmaceutical, animal husbandry, leather, dyeing, soap, chemical, resin and gum, oil and cosmetic utilize *Terminalia* species for their raw materials. *T.*

bellerica also serves as secondary food plants. The fruits are often collected as a valuable non-timber forest product (NTFP), providing both healthcare benefits and household income.



Triphala Churna made from Harad, Amla and Baheda

Pharmacological activities of *Terminalia*:

T. bellirica exhibits a wide range of pharmacological activities. The fruits are rich in bioactive compounds such as tannins, flavonoids, phenolic acids, and triterpenoids, which contribute to its diverse therapeutic properties (Saraswathi *et al*., 2012). One of the most prominent pharmacological activities of *T. bellirica* is its antioxidant capacity, primarily due to the presence of compounds like ellagic acid and gallic acid (Khan and Gilani, 2010; Sharma *et al*., 2021). These antioxidants help in neutralizing free radicals, thereby reducing oxidative stress and preventing cellular damage, which is crucial in managing chronic diseases like cancer, diabetes, and cardiovascular disorders (Kumar *et al*., 2010).

Additionally, *T. bellirica* possesses significant anti-inflammatory activity, which is beneficial in treating conditions associated with inflammation, such as arthritis, asthma, and gastrointestinal disorders. The anti-inflammatory effect is largely attributed to its ability to inhibit pro-inflammatory mediators and enzymes (Nag and De, 2011; Saraswathi *et al*., 2012). Moreover, *T. bellirica* has demonstrated potent antimicrobial properties, effective against a wide range of pathogens, including bacteria, fungi, and viruses, making it useful in treating infections and promoting wound healing. The fruit also exhibits hepatoprotective activity, protecting the liver from damage caused by toxins and diseases, which is supported by its traditional use in managing liver disorders (Chanda *et al*., 2013; Hanem *et al*., 2015).

Ecological Importance Beyond Medicine

Baheda is far more than a medicinal tree. It performs several ecological functions that support healthy forest ecosystems. Its flowers provide nectar for insects and pollinators, while its fruits are consumed by birds, monkeys, deer, squirrels, and other wildlife, facilitating natural seed dispersal. The extensive root system helps stabilize soil, reducing erosion in hilly regions.

As a large canopy tree, Baheda also contributes to carbon sequestration, helping mitigate climate change. In many tropical forests, Baheda acts as a keystone species that supports biodiversity and ecological resilience.



Pollination in Baheda flower through honey bee

Economic Value to Rural Communities

The dried fruits of Baheda are extensively traded in herbal markets and form an essential raw material for the Ayurvedic pharmaceutical industry. Local communities collect mature fruits from forests, providing seasonal income and supporting rural livelihoods. (Sahdev *et al*., 2025) Besides medicinal use, the wood is occasionally utilized for plywood, packing cases, furniture, and fuelwood. The seed kernels yield oil suitable for industrial applications, while the tannin-rich fruits are used in leather tanning and natural dye production.

Conservation Challenges

Despite its wide distribution, natural populations of *Terminalia bellirica* (Gaertn.) Roxb. face increasing pressure from habitat degradation, overharvesting of fruits, forest fragmentation, invasive species, and changing climatic conditions. In many parts of India, regeneration is further constrained by grazing, recurrent fires, and other anthropogenic disturbances that reduce seedling establishment and survival (Singh & Singh, 1992; Negi *et al*., 2018; Ravindranath *et al*., 2006). Long-term demographic studies have demonstrated that the persistence of tree populations depends on continuous seedling recruitment, successful transition through juvenile stages, and the survival of mature reproductive individuals. Consequently, sustainable harvesting of fruits, protection of natural habitats, restoration of degraded forests, and active participation of local communities are essential for the long-term conservation of *T. bellirica* (Caswell, 2001; Ticktin, 2004; Newton, 2007).

The Future of Baheda

As global interest in herbal medicine, nutraceuticals, and plant-based therapeutics continues to grow, Baheda (*Terminalia bellirica*) has attracted increasing scientific attention. Current research is focused on its phytochemical composition, pharmacological properties, molecular mechanisms, genetic diversity, and sustainable utilization, highlighting its potential for developing novel therapeutic agents and value-added herbal products.

Long-term conservation of *T. bellirica* requires the integration of scientific research with sustainable management strategies. Protecting natural populations, promoting plantation and agroforestry programs, conserving genetic diversity, restoring degraded habitats, and adopting sustainable harvesting practices are essential to ensure the continued availability of this valuable medicinal tree while supporting the expanding herbal and pharmaceutical industries.

Conclusion

Baheda exemplifies the remarkable connection between traditional knowledge and modern science. As the healing tree behind Triphala, it has served humanity for centuries through its medicinal, ecological, and economic contributions. Protecting Baheda is not only about conserving a tree but also it is about preserving a living legacy of natural healthcare, biodiversity, and sustainable forest management. With increasing scientific evidence supporting its therapeutic potential, Baheda is poised to remain one of nature's most valuable gifts to both medicine and conservation.

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DESHI BER- NUTRITIONAL SECURITY AND INCOME OF TRIBAL FRAMERS

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Introduction

Deshiber (*Ziziphus* rotundifolia), commonly known as bordi, is an indigenous fruit tree, widely found naturally in the arid, semi-aridregions of the country. It is valued for its ability to thrive well under harsh environmental conditions and produce nutritious fruits without any inputs. It is found abundantly in Rajasthan, Gujarat, Haryana, Punjab, Uttar Pradesh, Madhya Pradesh, Maharashtra, Bihar, Andhra Pradesh, and Tamil Nadu. The tribal communities and resource poor farmers of these areas are used it in various forms like as source of food, fodder, medicine, and income. In the context of climate change, malnutrition, and livelihood challenges, deshi ber has emerged as an important crop for enhancing nutritional security and improving the socio-economic status of tribal farmers.

Botanical description:

The genus *Ziziphus* belongs to family Rhamanaceae and has more than six hundred species, out of them about 18–20 species are native to India. The different species of genus *Ziziphus* are widely distributed in the different parts of the world. Among them, few species namely *Z. mauritiana* Lam., *Z. rotundifolia* Lam. and *Z. nummulariaBurm*. (f.) wt., are abundant in arid and semi-arid regions of the country. Among the different Ziziphus species, *Z. mauritiana* originated in South and Central Asia and is cultivated commercially in different parts of the country. It has emerged as an important fruit crop especially in arid and semi arid tracts of the India. *Z. rotundifolia* locally know an *deshi ber* or Bordi is another important species that produces small sized edible fruits and serves as a valuable source of wood and fodder. This

species is characterized by long, upright branches bearing stipular spines which are used as fencing materials. It is frequently utilized by local communities for various purposes such as house posts, handle of agricultural implements and other household and farm tools. It can attain a height of 5-12 meters. The leaves are simple, ovate, and glossy green on the upper surface. The tree bears small yellowish-green flowers and round to oval fruits that vary in size, shape, and color depending on the variety. Mature fruits are green, yellow, reddish-brown, or dark brown and contain a hard stone enclosing the seed. The tree possesses a deep root system, which enables it to survive under extreme drought conditions.

Geographical distribution:

Bordi (*Ziziphus mauritiana*), commonly known as *deshi ber*, is widely distributed throughout India, particularly in the tropical, subtropical, arid, and semi-arid regions. It occurs naturally in forests, wastelands, village commons, and agricultural fields, and is extensively cultivated in states such as Rajasthan, Gujarat, Haryana, Punjab, Uttar Pradesh, Madhya Pradesh, Maharashtra, Bihar, Andhra Pradesh, and Tamil Nadu. The species is especially abundant in the dry regions of northwestern and central India, where it serves as an important source of fruit, fodder, and income for rural and tribal communities. Its ability to grow under harsh environmental conditions has enabled its widespread distribution across diverse agro-climatic zones of the country.It can tolerate extreme temperatures, prolonged drought, low rainfall, and poor soil fertility. The tree grows successfully in sandy, rocky, saline, and degraded soils where many fruit crops cannot survive. Its deep root system allows efficient utilization of moisture and nutrients from deeper soil layers. These characteristics make it an ideal species for wasteland development, agroforestry systems, and climate-resilient farming in tribal areas.

Source of income:

The 15-20% population of Gujarat, Rajasthan, Madhya Pradesh states are directly or indirectly depended on natural plantation of Khejri, Bordi, Tamarind, Gonda, Ker, Karonda, Rayan, Mahua, Jungale Jalebi, Palmyra palm, etc in forest area for livelihood. They collected flowers, fruits, woods from forest and consume at household level and surplus sold out in the market for better livelihood. Bordi play important role nutritional security and source of income of the inhabitants of arid and semi-arid regions especially in tribal regions of the Gujarat, Rajasthan, Madhya Pradesh. Treecan grow on almost all types of habitats. All parts of the bordi plant are utilized in various ways and contribute significantly to the livelihood of rural

communities in arid and semi-arid regions. Its fruits are rich in nutrients and serve as an important source of nutritional security for local inhabitants. The fruits are also marketed, providing an additional source of income to farming households. The leaves, locally known as pala, are highly valued as livestock feed and constitute a vital component of the animal husbandry system in these regions.



Deshi ber on forest land



Deshi ber on farm boundary



Harvesting of fruits



Unhygienic drying of fruits



Hygienic Drying of fruits



Sale of produce

The wood is commonly used as fuel and for making handles of agricultural implements and other tools. In addition, the leaves possess medicinal properties and are used in traditional

healthcare practices. Owing to its hardiness, drought tolerance, and adaptability to adverse soil conditions, bordi is widely used as a rootstock for the commercial cultivation of ber (*Ziziphus mauritiana*).

Therefore, the promotion of deshi ber cultivation can play a significant role in enhancing nutritional security, increasing household income, and improving the overall socio-economic conditions of the resource poor farmers either by sale of fresh produces or value added post harvest products.

Importance of Bordi in commercial Horticulture: In view of commercial horticultural, itis widely used as rootstock for vegetative propagation of cultivated ber (*Z. mauritiana*). The plant growth in terms of rootstock scion compatibility, plant height, canopy spread, stem girth, fruit yield and quality was found better than other species used as root stock. The seeds of root stock require certain period of rest after ripening for better germination. The seed germination percentage increase with increasing seed storage period, the one year old seed germinate better. Seed has hard seed coat which delays seed germination process. It is better to remove hard seed coat, rupture of seed coat, socking of seed for higher seed germination. The extracted seed germinate within a week after sowing in polythene bags or beds. Nursery purpose the 300 gauge thickness polythine bag size 25 x 10cm is used. Bags are filled with well decomposed farm yard manure (FYM), red soil and silt in ratio of (3:1:1) and shifted in nursery bed. The sowing of the seeds is done during the month of February – March for getting buddable rootstock thickness during May-June. Seedlings are budded in the nursery at the age 90–100 days. The ber is commercially propagated by patch and 'T' budding at 10-15 cm height on root stocks with stem diameter of pencil thickness. Under central Gujarat conditions patch budding got more than 90 per cent success during May – June. The polythine budded plants are become transplantable after 30 days of budding.

Nutritional importance: *Deshi ber* fruits are rich in vitamin C, carbohydrates, dietary fiber, minerals, and antioxidants. They contain calcium, phosphorus, iron, potassium, and antioxidant compounds that contribute to overall health and well-being. Regular consumption of ber helps improve dietary diversity and provides essential nutrients, especially for children and women in rural communities. The fruits can be consumed fresh or processed into products such as candies, jams, squashes, and dried snacks, thereby improving food and nutritional security throughout the year.

Cultivation Practices: Deshi ber is propagated through seeds and vegetative methods such as budding and grafting. It requires well-drained soils and performs best under full sunlight. Planting is generally carried out during the monsoon season. Improved varieties are preferred for commercial cultivation due to their higher yield and fruit quality. Regular pruning is essential to maintain tree shape and promote fruiting. Although ber can survive under low-input conditions, the application of organic manure, balanced fertilizers, and timely irrigation during critical growth stages can significantly improve productivity.

Harvesting of fruit: The large number of bordi plants grown naturally in forest area, boundary of farms, community lands, etc. The local inhabitantscollect the fruits from these areas/forest areas and harvest the fruits. These harvested fruits are sorted, washed, etc in water and sold in the market at premium price, providing an important source of income for rural households.

Value Addition Opportunities: Value addition can significantly increase the economic value of deshi ber. The fruits can be processed into products such as candies, jams, jellies, squashes, pickles, dehydrated slices, chutneys, and beverages. These products have longer shelf life and can be marketed throughout the year. Small-scale processing enterprises can create employment opportunities for tribal women and youth while reducing post-harvest losses. Training in processing, packaging, and branding can help farmer's access wider markets and earn higher incomes.

Environmental: Furthermore, *deshi ber* contributes to environmental sustainability by preventing soil erosion, improving land productivity, and supporting agro-forestry systems. Its resilience to climate variability makes it an important crop for strengthening the livelihoods of tribal communities.

Conclusion

Deshi ber is a highly resilient and nutritious fruit crop with immense potential for improving the livelihoods of tribal farmers. Its adaptability to harsh environments, low cultivation costs, and rich nutritional profile make it an ideal crop for resource-poor regions. By promoting scientific cultivation, value addition, market linkages, and government support, deshi ber can contribute significantly to nutritional security, income generation, and sustainable rural development. Strengthening ber-based farming systems can therefore play an important role in enhancing the well-being and economic resilience of tribal communities across India.

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PRACTICAL APPLICATIONS OF SPENT MUSHROOM COMPOST – AN INSIGHT

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Introduction

The human demand for protein-rich food is ever-increasing which contributes to the expansion of mushroom industry in the world. Statistically, the word production of mushroom industry has reached a level greater than 25 million tons. In spite of many advantages, the production of mushrooms generates large volumes of solid waste products (called spent mushroom substrate) which constitute one of the most significant environmental issues for the mushroom industry as about 5 kg of waste substrates are generated from the production of 1 kg of mushrooms (Yang *et al.*, 2015).

At present, the management of organic waste is a major concern worldwide, as unscientific disposal of waste can adversely affect the environment. Inadequate management of waste leads to problems that impair human and animal health. It leads to land pollution if openly dumped, water pollution if dumped in low lands and air pollution if burnt. The open dumped sites of organic waste act as breeding ground for various disease vectors.

The waste disposal problems can be reduced by waste minimization, reuse and recycling of its components and converting the organic components of the waste into a valuable product and reused without adversely affecting the environment. Composting is an economic and sustainable option for organic waste management as it is comparatively easy to manage properly to produce a good quality product. It is a technique which facilities mass reduction of waste

resulting in its stabilization. The SMS remaining after the mushrooms are harvested is predigested as a result of mycelial enzymatic activity; it is also a uniform substrate, easy to handle and cheap, or even free. For all of these reasons, SMS is considered suitable for recycling (Domínguez-Gutiérrez et al., 2022).

Nutrient Composition and Importance of Spent Mushroom Substrate (SMS) Compost

Spent Mushroom Substrate (SMS) is the residual organic material left after mushroom cultivation and is considered a valuable organic amendment due to its high nutrient content and beneficial effects on soil properties. The nutrient composition of SMS varies with the mushroom species and substrate materials used; however, it generally contains 0.8–2.0% nitrogen (N), 0.2–0.8% phosphorus (P), 0.5–2.0% potassium (K), 1.5–8.0% calcium (Ca), and 0.2–0.8% magnesium (Mg) on a dry-weight basis (Phan & Sabaratnam, 2012). The relatively high calcium concentration is mainly attributed to the addition of gypsum during substrate preparation. In addition to these nutrients, SMS contains substantial amounts of organic matter, humic substances, and beneficial microorganisms that contribute to soil fertility and biological activity (Paredes et al., 2016).



Fig. 1. The diagram depicts production of Spent Mushroom Substrate (SMS)

Microbial Diversity in SMS compost

The wide range of beneficial microbes in SMS are as follows

- Bacteria: *Bacillus spp*., *Pseudomonas* spp., *Azotobacter* spp.

- Fungi: *Trichoderma* spp.
- Actinomycetes

Functional role of SMS derived microbes

Plant Growth Promotion: Bacteria that show plant growth promoting traits are exploited commercially to make bio-fertilisers. They produce Indole Acetic Acid (IAA) which directly influence the root development and plant growth.

Biocontrol Activity: The SMS derived microbes suppress plant pathogens through the production of antibiotics. The suppression of plant pathogens occurs through competition, mycoparasitism, enzyme production and induced systemic resistance.

Soil Health: SMS helps to improve soil structure and aeration. It adds organic carbon through decomposition which again helps in soil moisture retention.

Table 1 Physico-chemical parameters of spent mushroom substrates (Catal and Peksen, 2018)

Parameters	**Values**
pH	5 – 7
EC (d Sm^{-1})	0.89 – 4
Organic carbon (%)	50 – 60
Total N (%)	1.12 – 1.40
Total P (%)	0.132 – 0.442
Total K (%)	0.71 – 0.82

Importance of Re-composting

Composting of SMS further stabilizes the organic matter, reduces phytotoxic compounds, and enhances nutrient availability. Application of SMS compost improves soil structure, water-holding capacity, aeration, cation exchange capacity, and microbial activity while supplying essential nutrients required for plant growth (Medina et al., 2009). Consequently, SMS compost serves as an environmentally sustainable soil amendment and a valuable means of recycling agricultural waste into nutrient-rich organic fertilizer.

SMS is typically composted alongside other organic wastes, like livestock manure or wastewater silt, that cannot be composted on their own due to their high moisture content and tiny particle size. The advantages of combining SMS with slurry or another organic substance

have been highlighted in many types of research with the ideal mixing ratio identified. The findings demonstrated that compost is an effective approach for treating SMS, converting their raw organic material into humus, which makes it more valuable as a supplier of organic material for land (Meng et al., 2018).

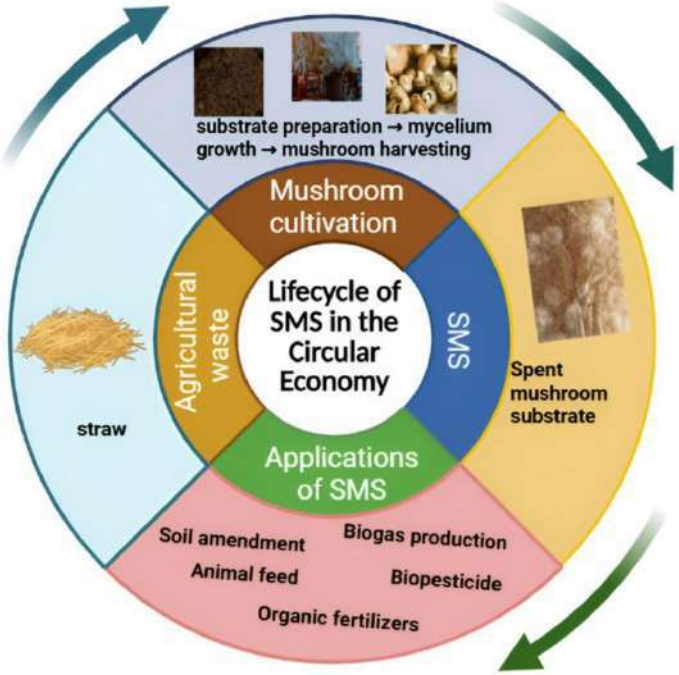


Fig. 2. Role of Spent Mushroom Substrate in Sustainable Agriculture (Parihar et al., 2026)

Beyond Agriculture: Environmental Applications

SMS-Derived Biochar in climate resilient agriculture

Carbon Sequestration of SMS-derived biochar enhances soil fertility, water-holding capacity, and microbial diversity, improving climate-resilient agriculture by reducing reliance on chemical fertilizers and enhancing crop stress resilience. Biochar systems can sequester 3.4–6.3 petagrams of CO_2-equivalent emissions, with SMS biochar offering long-term carbon storage (Anwar et al. 2024).

Resource reuse and recovery (circular economy)

Valorizing SMS reduces environmental degradation and the cost of waste disposal, aligning with SDG 12 by lowering waste impacts. Mushroom cultivation already converts low-value waste into food. Reusing SMS extends the biomass lifecycle, supporting sustainable and ethical production practices. Processes like drying, pelletizing, and nutrient enrichment can

enhance SMS as a fertilizer, though economic and logistical challenges remain for mass application (Juntahum et al. 2025).

SMC – as a growing medium

SMC has a relatively high content of minerals and could potentially be recycled to substitute as a growing medium, contributing to improve the sustainability of both the mushroom and greenhouse industry. The utilization of SMC to partially substitute or replace peat moss in soilless media may represent a great opportunity to recycle a local agricultural waste product, helping to reduce the environmental impacts of both the mushroom and greenhouse industries. The potential to utilize SMC to replace or partially substitute peat moss as a soilless medium has been tested experimentally showing promising results for different horticultural applications, including the production of ornamental crops, vegetable seedlings, and vegetable crops and microgreens.

Digital traceability

It provides evidence for regulatory compliance in waste and fertilizer policies and aligns with SDG 12 (Responsible Consumption and Production), supporting progress toward zero-waste agriculture. The SMARTmushroom project demonstrates the effectiveness of smart management systems in converting SMS waste into valuable products, using digital tools to support circular economy outcomes as in Table 10 (Fallah Shayan et al. 2022).

Conclusion

SMS positively affects soil fertility, crop yield, and crop resistance to both abiotic and biotic stresses in all agricultural systems. It is used in industrial applications as a renewable feedstock for producing biogas, biochar, biofertilizers, and bioplastics, which leads to a decrease in the use of fossil-derived materials. The attention on microbiome has uncovered that in SMS it is the combination of bacteria and fungi, the so-called consortia, that activates crucial biotransformations, thus indicating that the engineered microbial communities may further facilitate the SMS valorization. Furthermore, the transition from the laboratory insight to large-scale deployment depends on supportive policy and governance structures as the review nicely establishes. Combining SMS valorization with waste management laws, carbon credit markets, and digital traceability systems could make circular agriculture operational at a large scale

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CASSAVA TISSUE CULTURE - A REVOLUTIONARY BIOTECHNOLOGY APPROACH FOR HEALTHY, SUSTAINABLE CASSAVA PRODUCTION

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Abstract

Cassava (*Manihot esculenta* Crantz) is one of the most important tropical root crops cultivated for food security, industrial starch production and economic development. Although cassava is naturally adaptable to drought and poor soil conditions, conventional propagation through stem cuttings faces several limitations including slow multiplication, shortage of quality planting materials and spread of diseases. Tissue culture technology has emerged as a powerful biotechnology tool for overcoming these problems by enabling rapid multiplication, production of disease-free plants, conservation of genetic resources and improvement of desirable traits. Modern approaches such as somatic embryogenesis, genetic transformation, nodal segment culture, shoot tip culture and cryopreservation have further expanded the role of cassava tissue culture in sustainable agriculture.

Keywords: Cassava, *Manihot esculenta*, tissue culture, micropropagation and nodal segment culture.

Introduction

Cassava (*Manihot esculenta* Crantz) belongs to the family Euphorbiacae. It is majorly cultivated in tropical and subtropical regions because of its ability to tolerate drought, survive under marginal soil conditions and produce stable yields even under environmental stress. Cassava roots are rich in starch content and serve as an important source of carbohydrates. In addition to food use, cassava starch is widely used in textile, pharmaceutical, paper and biofuel industries. Traditionally, cassava is propagated using stem cuttings obtained from mature plants. This method helps in maintaining the genetic identity of varieties but it has several disadvantages like the multiplication rate is slow, large amounts of planting material are required for cultivation and diseases mainly **(Cassava mosaic virus)** transmitted by whitefly can easily spread through infected stems or cuttings. The increasing demand for healthy cassava planting materials has encouraged the development of tissue culture techniques for rapid and efficient propagation.

Plant tissue culture is a biotechnology method where small plant parts called explants are grown under sterile laboratory conditions using nutrient-rich artificial media. The technique is based on the principle of totipotency, where a single plant cell has the ability to regenerate into a complete plant when provided with suitable growth conditions. This ability makes tissue culture valuable for crop improvement, conservation and multiplication of elite cassava varieties.

Media preparation

Plant tissue culture mainly depends on the usage of media that is provided for tissue culturing. The media provides essential minerals, vitamins, carbohydrates and other nutrients required for cell division, plant regeneration, shoot and root development. Among different media, Murashige and Skoog (MS) media is widely used because of its balanced nutrient composition. The ratio between auxins and cytokinins determines whether the tissue develops into roots, shoots or callus. In cassava tissue culture it has a major advantage of the rapid production of large numbers of plants from a small amount of plant tissue. Through micropropagation, thousands of uniform plantlets can be produced within a short period under controlled conditions. There are two different concentration of media are prepared like for shooting and for rooting.

For Shooting:

- Weigh 4.4 g of Murashige and Skoog (MS) medium (Hi-Media PT021-25L) and dissolve

- it in 1 litre of distilled water.
- Add 25–30 g of sucrose and 0.8% (w/v) agar (8 g/L) to the medium.
- Add 2 mL of 1 mg/L 6-Benzylaminopurine (BAP) and 1ml of 0.5 mg/L NAA from stock solution to obtain the required concentration for shoot induction.
- Adjust the pH of the medium to 5.8 ± 0.1 using 0.1 N NaOH or 0.1 N HCl, if required.
- Heat the medium on a heating mantle until the agar dissolves completely and the medium becomes clear.
- Dispense the prepared medium into sterile culture bottles in the required volume.
- Sterilize the culture bottles by autoclaving at 121°C, 15 psi pressure, for 15 minutes.
- After autoclaving, allow the bottles to cool and solidify. Seal the bottles with thin film and label each bottle with the medium name, growth regulator, preparation date.

For rooting:

- Weigh 4.4 g of Murashige and Skoog (MS) medium (Hi-Media PT021-25L) and dissolve it in 1 litre of distilled water.
- Add 25–30 g of sucrose and 0.8% (w/v) agar (8 g/L) to the medium.
- Add 2 mL of 1 mg/L Indole-3-butyric acid (IBA) stock solution to the medium to promote root induction.
- Adjust the pH of the medium to 5.8 ± 0.1 using 0.1 N NaOH or 0.1 N HCl, if necessary.
- Heat the medium on a heating mantle until the agar dissolves completely and the medium becomes clear.
- Dispense the prepared medium into sterile culture bottles or culture tubes in the required quantity.
- Sterilize the medium by autoclaving at 121°C, 15 psi pressure, for 15 minutes.
- After autoclaving, allow the bottles to cool and solidify. Seal the bottles with thin film and label each bottle with the medium name, growth regulator, preparation date.

Steps involved in cassava tissue culturing

Explants Used in Cassava Tissue Culture

The success of cassava tissue culture depends on the type of explant we are selecting. Explants is a small pieces of plant tissue such as nodal segments, Meristem, Shoot tips, stem or roots excised from a healthy mother plant.

Shoot Tip Culture

Shoot tip culture is the most commonly used explants in cassava tissue culture because they contain actively dividing meristematic cells. These cells have a high capacity for regeneration and can develop into complete plants under suitable conditions. Shoot tip culture is also preferred for producing disease-free plants because meristematic regions generally contain fewer pathogens compared with mature tissues. Shoot tip-derived plants generally maintain genetic stability and preserve the characteristics of the original variety. Therefore, this method is widely applied for multiplication and conservation of valuable cassava genotypes.

Nodal Segment Culture

Nodal segments contain axillary buds that can develop into new shoots when cultured on suitable media. They are widely used because they are easy to establish and capable of producing multiple shoots through repeated sub culturing. Nodal culture is considered one of the simplest and most efficient methods for cassava micro propagation. The use of nodal explants helps maintain genetic uniformity because new plants develop from existing buds rather than from highly variable callus tissues. This makes nodal culture suitable for commercial multiplication of cassava planting materials.

Sterilization:

The success of in vitro culture largely depends on effective surface sterilization of the explants. The following procedure was adopted for the sterilization and inoculation of cassava nodal explants. Healthy and disease-free cassava plants were collected from the field, and nodal segments were excised using a sterile scalpel.

- The explants were immersed in 1-2% Bavistin fungicide solution (1-2 g in 100 mL of distilled water) for 20–30 minutes to eliminate fungal contaminants.
- The explants were rinsed thoroughly with sterile distilled water to remove any residual fungicide.
- They were then treated with Tween-20 (2-3 drops in 100 mL of distilled water) for 10-15 minutes with gentle agitation to remove surface debris and reduce microbial load.
- The explants were washed 2–3 times with sterile distilled water.
- Surface sterilization was carried out by immersing the explants in 70% ethanol for 30 seconds followed by washing 2-3 times with sterile distilled water.

- The explants were subsequently treated with 2 % sodium hypochlorite (NaOCl) solution or 0.1% mercuric chloride ($HgCl_2$) solution for 7-10 minutes with intermittent shaking.
- After chemical sterilization, the explants were washed 3–5 times with sterile distilled water to remove all traces of the sterilizing agent.
- Using a sterile scalpel, approximately 2-3 mm of tissue from both ends of each explant was trimmed to remove any tissue damaged by the sterilizing agents.
- The sterilized explants were carefully transferred aseptically into culture bottles containing sterile Murashige and Skoog (MS) medium using sterile forceps.
- All sterilization and inoculation procedures were performed under aseptic conditions inside a laminar airflow cabinet to prevent microbial contamination.

Shoot Initiation

After surface sterilization, the explants were aseptically inoculated onto Murashige and Skoog (MS) medium supplemented with appropriate concentrations of plant growth regulators. Under sterile culture conditions, the explants resumed active cell division and initiated shoot development. 6-Benzylaminopurine (BAP), a cytokinin, was incorporated into the culture medium to stimulate shoot initiation, promote axillary bud break, and enhance the formation of multiple shoots. The cultured explants were incubated under controlled environmental conditions at 25 ± 2°C with a 16-hour light and 8-hour dark photoperiod, where shoot initiation was observed within 2-4 weeks, depending on the genotype and culture conditions.

Shoot Multiplication

Shoot multiplication is a crucial stage in cassava tissue culture in which newly developed shoots are repeatedly transferred to fresh Murashige and Skoog (MS) medium supplemented with suitable concentrations of plant growth regulators to increase the number of shoots. During this stage, multiple shoots are produced from a single explant through continuous axillary bud proliferation. Periodic sub culturing at regular intervals under controlled environmental conditions promotes rapid shoot multiplication while maintaining the genetic uniformity and vigor of the plantlets. An efficient shoot multiplication system enables the large-scale production of healthy, disease-free, and true-to-type cassava planting materials, making it an essential step in commercial micro propagation programs.

Root Initiation

After approximately 2 weeks, the regenerated shoots were well developed and ready for

root induction. The healthy shoots were carefully excised and transferred aseptically to Murashige and Skoog (MS) rooting medium supplemented with an appropriate concentration of Indole-3-butyric acid (IBA). IBA, an auxin, is widely used for root induction as it effectively stimulates root initiation, promotes root elongation, and enhances the development of a healthy root system. The cultured plantlets were incubated under controlled environmental conditions until well-developed roots were formed, resulting in complete plantlets suitable for subsequent hardening and acclimatization.

Hardening

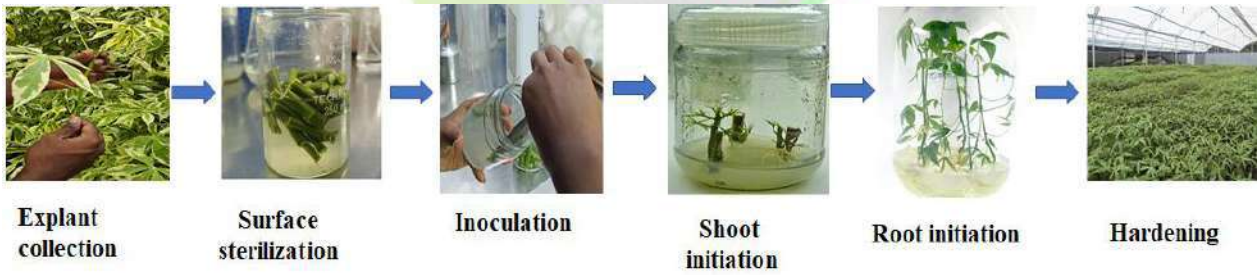
Plants produced through tissue culture grow under controlled laboratory conditions with high humidity and low environmental stress. Therefore, they need gradual adaptation before field planting. During hardening, plantlets are transferred from culture vessels to greenhouse or nursery conditions where they develop stronger roots and shoots.

1) **Primary hardening**

   To acclimatize rooted in vitro plantlets from culture-room conditions (high humidity, low light, sterile environment) to greenhouse or shade-house conditions. **Duration: 2-4 weeks**

2) **Secondary hardening**

   To strengthen acclimatized plantlets before field transplantation**.** Transfer successfully hardened plantlets into larger polybags or nursery pots containing fertile soil. **Duration: 3-4 weeks.**



Conclusion

Cassava tissue culture has become an essential biotechnology tool for modern cassava production. It enables rapid multiplication, production of disease-free planting materials, conservation of genetic resources and development of improved varieties. Although challenges such as high cost, contamination and genotype dependency remain, continuous advances in tissue culture, cryopreservation and genetic engineering provide promising solutions. Cassava

tissue culture will continue to support global food security and sustainable agriculture in the future.

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MICROPROPAGATION OF ROSE (*Rosa sp.*): ARISING NEW BIOTECHNOLOGY

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Abstract

Rose (*Rosa sp*.) is one of the most valuable ornamental crops in the global floriculture sector, contributing significantly to the flower industry due to its aesthetic, commercial and economic importance. Traditional propagation techniques such as budding, grafting and stem cuttings are commonly used for rose multiplication however, these methods are often constrained by low propagation efficiency, susceptibility to disease transmission and seasonal limitations. Plant tissue culture particularly micropropagation has emerged as a powerful biotechnological approach for the rapid production of disease-free, genetically uniform and high-quality rose plants. This article reviews the principles, methodologies, developmental stages, culture media, emerging technologies and future prospects of rose micropropagation, supported by recent scientific research and technological developments.

Keywords: Rose, Inoculation-Shoot tip culture-Media-Sterilization and Growth regulators.

Introduction

Rose (*Rosa* sp.) is one of the most widely cultivated and economically significant

ornamental flowering plants in the world. Often referred to as the "Queen of Flowers" it is highly valued for its vibrant colours, delightful fragrance, extended vase life and immense commercial appeal. Roses play an important role in the floriculture industry and are extensively utilized in bouquets, garlands, landscaping, perfumery, cosmetics, pharmaceuticals and various decorative applications. The global floriculture sector has witnessed substantial growth in recent years, driven by the rising demand for ornamental flowers in both domestic and international markets.

In India, rose cultivation has gained considerable importance, with major production centres located in Karnataka, Tamil Nadu, Maharashtra, Himachal Pradesh and West Bengal. Conventional propagation methods such as stem cuttings, layering, budding and grafting are commonly employed for rose multiplication however these techniques are often constrained by low multiplication efficiency, disease transmission, lack of genetic uniformity and seasonal limitations. To address these challenges modern biotechnological approaches particularly micropropagation through plant tissue culture have been developed. Rose micropropagation offers an effective means of producing large quantities of disease-free genetically uniform planting material within a relatively short period.

Importance of Rose Micropropagation

Rose micropropagation has become highly important in modern floriculture because of its numerous advantages. Conventional propagation methods are often slow and may transmit fungal, bacterial or viral diseases from mother plants to newly propagated plants. Micropropagation allows rapid multiplication of healthy plants in a limited space and time. It also supports conservation of rare and endangered rose varieties. Tissue culture-derived roses show better growth, uniform flowering and higher survival rates. Commercial flower growers prefer micro propagated roses because they produce export-quality flowers with uniform stem length, colour and blooming pattern. Furthermore, tissue culture technology enables year-round propagation independent of seasonal changes.

Principle of Rose Tissue Culture

Rose tissue culture works on the principle that plant cells can divide, differentiate and regenerate into complete plants under controlled laboratory conditions. The tissue culture process requires explants, nutrient media, growth regulators, sterile conditions and environmental control. The nutrient medium supplies essential minerals, vitamins, carbohydrates and hormones necessary for plant growth. Plant growth regulators play a major role in shoot multiplication,

rooting, and callus formation. Cytokinins (BAP) promote shoot development, while auxins (IBA) stimulate root formation. Environmental conditions such as temperature, humidity, light intensity and photoperiod also influence the success of tissue culture. The Murashige and Skoog medium is widely used because of its balanced nutrient composition and high regeneration efficiency in roses.

Explants Used in Rose Micropropagation

Different plant parts are used as explants in rose tissue culture. Common explants include shoot tips, nodal segments, axillary buds, leaves, petals and floral tissues. Among these nodal segments and shoot tips are most commonly used because they show better regeneration efficiency and reduced chances of somaclonal variation. The selection of healthy explants is essential for successful micropropagation. The explants should be collected from disease-free mother plants showing vigorous growth and true-to-type characteristics. The physiological condition and age of explants significantly influence regeneration response.

Varieties of rose that are suitable for micropropagation

- *Rosa indica*: Used widely as rootstock for grafting due to its hardiness and disease resistance. Micropropagation ensures uniform, vigorous rootstocks.
- *Rosa hybrida*: Includes popular hybrids like Grand Gala and First Red. These are characterized as vibrant flower nature and long blooming.
- *Rosa damascene*: Valued for its fragrant petals used in perfumes, it is traditionally propagated by suckers and using tissue culture method enables faster, disease free production.
- *Rosa bourboniana*: Fragrant Garden rose used in garlands and ceremonies. Micropropagation supports consistent flower quality and large-scale supply.

Process of Micropropagation in Rose

Selection of Explants

The process begins by selecting healthy, disease-free explant tissues such as shoot tip, nodal segments or auxiliary buds from young, actively growing mother plants. These parts have high regenerative ability and ensure better response in vitro. The physiological age and health of the donor plant are crucial for success.

Surface Sterilization

Explants are first washed under running tap water and cleaned by whipping with ethanol.

The initial surface sterilization was done by washing with Bavistin fungicide. Under a laminar airflow chamber, explants are treated with 70% ethanol for 30 seconds to 1 minute followed by treated with sodium hypochlorite (0.1-1%) or mercuric chloride (0.1%) for 7 minutes. Multiple rinses with sterile distilled water were carried in each chemical treatment t remove the residues. This process is essential to eliminate microbial contaminants.

Inoculation into media

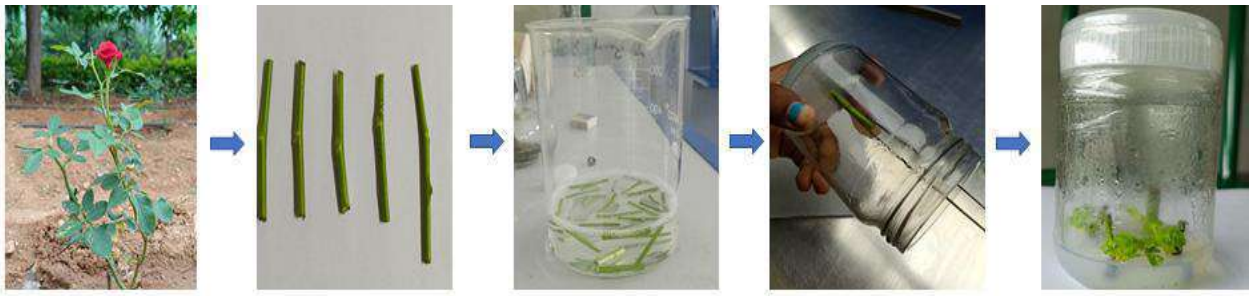
Sterile explants are transferred to Murashige and Skoog media enriched with macro and micronutrients, vitamins, 3% sucrose and solidified with agar. Growth regulators like Benzylaminopurine (BAP) and auxin IBA (Indole-3- butyric acid) are added based on the growth stage. Cultures are maintained at 23-27 ºC, 60-70% relative humidity and under 16-hour light / 8-hour dark photoperiod using fluorescent or LED lights.

Shoot Induction

Cytokinin's, especially BAP (usually around 1-3 mg/l), stimulate shoot bud formation within 1-2 weeks after inoculation. Low concentrations of auxins like NAA (0.1-0.5 mg/l) may be added to balance shoot proliferation. The regular subculture between days enables mass multiplication. Shoot induction is influenced by hormones combination, rose genotype and environmental settings.

Rooting of Shoots

Well-developed shoots are shifted to a rooting medium containing higher levels of auxins typically IBA (0.5-2.0 mg/L) or NAA. Within 2-3 weeks, root primordia form, eventually developing into a robust root system. Rooting success varies by cultivar and is affected by auxin type, light, and temperature.



Primary Hardening

Rooted plantlets are gently removed from culture vessels, cleaned of agar and transplanted into pots filled with sterile substrates like cocopeat, perlite or vermiculite. They are kept in mist chambers or greenhouses at 25-28ºC, 80-90% humidity and moderate light intensity to help them transition from lab to natural condition over 2-3 weeks.

Secondary Hardening

After initial acclimatization, plantlets are moved to nursery beds, polybags or pots containing soil: sand: compost (1:1:1). Exposed gradually to outdoor condition, they adapt to variations in light, temperature and humidity. This stage lasts 2-4 weeks, preparing them for field planting. Regular watering, light fertilization and pest monitoring are important during this phase.

Conclusion

Micropropagation as transformed rose cultivation by offering a reliable, efficient alternative to traditional methods. It enables year-round production of uniform, disease free and high-quality plant, meeting both domestic and global market demands. The technique also aids in conserving rare and indigenous rose varieties, supporting biodiversity and sustainable farming. as biotechnology advances, micropropagation continues to become more precise and cost effective, make it a key innovation in the floriculture industry. With its blend of science and beauty, micropropagation ensures roses remain a lasting symbol in garden and culture worldwide.

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TURKEY BERRY - A MEDICINALLY VALUED UNDERUTILIZED VEGETABLE

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Introduction

Turkey berry, botanically called Solanum torvum (2n = 24), belonging to Solanaceae family, is also called as Pokak, Pea eggplant and Devil's fig. *Solanum torvum* grows in wet thickets and woodlands, often along riverbanks in secondary growth, at elevations from about sea level to 2000 m. It is common in forest clearings, brushy pastures and other disturbed habitats such as roadsides, landslides, vacant lots, abandoned farmland, and around habitation and farm buildings. It is cultivated in India, China, Brazil, Cambodia, Bangladesh, Papua Guinea

ORIGIN AND DISTRIBUTION

Turkey berry originated is presumably native to tropical South America. It has been introduced and naturalized throughout tropical Africa, Asia, Australia, the Pacific Islands and parts of southern Europe and the USA.

BOTANICAL DESCRIPTION

The plant is usually 2 or 3 m in height and 2 cm in basal diameter. The shrub usually has a single stem at ground level, but it may branch on the lower stem. The stem bark is grey and nearly smooth with raised lenticels. Foliage is confined to the growing twig. The twigs are grey-green and covered with star-shaped hairs. The spines are short and slightly curved and vary from thick throughout the plant, including the leaf midrib, to entirely absent. The leaves are opposite or one per node, broadly ovate with the border entire or deeply lobed. The flowers are white, tubular with 5 pointed lobes, and grouped in corymbiform cymes. They are shed soon after opening. The fruits are called berries that grow in clusters of tiny green spheres that look like

green peas. They become yellow when fully ripe. They are thin-fleshed and contain numerous flat, round, brown seeds. Axillary, branched inflorescences bear up to 100 bright white, star-shaped flowers, ½ to 1 inch across, often with a mix of bisexual and staminate (male) flowers. The inflorescence branches, pedicels (flower stalks) and calyces bear scattered stellate hairs and short, simple gland-tipped hairs.

FLORAL BIOLOGY

Solanum torvum is andromonoecious, producing inflorescences with both hermaphroditic flowers and functionally staminate flowers, the latter situated on the distal portion of the inflorescence. In hermaphroditic flowers, which represent 80-85 % of all flowers, the style extends for about 2-2.5 mm beyond the anther cones, whereas in the functionally staminate flowers the style does not protrude from the anther cones. The flowers are nectarless and typically last only 1 day, although sometimes they may open for a second day. They are visited and pollinated by matinal and diurnal bees that "buzz" the pollen out of the poricidal anthers**.**

NUTRITIVE VALUE (PER 100 g OF EDIBLE PORTION)



CONSTITUENTS	AMOUNT
Water	80.90 g
Protein	2.00 g
Fat	0.10 g
Carbohydrate	7.90 g
Iron	2.00 g
Vitamin A	7.50 g
Vitamin B	0.08 g
Vitamin C	80.00 g

RELATED SPECIES

Several other *Solanum* species have at one time been included in *Solanum torvum* as subspecies or varieties:

i. *Solanum bahamense* var. *persicifolium*

ii. *Solanum chrysotrichum* var. *pleiotomum*

iii. *Solanum ferrugineum* var. *ferrugineum,*

iv. *Solanum ferrugineum* var. *hartwegianum*

v. *Solanum lanceolatum* var. *schiedeanum*

vi. *Solanum macaonense* var. *lasiostylum*

vii. *Solanum rudepannum* var. *fructipendulum,*

viii. *Solanum rudepannum* var. *ochraceo-ferrugineum*

ix. *Solanum scuticum* var. *Brasiliense*

x. *Solanum scuticum* var. *daturifolium,*

xi. *Solanum scuticum* var. *genuinum*

USES OF TURKEY BERRY

They are used in soups and sauces or chopped together with eggplant fruits or tomatoes. Plant possesses several medicinal properties *viz*., seeds are smoked in Malaysia for curing toothache. In India extracts of the plant are used as antidote to snake bite and insect twinges and fruits are said to be useful to relieve stomach pain. The glycoalkaloid solasodine that

is found in its leaves and fruits is used in India in the manufacture of steroidal sex hormones for oral contraceptives.

CLIMATE AND SOIL

Well drained loamy soils are suitable. It grows well under moderate climatic conditions. Being a hardy plant, even land with medium fertility can give a good stand.

PROPAGATION AND GRAFTING

Solanum torvum is normally propagated by seed. The 1000-seed weight is about 3.30 g. For direct seeding- approximately 500g to 1kg of seed is required for one hectare. For transplanting- approximately 10000 to 20000 seedlings are required per hectare. Seed is sown in a nursery and seedlings are transplanted after 5–6 weeks at a spacing of 1 m. Branch cuttings taken from high-yielding shrubs are also used for propagation. Semi-hardwood cuttings 12–15 cm long, collected from fresh shoots and with their leaves removed, will produce roots and new shoots in 3–4 weeks. Turkey berry has been grafted with egg plant in an attempt to incorporate favourable genes for resistance to Verticillium wilt into the vegetable.

WEEDING AND IRRIGATION

First weeding is done after 3–4 weeks and second weeding at 2–3 months. Irrigation should be given once in a week in the first month and later reduced to once in a fortnight.

MANURES AND FERTILIZER

Apply FYM 10 t/ha and N, P and K at 25, 40 and 80 kg/ha respectively as basal dose. 25 kg of N at second month after planting is required as top dressing.

HARVESTING

Clusters of immature green fruits are picked by the time these have reached the size of a pea or cherry, depending on the cultivar. They can be picked for consumption in many successive rounds, starting 2 weeks after first flowering.

DRYING

The mature *Solanum toruvm* fruits were collected, slit and soaked in butter milk for 30 minutes and then dried using sun, solar and cabinet drying method. The samples were dried till it reaches the safe moisture content of 7%. The drying time of *Solanum torvum* in sun was 84 hours, in cabinet at 60°C was 16 hours and in sun drying it was 84 hours. The yield of *solanum torvum* powder was high in cabinet drier (26.8 g/100 g whereas in sun (25.6 g/100 g) and solar drier (25.2 g/100 g) it was similar.

PEST AND DISEASE MANAGEMENT

Aphis fabae can cause a considerable reduction at harvest. Other significant pests include *Epilachna hirta* and root knot nematodes (*Meloidogyne*). *Zonocerus variegatus* can damage ripe fruits. Fungal diseases are not a serious problem, but plants can become infected with *Cladosporium oxysporum*

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ASPARAGUS- A MEDICINALLY VALUED UNDERUTILIZED VEGETABLE

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Introduction

Asparagus, is botanically called Asparagus officinalis (2n= 20), belongs to Liliaceae family, is an herbaceous perennial crop which is productive for fifteen years or more after establishment. Herbaceous and perennial that will reach the height of 100 cm to 150 cm, with stout stems with much-branched, feathery foliage. The tender shoots called 'spears' are used as vegetable and in preparation of soup. The canned and frozen spears are also used as processed foods.

ORIGIN AND DISTRIBUTION

The origin is considered to be Europe and Asia**.** Grown in large areas in countries like USA, Germany, Spain and France, while India's contribution is meagre.

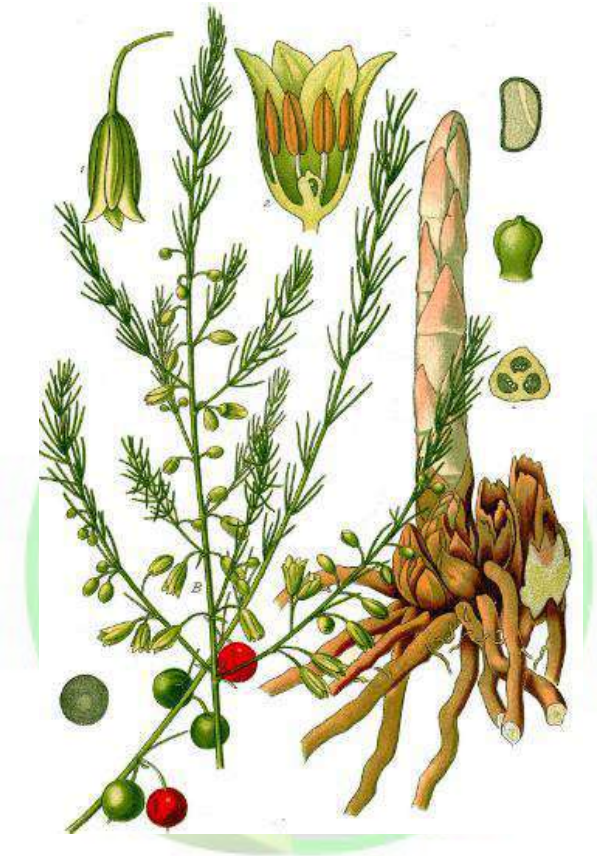
BOTANICAL DESCRIPTION

Asparagus species may be erect or climbing, and most of the species are more or less woody. The rhizome like, or sometimes tuberous, roots give rise to conspicuous fernlike branchlets. True leaves are reduced to small scales. Many species are dioecious (individuals are either male or female) and the small greenish yellow flowers in the spring are followed by red berries in the fall. Members of the genus are characterized by the presence of cladodes, which are leaflike organs in the axils of the true leaves.

FLORAL BIOLOGY

Asparagus is a cross-pollinating plant. The male plants are more desirable because they produce many smaller stalks. The female asparagus plants produce much fewer and larger

stalks. Flowers solitary or in pairs in the leaf-axils, unisexual, greenish yellow. Tepals shortly united at base, male flowers with free stamens inserted near the base of tepals and a rudimentary ovary; female flowers with superior, 3-celled ovary, short style, 3-lobed stigma. Fruit is small red berry.



RELATED SPECIES

More than 300 species of asparagus have been identified, of which, *Asparagus officinalis* is the only species cultivated commercially as a vegetable. *Asparagus officinalis* is native to Europe with other species of *Asparagus* as *A. acutifolius* which is not cultivated but whose young shoots are gathered and eaten in the spring.

CULTIVATED TYPES OF ASPARAGUS

Asparagus is broadly divided into three groups,

1. Green coloured spears: Most popular and mainly used in fresh market.

2. White or light green spears: These are mainly used for processing.

3. Purple Spears: These are mild in flavour, but sweeter than green asparagus.

USES OF ASPARAGUS

1. Asparagus is a nutritious vegetable that is eaten steamed, roasted, grilled, stir-fried or added to soups, salads and pasta dishes.
2. It provides Vitamin A, C, E, K, folate and fibre and being low in carbohydrates.
3. Its fibre helps to promote healthy gut bacteria.
4. Asparagus contains amino acid asparagine which can act as a diuretic factor.
5. It has high folate that is important for foetal development.
6. Asparagus contains antioxidants such as glutathione and flavonoids that helps to protect cells from oxidative stress.
7. Asparagus has anti-inflammatory properties, controls blood sugar level, heart health, and immune support.
8. In traditional Ayurveda, it is used in the name of Shatavari that helps in female reproductive health, promotes lactation of breastfeeding mothers, relives gastric ulcers, cope with stress and immune functions.

COMMERCIAL VARIETIES AND HYBRIDS

I. Varieties

1. Perfection: Recommended by IARI, New Delhi. It is an early, uniform, productive variety, delicious with high food value. The spears are large, green, succulent and light tipped. Average yield is 80-100 q/ha.

2. Selection-841: Bush type, medium, uniform plants and productive. The spears are 15-20 cm long, succulent, tender, green with better flavour and suitable for soup preparation. Yield is 90-110q green spears/ha.

Despite these varieties, UC-72, UC-66 and Sel-831 are also grown in Kashmir, India.

II. Hybrids

All available male hybrids are more productive and do not produce seed which sprouts to become a weed. Jersey Gem, Jersey Giant and Greenwich produce superior yields in North Carolina. Jersey Gem has the added benefit of having tolerance to the disease *Cercospora* leaf spot. The increased yields of hybrids make them worth the extra seed cost.

CLIMATE AND SOIL

Cool season crop. Asparagus is grown in temperate and sub-tropical regions. Mean day temperature of 25-30^{o}C and 15-20^{o}C at night are ideal. The optimum temperature for

germination is 24º C. Rhizome buds form at temperatures between 16 and 32 ºC. Asparagus grows well in well drained and friable soil to accommodate the plants excessive root system. Loams and sandy loams are preferred. Clay soils should be avoided. Asparagus tolerates salinity but not acidity. pH 6.0-7.0. Proper preparation of soil is essential as the crop occupies the soil for a number of years. If the soil is more acidic in nature, liming should be done.

FIELD PREPARATION

Field preparation should take place the year prior to planting. Plough down soil amendments before furrow construction or bed shaping. All furrows should be 6 to 8 inches below the normal soil surface. Rates of fertilizer for asparagus are dependent on soil test values and relative organic matter levels.

SOWING AND PLANTING

Seed rate is 3-4 kg/ha to raise the nursery. The depth of planting is 20-30 cm (25 cm most common). Density of plants 30000/ha. Planting Distance is 150 cm X 45 cm. Crown is planted in furrows of 30 cm width and 25 cm deep. Asparagus is raised through seeds, seedlings, as well as crowns. On commercial basis, cultivation through seed is recommended. In Mid hills- March-June; High hills- April-May is the preferred season.

1. CROWN PLANTING: Use only certified crowns for planting as they may carry several diseases. Plant asparagus crowns (roots plus plant buds) so that the top of the crown is 15 cm below the soil level. Depth of planting is critical, if planted too shallow, asparagus will produce a large number of small spears that are not commercially stable. If planted too deep, spears will be very large, but will be few in number. Plant crowns 30 cm apart in the row with the buds upright, and 150 cm between rows to have 21,750 crowns per hectare. Cover crowns with 5-7.5 cm of soil after planting. As plants grow, gradually fill in the rest of the furrow with 2.5-5 cm of soil in 3-5 cultivations, but do not completely cover plants. The furrow should be completely filled by July of the first year. Plant before the buds begins to appear in the spring.

2. DIRECT SEEDING METHODS: Seeds should be placed 5 cm apart in the row, 2 to 2.5 cm deep. Single row seeding require 2.5-3.4 kg of seed per hectare. Double row seeding requires 4.5 to 6.8 kg seeds per hectare. Asparagus seeds germinate best at 24°C. Direct seeding is preferred when the soil temperature is at least 16°C.

3. SEEDLING TRANSPLANT METHOD: Asparagus seedlings can be grown successfully in peat pots, plastic pots, trays, peat pellets or seedling type trays. Seedling growth and survival are

usually better with larger cells up to 5 x 5 cm seedling cells. Transplanting of seedling is preferred after the threat of frost but before temperatures get above 32°C. Favourable conditions usually occur in April and May.

INTERCULTURAL OPERATION

MANURING

Apply FYM @ 20t/ha.; N: P: K – 100:120:150 kg/ha. Half of FYM + half NPK should be applied in spring season before growth of the plant. Remaining half of the fertilizers should be applied after cutting of spears.

WEEDING AND IRRIGATION

Timely cultivation is a critical part of any asparagus weed control program, especially during the first two years. Use only very shallow disking (2.5 to 5 cm) to remove these weeds. Most of the grassy and perennial weeds are controlled by the use of Paraquat @ 2-3 kg a.i./ha before emergence of spears and spray 2,4-D @ 2 kg a.i./ha after the harvesting of spears. Glyphosate @ 2 l/ha is used before the emergence of spears and again at the end of harvesting. Adequate moisture should be maintained for good germination and early seedling growth. Asparagus beds should be well drained by means of open furrows. Irrigating asparagus with 25 mm water per week during the fern growing stage as a continuing operation is recommended to obtain high yield.

PLANT GROWTH REGULATORS

Abscisic acid appears to promote sink strength or encourage phloem uploading. Gibberellic Acid promotes growth of asparagus buds. Butyric Acid supports spear emergence.

BLANCHING

Mounding the soil to a height of 25-30 cm over the rows is practiced to blanch the young spears and get white asparagus for canning. After harvest, the spears should be held in a cool shaded place and sprinkled with water to prevent shrivelling and wilting. A single irrigation sprinkler over the boxes works well. Asparagus should be hydro cooled before packing.

HARVESTING

Harvested on limited basis (2 to 3 weeks, or 8 spears per plant) during the first year after planting. Harvesting should be limited during the second year as it results in slight reduction in spear size. It takes a long time for asparagus to develop a large root system. The spear length should be approximately 8-10 inches (20-25 cm) at cutting with spear tips tightly closed. Male

plants give the higher total yield while female plants produce larger individual spears. Yield varies with varieties, region, climate and sex form. On an average, 2.5-4 t spears are produced in one hectare.



PHYSIOLOGICAL DISORDER

1. Surface cracking: Surface cracking can occur when hot temperatures accelerate spear growth. As spear temperature rises, pressure increases in the spear causing the skin to rupture. Soil moisture content also influences cracking. In low soil moisture conditions, spear growth is slow and spears are less likely to crack. Rapid changes in moisture that typically occur after irrigation or rain may cause some spears to crack or have a rough feel.

2. Fasciation: Fasciation is the fusion or flatting of many stems that gives the spear a distorted appearance. Fasciated spears occur when the bud or buds have been damaged by cold, insects, bacteria or viruses, chemicals or mechanical injury. Plants that grow fasciated spears generally do not produce them every year and their appearance is unpredictable. In some plant species, genetic mutations result in year-to-year expression of the symptoms but this is uncommon in asparagus.

3. Fern tip wilting: Fern tip wilting occurs during periods of rapid growth and high temperatures. Water loss near the fern tip is greater than supply even when soil moisture levels are adequate. Fern wilts during the day and recovers overnight resulting in "S-crooked" appearance. When soil moisture levels are very low, spears may wilt and recover resulting in bent spears while in fern, the tips may dry out and dieback. Localised Ca deficiency in growing tips may be responsible for fern wilting because Ca is immobile in plants.

POST HARVEST MANAGEMENT

Once spears have been harvested, they must be cooled immediately to 32-36ºF (0-2ºC). Cooling preserves the sugar content along with fibre content is important in quality. Harvested spears are prepared for market by grading, sizing and bunching. Grades are based on freshness, length, diameter of the stalk, colour of the spear, tightness of spear tip and extent of bruising. Spears of large diameter are considered to be superior in quality. Asparagus is a very perishable crop and storage is not recommended. If market conditions demand, spears may be held at 0-2 degree C and 95% RH for no longer than 2-3 weeks.

PEST MANAGEMENT

1. Asparagus beetle: Asparagus beetles and their larvae attack on spears and ferns. Controlled by Spraying carbaryl (0.1%).

DISEASES MANAGEMENT

1. Crown rot: Asparagus is affected by two *Fusarium* species. The first is *Fusarium oxysporum pv. asparagi* which causes crown rot; and the second one is *Fusarium moniliforme* which causes root rot. Avoid planting Asparagus in soil in which asparagus has been grown in the last 5 years. Purchase only certified crowns. The root rot pathogen may be spread through asparagus seed. Make sure to treat seeds for producing crown.

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CHINESE CHIVE A FLAVOURING AND GARNISHING UNDERUTILIZED VEGETABLE

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Introduction

Chinese Chive, botanically called Allium tuberosum (2n= 32), belonging to Alliaceae family is a wonderful garnish vegetable. The leaves are having mild garlic like flavour, rich in vitamins, fibre, mineral and sulphur compounds that have antibiotic properties. Its leaves are used in salad and for flavouring and for garnishing various dishes. Many times the dehydrated leaves used for future seasoning of dishes. It is low in calories but rich in beneficial nutrients, vitamins, minerals and antioxidants. *Allium tuberosum* is a perennial plant cultivated in many countries in Asia. But it is still a minor vegetable in India.

ORIGIN AND DISTRIBUTION

Origin is considered to be China**.** A native of eastern Asia, *Allium tuberosum* has been used as a salad crop for centuries in China, Japan, South-East Asia and through to India. Chinese chives have been cultivated for more than 3000 years in China. It grows wild over much of eastern Asia, from Mongolia in the north to the Philippines in the south and from Japan to Thailand east–west. It is a plant that easily naturalizes from cultivation, so its initial centre of origin is unclear.

BOTANICAL DESCRIPTION

Allium tuberosum is a vigorous, bulbous, perennial herb. It forms clumps formed from basal rosettes of 2–8 narrow flat edible leaves and produces inflorescences in summer that are also edible. The inflorescences contain attractive white star-shaped florets with a strong scent, so that it is also grown as an ornamental species. The stem is a branched rhizome that forms a

thickened, underground storage structure that connects several shoots. The rhizome is coated by a fibrous brown mat formed from the remains of decayed leaf bases. Thick, persistent roots grow from the underside of the rhizome. Leaves arise as dense clumps from the rhizome. They are green or greyish green, but turn yellow and wither away after the flowers bloom. The umbel inflorescence has a round and hollow scape, 20-60cm tall. Flowers are purple, pink or white in colour are also found. Each flower is about ¼ inch across with 6 star-like tepals (sepal and petals are undifferentiated), 6 stamens with prominent brown tips (anthers) and a single slender style in the greenish center. Flower anthesis starts from the top of the umbel. Its cross pollinated but selfing also occurs.



FLORAL BIOLOGY

Florets produce viable seed via apomixis (seed is genetically the equivalent to vegetative reproduction as effective fertilization does not occur after pollination) Dormancy in Japanese cultivars of Chinese chive is triggered by exposure to photoperiods of 14 h or less for 30 days. Subsequent exposure to long periods at low temperature breaks the dormancy and permits regrowth as temperatures increase. Chinese chives require long photoperiods in order to bolt. The critical photoperiods needed are longer for Japanese cultivars than for strains from southern Asia. Many cultivars will not flower in the first year after sowing, indicating that a period of cool induction may be needed after the plants have reached a critical size.

RELATED SPECIES

There are five main species of chives grown throughout the world:

1. *Allium shoenoprasum*: Commonly called as Common chives is the most popular variety of chive. They are the smallest of the bunch, with hollow, grass-like leaves and purple flower heads. Common chives have a mild onion flavour and are often used in salads, soups, sauces and even as a garnish.

2. *Allium tuberosum*: Garlic chives or Chinese Chives, have white flowers, are a bit wider than common chives and have flat leaves with white flowers. They have a slight garlic flavour and are often used in stir-fries and other Asian dishes.

3. *Allium ledebourianum*: Giant Siberian chives or Wild onion Chives have vigorous bulbous perennial producing slender, aromatic mid-green leaves in clumps that die back as the flowering begins. Dense umbels of glossy pale violet-pink flowers

4. *Allium ursinum*: Commonly called as ramsons or wild garlic, is native to Europe and parts of Asia. It has flat, broad leaves and white flowers and it has a strong garlic flavour. Ramsons are often used as a garnish, in salads and in soups.

5. *Allium ampeloprasum*: Commonly called as Elephant garlic chives, are the largest of the chive varieties. They have wide leaves and white flower heads, and they have a milder garlic flavour than garlic chives. Elephant garlic chives are often used in soups, stews and sauces.

COMMERCIAL VARIETIES

The Varieties of Chinese Chive are mostly exotic

1. Fat Leaf: As the name suggests, the stalks are wide and thick

2. Knolau: Tall, strong and grows up to 50 cm

3. Monstrosum: Grows up to 80 centimetres tall

4. Neko: Forms flat, broad stalks with a delicate aroma

5. Pink bears: As the name implies pink flowers and wide, juicy leaves

6. Sapras: This gives high yield and are aromatic

7. Shiva: Grows up to 30 cm tall, is very strong-growing and high-yielding.

8. Wagners Kobold: Thin, aromatic stalks

9. Kiss me: Extra-wide stalks varieties

NUTRITIONAL VALUE

Garlic chives is rich in Dietary fibre, Carotene, Vitamins A, Vitamin C, Riboflavin, Potassium, Iron, Thiamine and Beta-carotene. Garlic chives contain 4.4g of Carbohydrates, 0.73g of Fats, 3.27g of Proteins, 2.5g of Dietary fibre, 1.9 g of Sugar, and 22.94 kcal of energy. Potassium (296 mg), Calcium (92 mg), Phosphorus (58 mg), Magnesium (42 mg). Vitamin C (58.1 mg), Vitamin A (1305 mcg), Vitamin K (213 mcg), Folate (105 mcg), *Allium tuberosum* contains phenylpropane glycosides like tuberonoid A and B, flavonoids (kaempferol and quercetin derivatives), pyrazine compounds, nucleosides and nucleotides (uracil, thymine,

thymidine deoxyriboside, adenine riboside), lignan compounds. *Allium tuberosum* essential oils contain mainly dimethyl disulfide, allyl methyl disulfide, dimethyl trisulfide, allyl methyl trisulfide, methyl 1-propenyl disulfide and diallyl disulfide. The leaves contain sulfides, linalool and flavonoid glycosides.

CLIMATE AND SOIL

Chives are tolerant to a wide range of soil conditions but fertile, well-drained medium loams with a pH of 6.0 - 7.0 are generally considered most suitable. Sandy soils can also be used if organic matter (30-40 t/ha) is incorporated. Optimum temperatures is 17-25^{o} C. Clay soils need good drainage as well as organic matter to improve the soil structure and fertility. Limestone must be applied at least six weeks before planting for liming to be effective.

LAND PREPARATION

Chive is a shallow rooted crop (25-30 cm), so land preparation should not be deep. Plough the land twice down and across the field, to a depth of 20-25 cm, and harrow to obtain a fine tilth. Form beds 120 cm wide and 20 cm high. For continuously cultivated lands, fork and rake the land before planting. If nut grass, *Cyperus rotundus*, is present at land preparation, use Roundup at 3-4 tbs/gal 7-14 days before planting. The chemical is most effective when the weeds are actively growing.

PLANTING TIME AND METHOD

Although Chinese chives can be propagated from seeds, this method is not suitable for commercial cultivation because of the long crop cycle (11-15 weeks). The propagation of Chinese chives vegetatively by division of existing clumps of bulbs is the common practice. A spacing of 10 cm within rows and 10 cm across rows should be maintained. In the recommended spacing, two bulbs should be planted per hole. For one hectare of pure stand chives, 6923 kg of planting material will be required.

FERTILIZER APPLICATION

Fym @ 10 t.ha^{-1}.Apply compound fertilizer (15:15:15) at the rate 414.7 kg/ha two weeks after planting. Apply urea at a rate of 138 kg/ha and muriate of potash at a rate of 103.6 kg/ha six weeks after planting.

WEEDING AND IRRIGATION

Chinese Chive is poor competitor with weeds for water and soil nutrients, due to its shallow fibrous root system and the lack of an aerial canopy to shade out other vegetation.

Portulaca oleracea L. is of major economic importance. It affects the plant from a very early stage; it grows vigorously competing with the plant and if not controlled, especially during the first three weeks of crop growth. *P. oleracea* can be controlled effectively with the broadleaf-specific chemical, Runstar @ 15 ml/2-3 gal water. Since this chemical does not affect straight vein weeds such as grasses, the most suitable method of control is hand weeding. Chives respond well to regular irrigation, especially in the dry seasons. Watering in the morning is highly recommended.

HARVESTING

The entire plant can be harvested six to eight weeks after planting. Always harvest early in the morning to prevent the subjection of plants to heat stress. The leaves should be crisp, clean and relatively free from discolouration. The roots should be thoroughly washed to remove all soil particles. The material should then be weighed and tied into the market-required bunches. Chinese Chive give a yield of 7-8 t/ha.

POST-HARVEST MANAGEMENT

Chive is a highly perishable crop and should therefore reach the market within 24 hours of harvesting. If refrigerated conditions are available, this can extend to 48 hours. Storing at 0-1°C at 95-100% relative humidity can extend the shelf life of chives for 7-14 days.

PEST AND DISEASES

1. Leaf miner, (*Liriomyza sp.*): Economically, this is the most important pest affecting chive cultivation on the coast. The larvae of the leaf miner feed between the leaf surfaces leaving irregular patterns of greenish-white mines on the leaves. This pest occurs year-round and it indiscriminately attacks plants of all stages of the crop cycle. Serious infestation causes yellowing and subsequently browning of infected leaves. Trigard 75% WP is recommended.

2. Pink root: It is seen in which the roots turn pink and gradually die off and yield reduction is there. In moist periods Downy mildew is found with furry growth and leaves turn into tan brown colour. Control measure includes 3-5 years of crop rotation with soil solarization. Using pest-free propagation materials. Infested or infected planting materials can infect an entire crop. Adequate soil inversion before planting. This method destroys insects and weeds and prevents the growth of weeds that are likely to harbour disease. Turning the soil exposes insects that pupate in the ground. Field sanitation is also a principal means of preventing pests and diseases.

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KALE- THE KING OF LEAFY VEGETABLE

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Introduction

Kale or Curly kale, botanically called *Brassica oleraceae* var *acephala* L (2n + 18), belonging to Brassicaceae family is a non-heading type of cabbage with rosettes of curled succulent leaves. Kale is a king of leafy vegetables, very close to wild cabbage and also called as "Cabbage's cousin. Kale is also called King of leafy vegetable and it is very close to wild cabbage. Kale is grown mainly for autumn and winter harvest, as cold improves its eating quality and flavour; its hardiness permits harvest of fresh greens after most fresh vegetables have become unavailable. The leaves can be eaten fresh or as a cooked vegetable. Kale is cultivated in the temperate climatic regions of Europe, Asia and the America.

ORIGIN AND DISTRIBUTION

Origin of Kale is considered to be Northern Mediterranean region. This leafy vegetable is a minor temperate vegetable which is introduced in the 19th century. Commercial cultivation of Kale leaves is limited in India. Romans and Sabellian kale, are considered to be the ancestors of modern kales. It became popular as an edible vegetable in 1990 due to its nutritive value. In India Kale is cultivated in the states of Jammu, Kashmir, Himachal Pradesh, Uttaranchal, Punjab, Haryana, Uttar Pradesh and Nilgiris of Tamil Nadu.

BOTANICAL DESCRIPTION OF KALE

Kale, is a leafy herbaceous biennial or perennial, but grown as an annual, plant growing to a height of 0.9 meter, grown as a leafy green vegetable. It produces shallow rooted taproot and shortened stem similar to cabbage, but does not produce cabbage head. Kale produces a rosette

of leaves with wavy to frilled margins, typically blue green but can also be light green/purple. The inflorescence is a spike-like racemose inflorescence with loose clusters of flowers. Pale yellow fragrant flowers with four free petals in cruciform fashion. Gamosepalous calyx with four sepals, green in colour. Petals four, pale yellow and cruciform corolla. Stamens six in two whorls, four stamens long and two stamens short. Ovary superior, bicarpellary, parietal placentation arranged on the false septum. Fruit a long siliqua, glabrous with short stout beak. Light brown, brown or dark brown or even black coloured, oval in shape and small in size

CULTIVATED TYPES OF KALE

I. Classification based on leaf type

1. Curly kale: It is also called Scots kale or blue curled kale. It is the most common variety, it is curly and wavy on the leaf edges. A bit tough compared to other varieties, eating it raw benefits from a mild massaging of salt, vinegar or lemon juice.

2. Lacinato or Tuscan kale: This is also called dinosaur kale, black cabbage, bumpy leaf cabbage or Cavolo Nero. They have thinner and more tender but dark green leaves than curly kale and required minimum cooking. They are important part of Italian cuisine. It is rich in minerals, fibre, vitamin C, Vitamin K and high in antioxidants.

3. Red Russian kale: They are also called scarlet kale or Russian kale. It is identical to curly kale. It is sweet, delicious with a mild flavour and tender, slate green with dark purplish stem. It is cold hardy. It is also called baby kale when its leaves are small and young and it is eaten mostly in this form. It is highly suited for smoothis and salad.

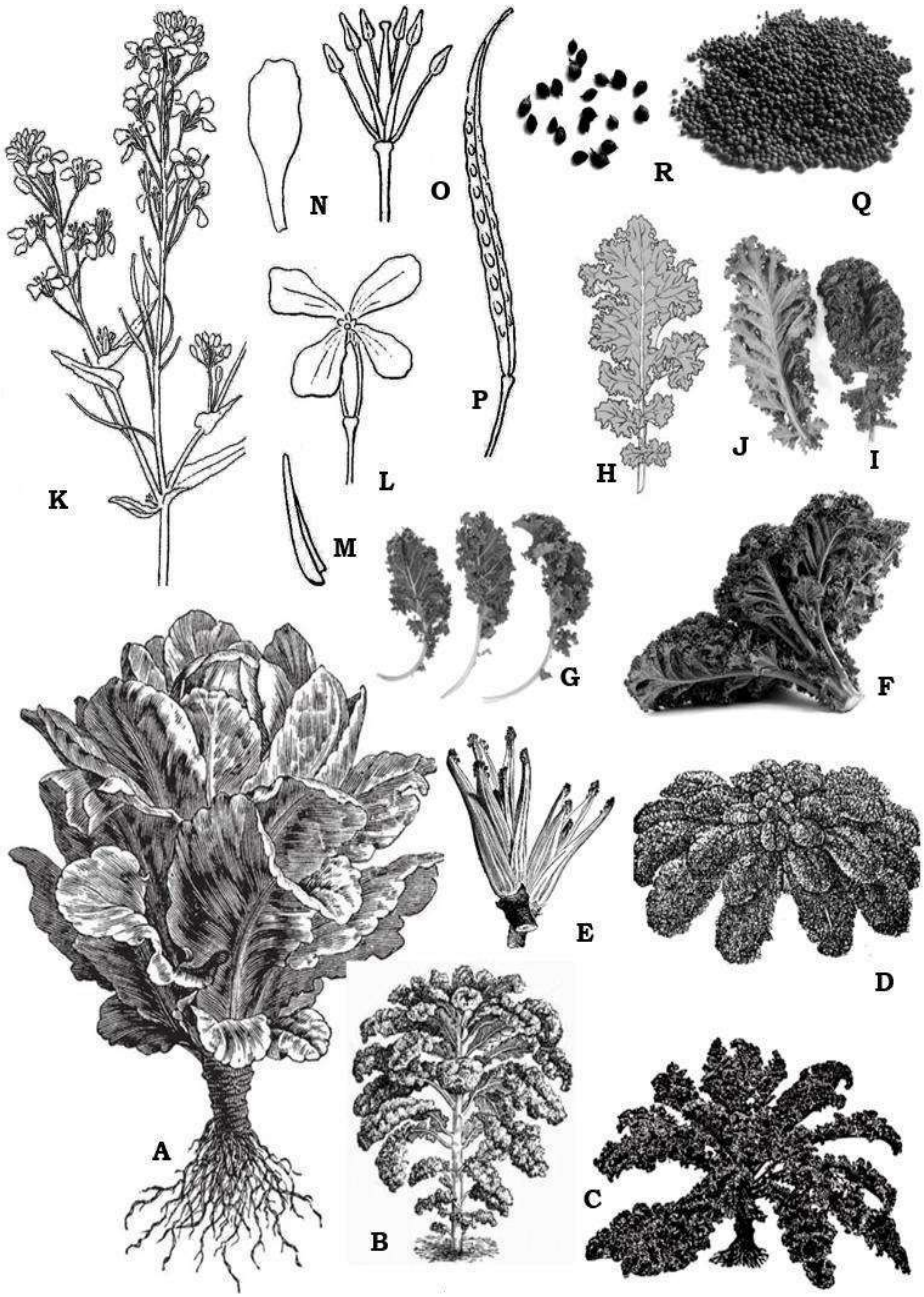
4. Winterbor kale: This kale has a high commercial vale. It has the most winter hardiness that can withstand freezing temperature. These are thicker and bluish green, suitable for kale chips

5. Scarlet kale: These are also called stunning purple leaf kale. The leaves and stalk are purple in colour and become more vibrant as temperature drops. It has highest total tocopherols and alpha tocopherol.

6. Redbor kale: These are deep reddish-purple leaves with frilly texture, which are crispy when eaten raw and tender when cooked. Thses are used in stews and pastas.

7. Sea kale or Beira kale: It is also called Portuguese cabbage. It has wavy green leaves, mainly used in traditional dishes of Portuguese kale soup. The thick stem are eaten like Celery stalk. It is rich in Indoles.

8. Walking stick kale: This is also called Cow cabbage or Jersey cabbage. It has gigantic green leaves and the plant can grow up to 12 feet tall. The younger leaves are eaten as they are tender in texture. The older leaves are good for animal feed.



Brassica oleracea var. *acephala.* Kale. A. Plant, B. Tuscan kale, C. Curly kale, D. Purple kale, E. Sea kale, F. Leaf top Cut off of Kale plant, G. Different shape of kale leaves, H. Single leaf showing veins and lobs, I. Upper side of leaf, J. Lower side of leaf, K. Inflorescence, L. Flower, M. Sepal, N. Petal, O. Androecium and gynoecium, P. Fruit, Q. Seeds and R. Close-up of seeds.



Different cultivated types of Kale

9. Darkibor kale: These have dark green leaves that are highly curled. They grow up to 50 cm high and thrive in a variety of weather conditions. Suitable for kale chips, stir fries and soups as well as for raw salad when young and tender.

10. Thousand head kale: It is considered as a non-kale cabbage that is much branching leafy greens and hence also called branching borecole. It grows up to six feet tall and the massive

leaves can reach a length of 90 cm. The leaves are slightly curled at the tips. Suited for soups and raw salad.

11. Siberian Kale: Siberian kale has hardy white stems that run from the base of the root through the leaves. The leaves of Siberian kale are large and flat with edges that have a ruffled shape. Leaves have a delicate texture and are bluish green in colour.

12. Galenga Kale or Portuguese kale: It has smooth and curled leaves, dark green to green or more or less waxy (blue grey green) and with various heights according to different juvenile periods and vernalization requirements. It has plenty of large leaves with long petioles, leaves can be curly or smooth, forming no head, and a long stem reaching over 1 m high at mature stage before bolting.

13. Japanese kale or ornamental kale: It has a rosette shape with fuchsia center and green outer leaves. The leaves are tougher with frills and has visual appeal. It is an ornamental kale. It can also be eaten. It has a sweet flavour and also delicious.

II. Classification based on plant height

1. Dwarf varieties: Plant height below 40 cm. *Eg*. Dwarf green curled, Curled scotch and Dwarf moss curled.

2. Medum tall varieties: Plant height ranging from 40 to 80 cm. *Eg.* Moist curled and Hamberger market.

3. Tall varieties: Plant height more than 80 cm. They shed leaves early and has less yield. *Eg*. Dazzling blue

NUTRITIONAL COMPOSITION OF KALEF

Raw kale leaves contains Carbohydrates 9.0 %, Protein 4.0 %, Fat 1.0 %, Lutein 241 mcg, Zeaxanthin 6261 mcg, Vitamin B_1 11 mg, B_2 13 mg, B_3 1 mg, B_5 0.9 mg, B_6 27 mg, B_9 141 mcg, Choline 0.8 mg, Vitamin C 120 mg, Vitamin E 1.54 mg, Ca 150 mg, Fe 1.5 mg, Mg 47 mg, K 491 mg, P 92 mg, Se 0.9 mg, Na 38 mg and Zn 0.6 mg. Kale also contains glucosinolate compounds, such as glucoraphanin, phenolics, polyphenols, glucosinolate, sugars, flavonoid and flavonoid glycoside.

TOXICITY IN KALE

Kale contains high levels of polyphenols, such as ferulic acid, with levels varying due to environmental and genetic factors. Boiling kale decreases the level of glucosinolate compounds, whereas steaming, microwaving, or stir frying does not cause significant loss.

Kale is high in oxalic acid and this can be reduced by cooking.

USES OF KALE

Flavoured kale chips are a substitute for potato chips. Kale is an excellent source of Vitamin C and Vitamin K. Kale is loaded with powerful antioxidants such as beta carotene, ascorbic acid, tocopherol and hence can fight against cancer. Kale is very high in total tocopherols and alpha tocopherol, lutein, zeaxanthin and beta carotene and hence beneficial to eye health. Kale is the most nutrient dense leafy vegetable that is available for temperate countries. Kale is also cultivated as a fodder crop to feed cattle in autumn and winter months. Kale is a listed green leafy vegetable for weight loss programme.

CLIMATE AND SOIL

Kale is a cold hardy vegetable, thrives well in cool weather. Kale does its best blooming in soil that hovers around 23°C. Kale much prefers full sunlight, though it can tolerate shade better than many other plants. At least 6 hours a day of sunlight is necessary for healthy kale, but more is better. Kale likes fertile, well-drained soil with pH of 6.5 to 7.5, this discourages diseases and lets the plant make the most of nutrients available to soil. They will tolerate sandy or clay soils, but the flavour and texture of the leaves will be poor.

CULTURAL PRACTICES

Propagation of kale is solely by seeds. It is first raised in a nursery before transplanting into main field. 350- 400 g seeds are sufficient for planting a hectare of the crop. The crop should be grown in a place where crops in the same family of kale have not been cultivated for about 1 year.

LAND PREPARATION

About 25 tonnes of FYM/ha is applied and land is ploughed. To get rid of broad leaf and grass weeds before ploughing, spray them with Catapult 480SL 200 ml/ 20 L. Ploughing should be done 2 to 3 weeks in advance about 7-9 inches deep, followed by harrowing, 2 to 3 weeks after ploughing. Crop residues can significantly increase yields.

SOWING AND TRANSPLANTING

Prepare the nursery bed, about 1 metre wide, required length. Drill the seeds across bed at a depth of about 2cm and cover them lightly with soil. Mulch the soil with dry grass, that should be removed after seed germination. Watering should be done. The seedlings are ready for

transplanting after 4-6 weeks, after attaining 3 to 4 leaves. In early spring, try to plant 3-5 weeks before the last frost. In late summer, plant 6-8 weeks before the first frost.

FERTILIZER APPLICATION

Kale is a heavy feeder. Chemical fertilizers of P & K of 75 kg/ha (full dose) should be applied whereas 'N' of 150 kg/ha should be applied in equal split doses, one dose at planting time, one dose after 1 month of planting and final dose 3 weeks before first harvesting.

WEEDING AND THINNING

Weeds pose serious problem to proper development of kale plants and therefore, weed control is essential in its farming. After hoeing, one or two hand weeding's are done in the plot. 0.5 lt/ha of Trifluralin or 0.5 lt/ha of Basalin applied before to planting will effectively suppress both monocot and dicot weeds. After the plants are well established, they are thinned to stand about 6 inches apart. When grown for home use, the plants removed in thinning are usually used as food.

HARVESTING

Pluck individual leaves of kale as you need them, counting on one or two leaves for each serving. In Kale leaves cultivation, harvesting starts from November and continues up to January. For better quality, it should be harvested at the right vegetative stage. Harvested leaves should be bundled, packed and marketed. This crop yields on an average 100 to 200 quintals/ha depending on the variety and farm management practices.

POST HARVEST HANDLING

Kale is harvested in plastic bags and stored in refrigerated containers for about one week. Suitable packaging can facilitate handling, protect the produce, extend storage/shelf life and help to maintain good quality. Kale should be tightly packed with a plastic liner to maintain moisture content in storage, reducing water loss and shriveling helping to maintain quality.

PHYSIOLOGICAL DISORDER

1. Phosphorus deficiency: Growth thin and upright; older leaves purple and reddish-purple tints.

2. Calcium deficiency: Death of growing point and severe collapse of leaf tissues.

3. Magnesium deficiency: Older leaves striking chlorotic marbling

PEST AND DISEASE MANAGEMENT

1. Aphids: They feed by sucking fluids from kale and they prefer tender seedlings, feed in large clusters. Eventually mass feeding leads to become yellow, stunted or misshapen. Finally leaves curls up and then drop off.

2. Alternaria leaf spot (Black spot, grey spot): Caused by *Alternaria brassicae* and *Alternaria brassicicola*. Small dark spots on leaves turn to brown or grey; lesions may be round or angular, that mat develop on stems and petioles. Management is to use pathogen free seed and crop rotation

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LEEK- A FLAVOURFUL UNDERUTILIZED SALAD VEGETABLE

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Introduction

Leek, botanically called Allium porrum (2n= 32), belonging to Aliaceae family is a non-bulb forming member of the onion family and is grown for its blanched stem and leaves. It is eaten raw alone or mixed in salads and cooked as flavouring in soups. It is not grown in India on commercial scale but is a favourite vegetable in a kitchen garden. Leek is cultivated for blanched stems and leaves. It is a biennial plant, consumed as salad and used in flavouring the soups.

ORIGIN AND DISTRIBUTION

The Allium species are not evenly distributed with in the northern hemisphere, since most of them occur in old world. Leek is thought to have been derived from the sand leek (*A. ameloprassum*) which grows wild in southern Europe, North Africa and the Middle East.

BOTANICAL DISTRIBUTION

Leek is a biennial onion-like plant, but larger than onion. Rather than forming a tight bulb like the onion, leek produces a long cylinder of bundled leaf sheaths, like garlic, the leaf blades are dorsiventrally flattened rather than being radial. The leaf bases of leek store some reserves as they do in onion but they do not thicken into a bulb. The flowers are light purple in colour and the flowering will produce clusters of six triangular seeds in-cased within the florets. The plants produce loculicidal capsules. If left into their second summer, leeks produce spherical clusters of purple, pink or white flowers on cylindrical stalks. Leek grows out of the cotyledon within the seed. Bulb solitary, cylindric ovoid to sub-globose, sometimes bearing bulbils; tunic white, membranous, entire. Leaves broadly linear to linear-lanceolate, shorter than scape, 1-5 cm wide

or more, slightly conduplicate, abaxially keeled. Scape 60-80 cm or more, terete, covered with leaf sheaths. Spathe 1-valved, deciduous; beak long. Umbel globose, densely many flowered. Pedicels subequal, several times as long as perianth, bracteolate. Perianth white to pale purple; segments with green midvein, sub-oblong, apex acute; outer ones denticulate along midvein abaxially. Filaments slightly longer than perianth segments, connate at base and adnate to perianth segments; outer ones narrowly triangular to linear-triangular, margin denticulate toward base; inner one oblong, as wide as perianth segments, one toothed on each side, teeth with apex elongated into a twisted, filiform cusp much longer than anther-bearing cusp. Ovary ovoid-globose, with transversely convex nectarines near middle of septa. Style exserted.



RELATED SPECIES

The leek or garden leek has related species viz.,

1. *Allium ampeloprasum*: The wild plant is commonly known as wild leek or broadleaf wild leek. Its native range is southern Europe to southwestern Asia and North Africa, but it is cultivated in many other places and has become naturalized in many countries.

2 *Allium ampeloprasum ssp. persicum*: Persian leek, cultivated in the Middle East and Iran, grown for culinary purposes and called *tareh* in Persian. The linear green leaves have a mild onion flavour and are eaten raw, either alone, or in food combinations.

3. *Allium ampeloprasum* var. *kurrat*: Kurrat or Egyptian leek or salad leek. This species has small bulbs, and primarily the leaves are eaten.

4. Allium ampeloprasum* var. *ampeloprasum Commonly called Great-headed garlic or Elephant Garlic. It has a tall, solid, flowering stalk, flat leaves. The flavour is milder than garlic and can be eaten raw in salads, roasted, or sauteed, but is generally not a substitute for conventional garlic in cooking.

COMMERCIAL VARIETIES

1. PPL-1: It is a selection from exotic germplasm. The whole plant is consumed. Leaves light green, swollen stem and do not form bulb. Ready in 150-160 days and good replacement for green onion.

2. Palam Paushtik: An alternative of green onion, suitable for salad, soup and cooking. Matures in about 140-150 days with average yield of 300-350 q/ha.

Main fall varieties (August to October)

American Flag, Jolant, Kilima, King Richard, Primor.

Late fall - winter (October to December)

Derrrick, Electra, Goldina, Goliath, Kilima, Tivi, Wintereuzen.

Overwinter (spring harvest)

Carina, Conqueror (moderate bulbing), Eskimo and Siberia. These varieties mature in 80-120 days.

CLIMATE AND SOIL

Leeks grow best in a cool to moderate climate. A well-aerated soil with both good drainage and good moisture retention. pH of 6.5 to 7 is best. Deep ploughing is recommended so that a longer shaft can be developed. Growing in heavy soil harvest is delayed.

SEEDING AND TRANSPLANTING

For Mid hills Leek is sown in September- October; for High hills it is sown in March-May. Seed rate of Leek is 5-7 kg/ha, and spacing to be adopted is 40 x 10 cm. Use treated high quality seed for transplant production. Direct field seeding is possible but not recommended due to the lack of registered herbicides and length of time needed to harvest from direct-seeded plantings (8-12 months or longer). Leeks are normally transplanted. They should be seeded under protection early in the season (February to March) or in outdoor seedbeds (April to May). Leeks for harvesting in August-September should be sown from mid-February to mid-March. For harvesting in early winter sow, the crop from mid-March to mid-April. For spring harvest,

seed may be sown from April to mid-May. The right varieties (above) must be used for each harvest season.

At transplanting, leek seedlings should be placed in furrows 15 cm deep. Furrows are filled in during cultivation and as the plants develop, the rows should be hilled up. Leeks should have a white shaft that reaches almost to the base of the leaves. Care must be taken not to allow soil between leaves as it will penetrate the shaft. Another method of transplanting is to drop each seedling into an individual hole, 15 cm deep, pressed into the ground. This procedure eliminates the need for filling of furrows but ridging should still be done. Seedlings are spaced at a spacing of 40 x 10 cm.

MANURES AND FERTILIZERS

Apply 20-25 t. ha^{-1} well rotten FYM or compost along with 80-100kg N, 60 kg P_2O_5 and 80 kg K_2O per ha. Entire quantity of FYM, P_2O_5, K_2O and half N should be thoroughly mixed in the soil at the time of planting. Remaining N is side dressed one month after planting.

USE OF GROWTH REGULATORS

For proper growth and development, spray ethephon @ 50mg/l as foliar spray applied 20-25 DAP. NAA @ 50 mg/l should be applied at 60 and 90 DAP.

WEED CONTROL AND IRRIGATION

Application of 1 kg Bladex + 1.5 kg Tribonil controls weeds. Irrigate uniformly to maintain vigorous, uniform growth and tender stalks. A total of 12-15 inches of water may be required depending on planting date, seasonal variation and variety. Lighter soils need more frequent water applications but less water applied per application.

SPECIAL PRACTICE

1. Blanching is important in leek cultivation. To grow large, white, succulent leeks, blanch the lower part of the stem by hilling up soil or mulch around stalks to exclude the light as they develop. Blanching will make the stalks longer and tender. Hill up around stalks to just below the leaf junction. Do not mulch higher than the leaf junction; this will help prevent soil from lodging between leaves and stem.

HARVESTING AND YIELD

Leeks do not bulb or go dormant in the fall but continue to grow slowly. The time of harvest is therefore, very flexible, depending on the time of planting, market conditions, and variety of leek planted. Small leeks can be sold starting in early August and varieties that have

frost tolerance may be harvested throughout the fall and winter months. Machine harvest of leeks is now possible, but most leeks are lifted or dug by machine and then harvested, cleaned and packed by hand. Single or multiple row harvesters can be used effectively. Leek gives an yield of 9.5 t per hectare.

POST HARVEST MANAGEMENT

1. Packaging: Leeks are commonly trimmed to 12 inch length, bunched depending on diameter and often placed in polyethylene film bags. They are usually packaged in 5 kg cartons or wire bound crates, holding 10 film bags, each 500 g. Other crates may be packaged with 18-24 bunches with a net weight up to 15 kg.

2. Storage: Store leek seed at 0° C and 95 to 100 per cent relative humidity. Leeks, if properly handled, can be kept satisfactorily for 2-3 months at 0^{o} C. Leeks should be cooled promptly after harvest to near 0 degree C by hydro cooling, crushed ice or vacuum cooling and they should be kept at this temperature with high relative humidity throughout storage. The use of polyethylene film crate liners and of crushed ice can aid in preventing moisture loss. Respiration or heat evolution of leeks is about eight times faster at 21.1^{o}C than at 0^{o} C. Storage for 4-5 months at 0^{o} C is possible by using a controlled atmosphere (CA), although there will be some loss in quality. The best CA contains from 1-3 per cent oxygen and from 5-10 per cent carbon dioxide.

PEST AND DISEASE MANAGEMENT

1. Thrips (*Thrips tabaci, Frankliniella occidentalis*): Thrips are tiny insects that attack a wide range of plant species globally and are a major enemy of leek plants, causing significant yield losses. Their destructive activity could either be direct, by sucking foliar sap, or by transmitting dangerous viruses such as IYSV to infested plants. Thrips are usually found on the underside of leaves, protected from the sun, close to the conjunction point with the stem. Except for detecting the insect directly, the grower may also observe common symptoms like the whitish-silvery discoloration (in patches) and the twist and wilting of leaves. Population Monitoring (Should be intensified during spring and early summer so that the conditions are favorable for the insect). Pheromone traps provision, weed and crop residue removal (thrips overwinter in species like alfalfa, clover, and small grains). Plant barriers (some farmers plant 2 rows of maize or 1 row of maize and 1 row of wheat around the field 30 days before planting the leeks to serve as barriers and block the movement of thrips). Conventional farmers may also apply chemical pesticides, always after discussing with a licensed agronomist *(e.g.,* Profenofos, Carbosulfan, Malathion,

Delegate, or Fipronil). In this case, spraying with a suitable-registered product should occur when 20-30 adults are counted per plant, or on average 1 thrip per leaf (check 50-100 plants randomly). Insecticidal soaps may also be used. However, it is essential to avoid continuous and excessive use of pesticides (especially with the same mode of action) since thrips can easily develop resistance to them.

2. White Tip Disease (*Phytophthora porri*): White Tip Disease is a destructive, fungal disease that can appear in a leek field during days of increased temperature (during summer) and humidity levels or after heavy rains. In the case of an infection, the farmer may observe spots on the leaf tips and margins with a water-soaked appearance. Stems can also be infected and begin to wilt. Soft rot may gradually appear on all vegetative organs of the plant.



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SECONDARY METABOLITES IN CAMPHOR BASIL

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Abstract

Ocimum kilimandscharicum (camphor basil) is an aromatic and medicinal plant rich in biologically active secondary metabolites. The major phytochemicals include phenolic compounds, terpenoids, flavonoids, and phenylpropanoids, with important constituents such as camphor, linalool, 1,8-cineole, eugenol, methyl eugenol, and rosmarinic acid. These compounds possess antioxidant, antimicrobial, anti-inflammatory, and insect-repellent properties and play a vital role in plant defense and stress tolerance. Owing to its diverse bioactive constituents, camphor basil has significant applications in the pharmaceutical, food, cosmetic, and essential oil industries.

Keywords: *Ocimum kilimandscharicum*, Camphor basil, Secondary metabolites, Phenolic compounds, Terpenoids, Flavonoids, Essential oil, Antioxidant, Antimicrobial.

Introduction

Camphor basil is an important aromatic and medicinal herb belonging to the family Lamiaceae. It is widely cultivated for its essential oil, flavor, and therapeutic properties. The plant produces a wide range of secondary metabolites, which are organic compounds not directly involved in growth and development but play an important role in plant defense and environmental adaptation.

In camphor basil, secondary metabolites are present in all part of plant.These compounds include phenolics, flavonoids, terpenoids, and phenylpropanoids. Among them, essential oil

components such as linalool, eugenol, and methyl chavicol are the major secondary metabolites responsible for the characteristic aroma of basil.

These secondary metabolites help the plant in protection against pests and diseases, attraction of pollinators, antioxidant activity, and stress tolerance. They also contribute to the medicinal, culinary, and industrial value of camphor basil.

SECONDARY METABOLITES

PHENOLIC COMPOUNDS

Rosmarinic acid :

It is biosynthesized from caffeic acid and 3,4-dihydroxyphenyllactic acid through the phenylpropanoid pathway. This compound acts as a strong antioxidant and protects plant cells from oxidative damage. It also possesses antimicrobial and anti-inflammatory properties. Rosmarinic acid plays a key role in plant defense against pathogens and environmental stress conditions.

Caffeic acid:

It is produced through the phenylpropanoid pathway from phenylalanine. Caffeic acid acts as a strong antioxidant and protects plant cells from oxidative stress. It also shows antimicrobial activity against pathogens. This compound plays an important role in plant defense and contributes to the medicinal value of sweet basil.

Chicoric acid:

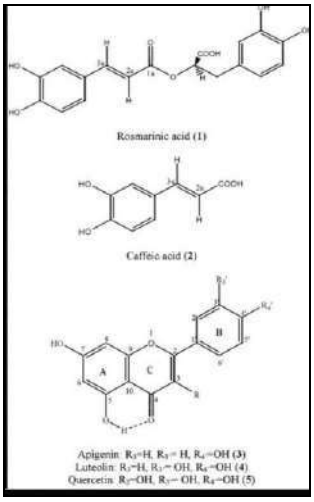
It is formed from tartaric acid and caffeic acid derivatives. Chicoric acid acts as a strong antioxidant and helps protect the plant from oxidative stress. It also shows antimicrobial and immune-boosting properties. This compound contributes to plant defense and medicinal value.

Ferulic acid:

It is synthesized via the phenylpropanoid pathway from caffeic acid. Ferulic acid is involved in cell wall lignification and cross-linking of polysaccharides. It exhibits strong antioxidant and antimicrobial activity. It contributes to plant defense against biotic and abiotic stress.

Linalool:

It is synthesized through the terpenoid pathway in glandular trichomes. Linalool is responsible for the characteristic floral aroma of basil. It exhibits antimicrobial and insect-repellent properties. It plays an important role in plant defense and pollinator attraction.



TERPENOIDS

Eugenol:

It is synthesized through the phenylpropanoid pathway from phenylalanine. Eugenol contributes to the characteristic clove-like aroma of basil. It possesses strong antimicrobial and antioxidant properties. It plays a role in plant defense against pests and pathogens.

1,8-cinole:

1,8-Cineole (eucalyptol) is a monoterpene oxide secondary metabolite present in Ocimum kilimandscharicum .It is synthesized through the terpenoid pathway in glandular trichomes. It contributes to the fresh, camphor-like aroma of basil. 1,8-Cineole exhibits antimicrobial and insect-repellent properties. It plays a role in plant defense and stress tolerance.

Camphor:

Camphor is a bicyclic monoterpene ketone secondary metabolite found in Ocimum kilimandscharicum .It is synthesized through the terpenoid pathway. Camphor contributes to the strong, pungent aroma of basil. It shows antimicrobial and insect-repellent activity. It helps in plant defense against pests and pathogens.

FLAVONOIDS

Luteolin:

It is synthesized through the phenylpropanoid pathway. Luteolin exhibits strong antioxidant and anti-inflammatory properties. It protects plant tissues from UV radiation and oxidative stress. It also contributes to plant defense against pathogens.

Apigenin:

It is synthesized through the phenylpropanoid pathway. Apigenin exhibits antioxidant and anti-inflammatory activity. It helps protect plant tissues from oxidative stress and UV damage. It contributes to plant defense and overall medicinal value.

PHENYLPROPANOIDS:

Eugenol:

Eugenol is a phenolic secondary metabolite mainly found in clove and camphor basil.

It has strong antimicrobial, antioxidant, and analgesic properties, and is widely used in pharmaceutical, dental, and flavoring applications.

Methyleugenol:

Methyl eugenol is a phenylpropanoid compound found in camphor basil essential oil.

It acts as an aroma compound and insect attractant, and also shows antimicrobial and antioxidant activity.

Conclusion

Camphor basil is an important aromatic and medicinal plant rich in valuable secondary metabolites such as eugenol, methyl eugenol, linalool, and rosmarinic acid. These compounds provide antioxidant, antimicrobial, and therapeutic properties. Due to its wide use in food, medicine, perfumery, and essential oil production, sweet basil has significant economic and medicinal importance.

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OCIMUM KILIMANDSARICHUM L.: A TRADITIONAL HERBAL MEDICINE AND NATURAL PROTECTOR

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Abstract

Ocimum kilimandscharicum L. is an important medicinal and aromatic herb widely used in traditional healthcare practices in Tamil Nadu and other parts of India. The plant has long been valued in folk medicine for its therapeutic, antimicrobial, anti-inflammatory, and insect-repellent properties. Traditionally, the leaves are prepared as a kashayam (herbal decoction) to treat common ailments such as cold, cough, fever, digestive disorders, and weakened immunity. In addition to its medicinal value, Thiruneetru Pachai Ilai serves as a natural insect repellent, with its essential oils effectively deterring mosquitoes, flies, and storage pests, offering an eco-friendly alternative to synthetic chemicals. Scientific studies have validated many of these traditional applications, attributing the plant's effectiveness to bioactive compounds such as linalool, estragole, flavonoids, and tannins. This review highlights the traditional significance, preparation methods, medicinal applications, and ecological benefits of Thiruneetru Pachai Ilai, emphasizing its potential role in sustainable healthcare and natural pest management.

Keywords: Antimicrobial activity, Natural insect repellent, *Ocimum kilimandscharicum*, Thiruneetru pachai ilia.

Introduction

India has a rich tradition of using medicinal plants for healthcare, especially in rural areas where natural remedies treat common ailments. One such valuable herb is Thiruneetru Pachai Ilai (*Ocimum kilimandsarichum* L.), which has been used for generations in Tamil Nadu as a cornerstone of traditional medicine. This aromatic plant is well known for its healing

properties and its ability to repel insects naturally. Even in modern times, it continues to play an important role in eco-friendly and sustainable living practices.

Traditional Importance: Thiruneetru Pachai Ilai holds a special place in *"paati vaithiyam"* (grandmother's medicine). Historically, before the widespread availability of modern pharmaceuticals, households relied on such easily accessible herbs. The name itself is associated with purity; the pleasant aroma of the leaves is traditionally believed to purify the surroundings and create a healthy environment. Beyond its physical uses, the plant is often linked with spiritual and cultural practices in South India.

Preparation and Use as Herbal decoction (Kashayam): One of the most common applications of this plant is in the form of kashayam (herbal decoction). The decoction is prepared using Fresh leaves that are collected, washed thoroughly, and boiled in water for several minutes. The extract is then filtered and consumed warm (Figure.1). This herbal drink acts as a natural remedy with antimicrobial and anti-inflammatory properties, making it effective against common infections. It is traditionally used to provide relief from cold, cough, and fever, while also aiding digestion and improving immunity (Dharsono *et al.*, 2022).

Natural Insect Repellent (Poochi Viratti): A significant secondary use of Thiruneetru Pachai Ilai is as a natural insect repellent. Research indicates that the essential oils in *Ocimum kilimandsarichum* particularly compounds like linalool and estragole, possess potent biocidal activity against various pests (Siti Sa'adah *et al*., 2024). Leaves are often dried and burned to produce insect-repelling smoke. Fresh crushed leaves can be placed in house corners or storage areas to protect grains from infestation.



Figure 1. Preparation of Ocimum tonic.

Medicinal Uses for Skin and External Application

The leaves are highly valued for treating minor dermatological issues due to their antiseptic nature. A paste made from the leaves or the extracted juice is applied directly to affected areas. It helps reduce itching and irritation, treats skin infections, and facilitates the healing of minor wounds. Scientific reviews confirm that the plant contains phytochemicals like tannins and flavonoids that support these wound-healing and antimicrobial effects.

Respiratory and Therapeutic Uses: The plant is particularly beneficial in relieving respiratory distress, a use widely documented in traditional systems across India and Brazil. Steam inhalation using boiled leaves or exposure to the smoke from burning leaves. These practices help clear nasal congestion and provide relief from sinus problems and bronchitis. Its bronchodilatory properties help improve breathing during acute lung ailments (Aminian *et al.*, 2022).

Conclusion

Thiruneetru Pachai Ilai is a valuable medicinal herb that has been an integral part of traditional healthcare systems for generations. Its wide range of applications, including the treatment of common illnesses, skin disorders, and respiratory problems, demonstrates its importance in folk medicine (Rodriguez-Gonzalez *et al.*, 2019). The plant also serves as an effective natural insect repellent, providing an environmentally friendly alternative to chemical pesticides. Scientific research supports many of its traditional uses by identifying bioactive compounds responsible for its antimicrobial, anti-inflammatory, wound-healing, and insecticidal properties. As interest in sustainable healthcare and natural products continues to grow, Thiruneetru Pachai Ilai offers significant potential for promoting community health and eco-friendly pest management. Preserving and further studying this traditional medicinal plant can contribute to the development of safe, affordable, and sustainable solutions for future healthcare needs.

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OCIMUM KILIMANDSCHARICUM (CAMPHOR BASIL): BOTANICAL PROFILE, PHYTOCHEMISTRY AND MEDICINAL SIGNIFICANCE

Article ID: AG-VO6-I07-67

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Abstract

Ocimum kilimandscharicum (Kapoor Tulasi/Camphor Basil) is an aromatic medicinal herb of the family Lamiaceae, valued for its camphor-rich essential oil and diverse therapeutic properties. It contains bioactive compounds such as camphor and 1,8-cineole, which exhibit antimicrobial, anti-inflammatory, antioxidant, and insect-repellent activities. Traditionally used for treating respiratory, skin, and digestive ailments, the plant has also gained scientific recognition for its pharmacological potential. Its rich phytochemical composition makes it an important resource for herbal medicine and natural product research.

Introduction

Ocimum kilimandscharicum, popularly known as Kapoor Tulasi or Camphor Basil, is an aromatic perennial herb belonging to the family Lamiaceae, valued for both its distinct morphology and medicinal properties.[1] The plant grows as a bushy herb or small shrub reaching about 1–2 metres in height, with a well-developed tap root system that supports efficient absorption of water and nutrients.[2] Its stem is erect, quadrangular, and highly branched, while the leaves are simple, opposite, ovate to elliptic with serrated margins and covered with numerous oil glands. These glands are responsible for the strong camphor-like aroma released upon crushing, indicating the presence of bioactive compounds.[3]

The plant is known under various regional names such as Kapur Tulsi in India, where it was introduced from its native East African habitat and is now widely cultivated.[1,4] Its essential

oil, which predominantly contains camphor (up to 63%), along with 1,8-cineole, limonene, and camphene, forms the biochemical basis for its broad range of therapeutic applications.[5]



Botanical Description

Habit

Ocimum kilimandscharicum is a perennial aromatic herb or sub-shrub that grows approximately 1–2 m in height.[2,6] The plant is bushy with several branches and emits a strong camphor smell when the leaves are crushed, a characteristic that immediately distinguishes it from other members of the genus Ocimum.[3]

Root System

The plant possesses a well-developed taproot system with many lateral roots, which aid in efficient nutrient and water absorption.[2] Deep, soft-wooded tap roots have been described as a consistent morphological feature of this species.[7]

Stem

The stem is erect, quadrangular (four-sided), and highly branched — a typical characteristic of plants in the Lamiaceae family.[1,3] Young stems are usually green and slightly hairy, with pubescent quadrangular branchlets described consistently across populations.[2]

Leaves

Leaves are simple, opposite, ovate to elliptic in shape with serrated margins. They are green, soft, and aromatic, containing numerous essential oil glands responsible for the camphor-like smell.[3,7] The leaves are generally 3–7 cm long with a distinct petiole, and the leaf surface is pubescent with the base narrowing progressively.[2]

Inflorescence

The inflorescence is a terminal raceme or spike, bearing many small flowers arranged in whorls (verticillasters) along the axis.[3,9] Flowers and fruits appear almost throughout the year, with peak production reported mainly during September to February.[9]

Flowers

Flowers are small, bisexual, and zygomorphic, usually white to pale purple in colour.[3] The calyx is tubular and persistent, while the corolla is bilabiate (two-lipped) a hallmark of the family Lamiaceae.[1]

Fruit and Seeds

The fruit is a schizocarp that splits into four small nutlets when mature.[3,9] The seeds are small, brown to black, and capable of good germination under favourable conditions. The plant can be propagated both by seeds and vegetatively.[2]

Aroma and Phytochemicals

The plant is rich in essential oils, with camphor being the dominant constituent (ranging from 48.9% to 63.4% depending on the chemotype and season), followed by 1,8-cineole, limonene, camphene, and alpha-pinene.[5,8] These compounds collectively contribute to its strong medicinal and antimicrobial properties and are extensively studied in secondary metabolite analysis and pharmacological research.[4,10]

Medicinal Values

Respiratory Ailments

The leaves are commonly used in traditional medicine to treat cough, cold, asthma, and bronchitis.[1,4] The compound 1,8-cineole (eucalyptol) present in the essential oil has well-documented mucolytic and bronchodilatory properties that help clear nasal congestion and improve breathing, making steam inhalation with the leaves a scientifically plausible traditional remedy.[11]

Antimicrobial Activity

The essential oil of *Ocimum kilimandscharicum* shows strong antibacterial and antifungal activity against a range of pathogens including *Staphylococcus aureus, Enterococcus faecalis, Escherichia coli, Pseudomonas aeruginosa,* and *Candida albicans*, making it useful in treating minor infections and wounds.[5,10] This activity is attributed mainly to the camphor and cineole constituents.[4]

Anti-inflammatory and Analgesic Properties

Leaf extracts and isolated essential oil help reduce inflammation, swelling, and pain. A peer-reviewed study demonstrated that the essential oil obtained from *O. kilimandscharicum* leaves significantly inhibited pain and inflammatory parameters in carrageenan-induced and zymosan-induced articular inflammation models in mice.[12] The authors concluded that camphor and associated anti-inflammatory compounds present in the oil contribute to its analgesic and anti-arthritic properties, validating its traditional use in remedies for body aches and joint pain.[12]

Mosquito and Insect Repellent

Due to its camphor content, the plant acts as a natural mosquito and insect repellent, a property widely exploited in rural communities in East Africa.[1] Field trials in western Kenya documented that thermally expelled O. *kilimandscharicum* repelled up to 52% of the malaria vector *Anopheles gambiae* in experimental huts, and a combination with *Lantana uckambensis* enhanced this repellency to 54.8% — efficacies comparable to standard botanical repellents.[13] Additional field evaluations confirmed high biting protection (83–91%) and feeding inhibition against multiple mosquito species.[14]

Skin Care and Wound Healing

Paste or oil derived from the leaves is applied in traditional practice to treat skin infections, itching, and minor wounds.[1,4] Pharmacological investigations have confirmed wound-healing, antifungal, and antioxidant properties in the plant, supporting these ethnomedicinal applications.[3]

Digestive Aid

The plant is also used in small quantities to improve digestion and relieve stomach discomfort.[1,2] Traditional use for treating abdominal pains and diarrhoea has been documented across East African and Indian populations, and antidiarrhoeal pharmacological activity has been confirmed experimentally.[3,4]

Aromatherapy and Stress Relief

The aroma has a mild calming effect and is employed in aromatherapy to reduce stress and improve mental relaxation.[1] The plant's essential oil is described as an ingredient in commercially developed Naturub® aromatherapeutic products, developed collaboratively by the International Centre of Insect Physiology and Ecology (ICIPE), the University of Nairobi, and

Kenya Wildlife Service, underscoring its transition from folkloric use to commercial application.[2]

Conclusion

Ocimum kilimandscharicum is a botanically well-characterised and pharmacologically promising medicinal plant. Its distinctive quadrangular stem, camphor-rich essential oil, and broad spectrum of biological activities ranging from antimicrobial and anti-inflammatory to insect repellent make it a subject of increasing scientific interest. Continued research into its phytochemistry and clinical applications holds considerable potential for developing affordable, plant-based therapeutic and vector-control products, particularly in tropical regions where the plant grows readily.

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THIRUNEETRU PACHILAI AN EXCLUSIVE MEDICINAL PLANT IN SIDDHA

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Abstract

Ocimum kilimandscharicum (camphor basil) is an important medicinal and aromatic plant widely used in the Siddha system of medicine. It is rich in camphor and other bioactive compounds that possess antimicrobial, anti-inflammatory, antipyretic, and expectorant properties. The plant is traditionally used to manage respiratory disorders, fever, skin infections, and inflammation. Siddha formulations such as kudineer, chooranam, thailam, and leaf juice are prepared from different parts of the plant. This review highlights its traditional uses, medicinal properties, and potential for herbal drug development.



Keywords: Ocimum kilimandscharicum, Siddha medicine, Camphor basil, Medicinal plant, Phytochemicals, Essential oil, Herbal formulations, Respiratory disorders.

Introduction

The Siddha system of medicine is one of the oldest traditional medical systems that relies mainly on medicinal plants for prevention and treatment of diseases. Aromatic medicinal herbs play an important role in Siddha formulations due to their therapeutic and antimicrobial properties. *Ocimum kilimandscharicum,* commonly known as camphor basil, is a medicinally

important aromatic plant belonging to the family Lamiaceae. The plant is rich in camphor and essential oils, which contribute to its wide use in treating respiratory disorders, fever, inflammation, and skin diseases in Siddha medicine. In Siddha practice, this plant is valued for its heating nature, expectorant action, and ability to balance Kapha and Vatha doshas. The leaves and essential oil are commonly used in decoctions, herbal oils, steam inhalation, and chooranam preparations. Due to its strong medicinal properties, *Ocimum kilimandscharicum* is considered an exclusive medicinal plant for respiratory and infectious diseases.

Primary objective

To evaluate the medicinal importance of *Ocimum kilimandscharicum* in the Siddha system of medicine. This objective focuses on understanding how the plant is traditionally used in Siddha for treating various diseases. It includes studying its role in managing respiratory disorders, fever, inflammation, and microbial infections, and highlighting its significance as an exclusive medicinal herb.

Secondary Objectives

1. To document the traditional Siddha uses of *Ocimum kilimandscharicum.*

This objective aims to collect and describe information about how different parts of the plant such as leaves, stem, and essential oil are used in Siddha medicine. It also includes recording its applications in treating cough, cold, asthma, sinusitis, and skin diseases.

2. To study the phytochemical constituents responsible for medicinal properties.

The purpose of this objective is to identify important bioactive compounds like camphor, cineole, eugenol, and flavonoids. These compounds contribute to antimicrobial, anti-inflammatory, and expectorant activities of the plant.

3. To explain the therapeutic properties of *Ocimum kilimandscharicum.*

This objective focuses on understanding the pharmacological activities such as antimicrobial, antipyretic, analgesic, anti-inflammatory, and antioxidant properties that support its use in Siddha medicine.

4. To describe the methods of preparation used in Siddha formulations.

This includes studying different preparations such as kudineer, chooranam, thailam, leaf juice, and steam inhalation. It helps in understanding how the plant is administered for treating different ailments.

5. To evaluate the role of *Ocimum kilimandscharicum* in treating respiratory disorders.

This objective highlights the plant's importance in managing cough, cold, asthma, bronchitis, and sinus congestion due to its camphor-rich essential oil and expectorant action.

6. To assess the potential of the plant for herbal drug development in Siddha.

This objective aims to explore the possibility of using *Ocimum kilimandscharicum* in developing new Siddha herbal formulations based on its medicinal value and therapeutic effectiveness.

SIDDHA MEDICINAL USES

1. Bronchitis and Asthma

Ocimum kilimandscharicum is widely used in Siddha medicine for treating bronchitis and asthma due to its camphor-rich essential oil. The phytochemicals such as camphor and 1,8-cineole act as expectorants and bronchodilators. They help in loosening mucus, clearing phlegm, and opening the airways. Leaf decoction (kudineer) is commonly given to reduce cough, wheezing, and breathing difficulty. Steam inhalation with crushed leaves also helps relieve chest congestion and improves airflow. Thus, the plant reduces inflammation in bronchi and supports easy breathing.

2. Fever and Flu

The leaves of *Ocimum kilimandscharicum* are used in Siddha medicine to treat fever and flu. The plant shows antipyretic, antimicrobial, and anti-inflammatory properties that help reduce body temperature and control infection. Leaf decoction promotes sweating, which helps lower fever naturally. It also relieves associated symptoms such as body pain, headache, and throat irritation. The essential oil vapors help clear respiratory infection and improve recovery from flu.

3. Nasal Congestion

Ocimum kilimandscharicum is effective in relieving nasal congestion because of its strong aromatic camphor content. When leaves are used for steam inhalation, volatile compounds such as camphor and cineole act as decongestants. These compounds help open blocked nasal passages, reduce sinus inflammation, and loosen mucus. In Siddha practice, crushed leaves are added to hot water and the steam is inhaled to relieve sinusitis, cold, and blocked nose. This provides quick relief and improves breathing.

4. Insect Bites

The leaf paste or essential oil of *Ocimum kilimandscharicum* is applied externally on insect bites. The plant has antiseptic, anti-inflammatory, and antimicrobial properties. These

properties help reduce itching, swelling, and redness caused by insect bites. Camphor and eugenol present in the plant also provide cooling and soothing effects. Application of leaf juice prevents infection and promotes faster healing of the affected

MEDICINAL PROPERTIES

1.Antimicrobial Activity

Ocimum kilimandscharicum possesses strong antimicrobial activity due to the presence of phytochemicals such as camphor, 1,8-cineole, eugenol, and linalool. These compounds inhibit the growth of bacteria, fungi, and some viruses. The essential oil disrupts microbial cell membranes and prevents multiplication of pathogens. In Siddha medicine, leaf extract and essential oil are used to treat respiratory infections, skin diseases, wounds, and throat infections. This antimicrobial property helps in preventing infection and promoting faster healing.

2. Anti-inflammatory Activity

The plant shows anti-inflammatory activity because of bioactive compounds like flavonoids, camphor, and terpenoids. These compounds reduce inflammation by inhibiting inflammatory mediators and decreasing swelling and pain. In Siddha practice, leaf paste or medicated oil prepared from *Ocimum kilimandscharicum* is applied externally to relieve joint pain, muscle pain, and swelling. It is also used internally to reduce inflammation associated with respiratory disorders such as bronchitis and asthma.

3. Antipyretic Activity

Ocimum kilimandscharicum has antipyretic (fever-reducing) properties. The phytochemicals present in the plant help regulate body temperature by reducing inflammation and controlling infection that causes fever. Decoction of leaves is commonly used in Siddha medicine to treat fever, cold, and flu. The plant also promotes sweating, which helps in lowering body temperature naturally.

4. Antiseptic Activity

The antiseptic property of *Ocimum kilimandscharicum* is mainly due to camphor, eugenol, and phenolic compounds. These compounds prevent the growth of harmful microorganisms on wounds and cuts. The leaf juice or essential oil is applied externally to clean wounds, insect bites, and skin infections. It helps prevent pus formation, reduces infection, and promotes healing. In Siddha medicine, it is also used in herbal oils for skin protection.

SIDDHA FORMULATION

1.Powder (Chooranam)

The dried leaves of *Ocimum kilimandscharicum* are powdered to prepare chooranam. Fresh leaves are collected, shade dried, and finely powdered. This powder is stored in an airtight container. In Siddha medicine, the chooranam is taken with warm water or honey. It is mainly used for treating cough, cold, asthma, and digestive disorders. The camphor-rich powder acts as an expectorant, helps remove phlegm, and improves breathing. It also shows antimicrobial activity and supports immune response.

2. Thailam (Medicated Oil)

Thailam is prepared using *Ocimum kilimandscharicum* leaf extract mixed with base oil such as sesame oil. The leaf juice or decoction is boiled with oil until the moisture evaporates and active compounds get infused into the oil. The prepared medicated oil is used for external application. In Siddha practice, this thailam is applied to chest for cough and cold, to joints for pain and inflammation, and to skin for infections. The camphor content provides warming effect, reduces swelling, and relieves pain.

3. Herbal Decoction (Kudineer / Kashayam)

Herbal decoction is prepared by boiling fresh or dried leaves of *Ocimum kilimandscharicum* in water. The mixture is boiled until it reduces to half and then filtered. This decoction is taken warm. It is commonly used for fever, bronchitis, asthma, and throat infections. The decoction helps loosen mucus, reduce fever, and improve respiratory function. It also acts as antimicrobial and anti-inflammatory agent.

4. Leaf Juice (Saaru)

Fresh leaf juice is prepared by crushing or grinding the leaves and filtering the extract. The juice is used both internally and externally. Internally, small quantities are given for cough, cold, and fever. Externally, the leaf juice is applied on insect bites, skin infections, and wounds. The juice shows antiseptic, antimicrobial, and anti-inflammatory properties. It helps reduce swelling, itching, and promotes healing.

Conclusion

Ocimum kilimandscharicum is an important aromatic medicinal plant widely used in the Siddha system of medicine. The plant is rich in camphor and other bioactive phytochemicals such as cineole, eugenol, and flavonoids, which contribute to its therapeutic properties. In Siddha

practice, the leaves and essential oil are commonly used for treating respiratory disorders like bronchitis, asthma, cough, and nasal congestion. It is also used in the management of fever, flu, skin diseases, inflammation, and insect bites. The plant exhibits antimicrobial, anti-inflammatory, antipyretic, and antiseptic activities, which support its traditional medicinal applications. Different Siddha formulations such as chooranam (powder), kudineer (decoction), thailam (medicated oil), and leaf juice are prepared from *Ocimum kilimandscharicum* for both internal and external use. These formulations help in relieving symptoms, reducing infection, and promoting healing.

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UTILIZATION OF DAMMER BEE CERUMEN IN COSMETIC SCIENCE

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Introduction

The global cosmetics industry is increasingly seeking natural, sustainable, and biologically active ingredients. While propolis from *Apis mellifera* (the European honeybee) has been extensively studied, a chemically distinct and potentially equally valuable product from stingless bees **cerumen** begins to attract scientific attention. Produced by dammer bees such as *Tetragonula iridipennis*, cerumen is a complex mixture of plant latex, resin, bee wax, and other bee secretions. Unlike the propolis of honeybees, which is used primarily for sealing and sanitizing the hive, cerumen serves as the primary construction material for stingless bee nests, including brood cells, storage pots, and involucrum. This article reviews the chemical composition, biological properties, and emerging cosmetic applications of dammer bee cerumen.

Chemical Composition and Botanical Origins

The chemical profile of dammer bee cerumen is remarkably complex and varies significantly depending on the botanical sources available to foraging bees. For *Tetragonula iridipennis*, foragers collect plant latex and resin from diverse species including *Artocarpus heterophyllus*, *Calotropis gigantea*, *Ficus bengalensis*, *F. religiosa*, *Mangifera indica*, *Tabernaemontana divaricata*, and *Vachellia nilotica*. Resin foragers are less numerous than nectar or pollen foragers, spending more time per foraging bout and performing fewer trips per day.

Chemically, the cerumen of Indian stingless bees is predominantly of the 'gallic acid–naringin' type, which may also contain sugars, steroids, and terpenes; the composition varies with its latex and resin sources. Studies on Australian *Tetragonula carbonaria* cerumen have identified distinct GC-MS fingerprints with a mixed diterpenic profile, featuring pimaric acid (6.31 ± 0.97% w/w), isopimaric acid (12.23 ± 3.03% w/w), and gallic acid (5.79 ± 0.81% w/w) as useful chemical markers.

Biological Activities: The Scientific Rationale for Cosmetic Use

The presence of these bioactive compounds endows dammer bee cerumen with a suite of properties highly desirable in dermatological and cosmetic applications.

Antimicrobial Activity: Terpenes, a significant component of the cerumen, provide substantial antimicrobial activities against broad-spectrum pathogens. Studies on African *Meliponula ferruginea* cerumen have confirmed its antimicrobial and anti-quorum sensing properties. This property is invaluable for cosmetic products designed for acne-prone skin or as natural preservatives in formulations.

Antioxidant Activity: The phenolic and flavonoid contents of cerumen provide antioxidant activities. Research on Australian *Tetragonula carbonaria* cerumen demonstrated antioxidant activity using Ferric Reducing Antioxidant Power (FRAP) assays, with values ranging from 5.19 ± 0.40 to 16.2 ± 0.70 mmol Fe^{2+}/kg of raw cerumen, and total phenolic content values from 3.77 ± 0.12 to 81.3 ± 2.04 mg GAE/g of raw cerumen. High-performance thin-layer chromatography (HPTLC) analysis revealed the presence of gallic acid and kaempferol in ethanolic extracts, which contribute to this antioxidant activity. These compounds neutralise free radicals, a primary cause of premature skin ageing.

Anti-inflammatory Activity: Cerumen extracts from *T. carbonaria* have been shown to inhibit 5-lipoxygenase (5-LOX), an enzyme that catalyses the production of pro-inflammatory mediators, with an IC_{50} of 19.97 ± 2.67 µg/ml. The extracts demonstrated similar potency to Trolox (IC_{50} 12.78 ± 1.82 µg/ml). This anti-inflammatory activity makes cerumen a valuable candidate for soothing irritated or sensitive skin.

Anticancer Activity: Cerumen extract has also demonstrated significant anticancer activity against several cancer cell lines, further underscoring its broad therapeutic potential.

A comprehensive review by Al-Hatamleh et al. (2020) highlights the medicinal benefits of stingless bee products—including honey, propolis, pollen, and cerumen emphasizing their

potential antioxidant properties that play a vital role in preventing and treating diseases associated with oxidative stress, microbial infections, and inflammatory disorders.

Cerumen in Cosmetic Formulations

i). Skincare and Moisturisation: The waxy, resinous nature of cerumen makes it an excellent emollient. It can form a protective, occlusive layer on the skin that locks in moisture and reduces trans-epidermal water loss. Its inherent antimicrobial and antioxidant properties provide added functional benefits beyond simple hydration. Cerumen is already finding applications in the beauty industry for artisanal products including natural lip balms, solid perfumes, and eco-friendly surfboard wax.

ii). Anti-Ageing and Anti-Wrinkle Products: The potent antioxidant and anti-inflammatory properties of cerumen position it as a promising anti-ageing ingredient. By neutralizing free radicals and reducing inflammation, it can help prevent the degradation of collagen and elastin.

iii). Anti-Acne and Clarifying Treatments: The antimicrobial and anti-inflammatory actions of cerumen make it suitable for products targeting acne, helping to combat acne-causing bacteria while soothing associated inflammation-.

Challenges and Future Perspectives

Several challenges remain. The primary obstacle is the lack of standardized information on chemical composition, as cerumen from different species and geographic locations can have vastly different profiles-. Additionally, the supply chain is underdeveloped stingless beekeeping (Meliponiculture) is less prevalent than traditional apiculture, and cerumen yield per hive is relatively low. Safety considerations also warrant attention: while generally recognized as safe, allergic contact dermatitis to bee products is documented, necessitating patch testing and appropriate concentration limits. Future research should focus on standardizing extracts, conducting rigorous human clinical trials, establishing sustainable sourcing practices through meliponiculture, and exploring advanced delivery systems to enhance stability and skin penetration.

Conclusion

Dammer bee cerumen represents a promising frontier in cosmetic science. Its unique composition a sophisticated blend of plant resins, waxes, and bee secretions confers remarkable antimicrobial, antioxidant, anti-inflammatory, and wound-healing properties. While often

confused with propolis, cerumen is a chemically and functionally distinct material with immense potential for developing multifunctional, natural skincare products.

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IMPACT OF NON-CHEMICAL WEED MANAGEMENT ON SOIL HEALTH, PLANT HEALTH AND HUMAN HEALTH

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Abstract

Weed management is a major challenge in modern agriculture, with conventional herbicide-based practices contributing to environmental pollution, herbicide resistance, and risks to human and ecosystem health. Increasing awareness of these adverse effects has accelerated interest in non-chemical weed management as a sustainable alternative. This review highlights the role of non-chemical weed management techniques in improving soil health, plant health, environmental quality, animal well-being, and human health. The major approaches discussed include mechanical, cultural, biological, physical, and thermal weed control methods such as manual and mechanical weeding, cover cropping, mulching, crop rotation, allelopathy, bioherbicides, soil solarization, and flame weeding. These practices effectively suppress weeds while minimizing dependence on synthetic herbicides. Non-chemical strategies improve soil physical, chemical, and biological properties by enhancing soil organic matter, nutrient cycling, microbial diversity, and moisture conservation. They also promote healthier crop growth through improved rhizosphere conditions, reduced weed competition, and enhanced nutrient availability. Furthermore, these practices contribute to environmental sustainability by reducing herbicide residues, preventing soil and water contamination, conserving biodiversity, lowering greenhouse gas emissions, and minimizing microplastic pollution associated with conventional agricultural practices. From a human and animal health perspective, reduced exposure to toxic herbicide

residues enhances food safety and decreases occupational health risks for farm workers. Overall, integrating non-chemical weed management into crop production systems supports sustainable agriculture by maintaining long-term productivity while protecting natural resources and public health. Future research should focus on integrating these approaches with precision agriculture and climate-resilient farming systems to develop economically viable and environmentally sustainable weed management strategies.

Keywords: Allelopathy, bioherbicide, flame weeding, microplastic pollution, soil solarization,

Introduction

Weeds are a major threat to crop yields, frequently causing more economic damage than insects, fungi, or other pests (Gharde *et al.*, 2018). The success of these invasive species stems from specific biological advantages. They grow at an accelerated pace, produce an abundance of seeds, and utilize multiple methods to spread across landscapes, all while enduring harsh or unpredictable climates. Ecologically, they are opportunistic; they quickly colonize disrupted soils, maximize their intake of abundant resources, and exhibit high phenotypic plasticity—meaning they can physically alter their growth habits to withstand unstable environmental conditions Gebrekida (2025). Weeds are a hidden foe for crop plants, interfering with their functions and suppressing their growth and development. Yield losses of 34% are caused by weeds among the major crops, which are grown worldwide (Jabran *et al.*, 2015).

Although modern farming depends on herbicides to manage weeds and sustain crop yields, their use comes with a cost. Runoff and pollution from these chemicals pose a grave danger to our environment, ecosystems, and food security, Moreover, excessive herbicide use can cause crop toxicity, leave harmful soil and plant residues, trigger weed resistance, and threaten non-target wildlife Additionally, these chemical residues can enter the food chain, placing unintended wildlife and organisms in jeopardy, when herbicides migrate away from their intended application sites, they pose a severe threat to surrounding environments. This off-site movement typically occurs through three major pathways: surface runoff into lakes and streams, leaching downward through soil layers into vulnerable groundwater reserves, and volatilizing as vapor into the atmosphere. Once these chemicals infiltrate these diverse ecological spheres, they unleash a cascade of detrimental consequences that can degrade water quality and disrupt entire ecosystems (Parven *et al.*, 2025). The repeated and frequent reliance on herbicides, especially those with a single mode of action, has created strong selection pressure that promotes the

survival, reproduction, and spread of herbicide-resistant weed populations. The rapid spread of herbicide-resistant weeds has created major challenges worldwide, affecting both agricultural productivity and environmental sustainability.

The increasing prevalence of resistant weed populations has led to increased herbicide application rates, higher production costs for farmers, and considerable reductions in crop yields. Furthermore, the intensified use of herbicides has raised environmental concerns, including adverse effects on non-target organisms and disturbances to ecosystem functioning and biodiversity Gebrekida (2025). Non-chemical weed management is a holistic agricultural approach that relies on ecological principles to preserve soil health, protect biodiversity, and maintain steady crop productivity. While this methodology drastically reduces the farming system's dependence on synthetic chemicals, growers still retain the flexibility to use standard herbicides as a last resort in highly critical, severe infestations. By balancing the natural relationships between weeds, cultivated crops, and the surrounding environment, non-chemical weed management successfully offsets the destructive environmental footprints left behind by conventional, spray-heavy farming. Furthermore, these sustainable practices have proven highly effective at keeping weed populations suppressed over the long term. Because they rely on physical, cultural, and biological tactics rather than constant chemical applications, they achieve this control without triggering herbicide resistance in mutant weeds or causing accidental harm to beneficial insects, wildlife, and neighboring organisms (Boutagayout *et al.,* 2025).

Different types of non-chemical weed management

Mechanical Weed Management

The integration of automation in agriculture has significantly advanced mechanical weed management. The swift adoption of sensors, microcontrollers, and computing power has laid the groundwork for autonomous agricultural guidance systems. These automated setups optimize field operation times, eliminate heavy labour dependencies, and mitigate health risks and physical drudgery, ultimately boosting farm efficiency. Traditionally, farmers have relied on manual tools such as the khurpi, grubber, spade, wheel hoe, and push-pull weeders to eliminate inter- and intra-row weeds, achieving high weeding efficiencies ranging from 72% to 99% (Kumar *et al.,* 2022).

Cultural Weed Management

As an agronomic practice, planting cover crops as intercrop is highly effective for weed

management. Throughout their active growth period, these crops hinder weed development by competing directly for essential resources and releasing allelopathic compounds natural biochemicals that inhibit other plants via their root exudates into the soil (Zannopoulos *et al.*, 2024)**.** Mulching is another practice primarily controls weed populations by depriving them of sunlight or altering the microenvironment, which either inhibits weed seed germination entirely or stunts early-stage weed growth immediately after emergence Coolong, (2012).

Biological Weed Management

Biological weed control involves using living organisms, such as insects or fungi, to intentionally decrease the growth, spread, population, or overall damage of weeds. The bioherbicide method relies on releasing large amounts of specific microorganisms to target and control weed outbreaks within a single season. This approach works best for managing weeds in crops that are planted and harvested annually Kremer, (2005). Allelopathy is another biological which is a natural process where plants interact chemically with one another, making it a highly effective and eco-friendly option for controlling weeds in farming. In crop fields, farmers can utilize this phenomenon through practices like intercropping, rotating crops, growing cover crops, applying mulch, or using plant-based water extracts (Khamare *et al.*, 2022).

Physical and Thermal Methods

Soil solarization is a non-chemical weed control method used in organic and integrated cropping systems **(**Kanellou *et al.*,2023), Flame weeding is another method employs targeted, thermal energy to destroy unwanted vegetation, serving as a sustainable, ecologically responsible alternative to conventional chemical or mechanical weed control methods (Upadhyay *et al.*, 2024).

Impact of Non-Chemical Weed Management on Soil Health

Cover crops primarily consist of legumes grown to blanket the soil surface, thereby enhancing its physical, chemical, and biological attributes. Through rapid canopy establishment, they serve as a critical tool for weed management by effectively suppressing weed growth. Furthermore, a cover crop exhibits strong resilience to adverse weather, fixes atmospheric nitrogen, and develops deep root systems for nutrient absorption. accumulates high biomass quickly, remain easy to manage without competing with the primary crop, resist pests, and offer a cost-effective cultivation strategy (Sharma *et al.,* 2018). Each year, there is a noticeable surge in destructive, soil-borne agricultural pests and diseases. This rising threat includes devastating

issues like verticillium, blight, greensickness, root rot, and root-knot nematodes. These persistent pathogens aggressively target crops from the roots up, severely compromising plant health. As a result of these infestations, farmers regularly face substantial drops in their annual harvests. Typical damage leads to a significant reduction in overall crop yields, usually ranging from 20% to 60%. In the most severe cases, however, these destructive outbreaks can completely decimate fields, causing losses well beyond 60%. Soil flame disinfestation (SFD) is an innovative, chemical-free technique that uses direct flame sterilization to physically eliminate soil-borne pests. By applying heat directly to the soil, SFD offers an eco-friendly and creative alternative for managing agricultural infestations without relying on traditional pesticides (Upadhyay *et al.*, 2024).

Impact of Non-Chemical Weed Management on Plant Health

Beyond their well-established role in weed suppression, cereal rye and alternative grass cover crops play a fundamental role in Rhizosphere Preparation The extensive, fibrous root systems of grass crops (like cereal rye) structurally optimize the *rhizosphere* (the soil zone directly influenced by root secretions and microorganisms). By stabilizing soil aggregates, they create a loose, well-aerated seedbed that allows the main crop's emerging roots to penetrate deeper with less physical resistance. By improving soil pore structure and water-holding capacity, grass cover crops ensure that critical moisture is retained in the upper soil layers. This prevents the seedbed from drying out rapidly, providing the main crop seeds with the consistent moisture required for uniform germination and quick seedling emergence. Grasses act as highly efficient nutrient scavengers during the off-season, catching mobile nutrients like nitrogen that would otherwise leach away. When these grass crops are terminated at the start of the main season, they gradually decompose, slowly releasing these captured nutrients right when the young main crop needs them most for early-stage vegetative growth. The dense surface residue left behind by grass cover crops creates an immediate physical barrier. This mulch layer suppresses early-season weed flushes by blocking sunlight from weed seeds, reducing resource competition for the main crop during its most vulnerable early growth stages, while simultaneously shielding the fragile soil surface from heavy rainfall (Abbas and Arshad, 2026).

Environmental Benefits of Non-Chemical Weed Management

The adoption of biodegradable and photodegradable mulching materials represents a significant paradigm shift in sustainable agriculture, offering profound ecological benefits that

extend far beyond simple weed suppression. By naturally breaking down over time through microbial activity or solar radiation, these advanced materials eliminate the need for mechanical or manual removal at the end of the cropping season. In traditional farming, the removal and disposal of conventional polyethylene plastic mulches pose a severe ecological threat; they frequently end up in landfills or are burned on-site, releasing toxic dioxins and greenhouse gases into the atmosphere. Furthermore, conventional plastics often leave behind microplastic fragments that accumulate in the soil profile, disrupting the soil microbiome, impairing structural aggregation, and hindering water infiltration. In contrast, biodegradable and photodegradable options seamlessly integrate back into the ecosystem. As they decompose, they pose zero risk of chemical leaching, effectively preserving the structural and biological integrity of the rhizosphere. This preservation of soil health fosters a thriving community of beneficial soil microorganisms and maintains natural soil moisture dynamics. Ultimately, by mitigating the long-term risks of microplastic pollution and reducing the carbon footprint associated with manufacturing, transporting, and disposing of synthetic plastics, these eco-friendly mulches serve as a cornerstone for long-term environmental protection and sustainable land management (Pavlović *et al.*, 2022).

Impact of Non-Chemical Weed Management on Human Health

When synthetic weedkillers are sprayed onto fields, there is an inherent risk that chemical residues will persist in the soil and eventually be absorbed by the roots of the food crops. By utilizing a false seedbed, the entire early vegetative management phase is kept entirely clean. This ensures that the final harvest is completely free of synthetic chemical residues, meeting the highest standards for organic certification and consumer safety. The health benefits of removing herbicides from the agricultural cycle extend from the farm to the dinner table. Field workers are spared from the acute occupational hazards of handling, mixing, and inhaling toxic chemical mists. Simultaneously, consumers are protected from long-term, chronic exposure after using non-chemical weed management techniques causing low-level chemical residues in their diets residues that modern toxicological studies frequently link to endocrine disruption, reproductive issues, and cellular abnormalities (Pavlović *et al.*, 2022).

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CLIMATE – RESILIENT SOIL AND WATER CONSERVATION TECHNIQUES FOR DROUGHT- PRONE REGIONS

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Introduction

NOAA (National Oceanic and Atmospheric Administration) says there is an 82% chance of El Niño developing between May and July (2026), with early projections suggesting the Pacific warming event could rival the 1876-78 event, which contributed to severe global droughts and famine. Meanwhile, the India Meteorological Department (IMD) had earlier projected below-normal rainfall, at 90 per cent of the long-period average during the southwest monsoon, on May 29. There is a 60 per cent chance of a deficient monsoon season which could mean many regions undergoing much drier than normal conditions or even droughts. These estimates have raised alarm within the Union Ministry of Agriculture and Farmers Welfare, which has asked Indian Council of Agricultural Research (ICAR) and state agricultural universities and departments to revise contingency plans specifically for an El Niño year, before Kharif season peaks. The revised plans are expected to be submitted to the ministry by June 20. The severe El Niño effect has caused a weak Southwest monsoon and reduced inflows from Karnataka, forcing Tamil Nadu to miss the customary June 12 opening of the Mettur Dam for the *Kuruvai* paddy season.

Central Government Action Plan

- **Vulnerability Mapping:** The Ministry of Agriculture has identified 197 highly vulnerable districts to deploy targeted contingency plans
- **District Contingency Plans:** Advanced agricultural protocols have been mapped out so farmers are immediately guided to skip sowing or switch to drought-resistant crops if monsoons stall in their specific talukas.

- **Buffer Stocks & Trade Controls:** To control food inflation, the government is utilizing buffer stocks (through the FCI), reducing import duties on critical commodities, and imposing targeted export restrictions on items like sugar
- **Weekly Surveillance & State Synergy:** Union Agriculture Minister Shivraj Singh Chouhan is actively reviewing the *Kharif* season sowing progress in tandem with state governments to guarantee uninterrupted farming momentum

Tamil Nadu state government action against agricultural crisis due to drought

To mitigate the agricultural crisis, Tamil Nadu Government announced a ₹134.83-crore Kuruvai Special Package with the following localized initiatives:

- **Filter-point & Borewell Subsidies:** An allocation of ₹77.50 crore has been directed to delta districts to help farmers utilize groundwater and filter-point irrigation systems
- **Non-Delta Cultivation:** ₹57.33 crore is earmarked to incentivize paddy cultivation in non-Cauvery delta districts to make up for the shortfall
- **Uninterrupted Power:** The state has promised a guaranteed 18 hours of continuous three-phase electricity daily to farmers to run water pumps and sustain crops.
- **Input Distributions:** Free or subsidized seeds, fertilizers, and agricultural machinery are being distributed to minimize the financial burden on affected farmers.

Soil and Water conservation techniques to mitigate drought

1. Soil Moisture Retention

- **Mulching:** Cover the soil with organic materials (e.g., straw, wood chips) to lower surface temperatures, slow down evaporation, and prevent weed growth. Mulching holds massive potential in India to transform agriculture by boosting crop yields by 15–40% and cutting water usage by 30–50%
- **Conservation Tillage:** Avoid turning over the soil excessively. Leaving crop residue on the surface improves soil structure and its ability to absorb and retain water. Recent satellite data highlights significant technology adoption in states like Punjab, where districts such as Sangrur, Moga, and Hoshiarpur show Zero Tillage and Surface Tillage adoption rates ranging from 50% to 60% for wheat and rice rotations
- **Cover Cropping:** Grow dense, low-lying plants during off-seasons. Their root networks increase organic matter and keep the soil porous. Decomposing cover crops build Soil

Organic Matter (SOM). Every 1% increase in SOM can help an acre of soil hold roughly 20,000 gallons more water.

2. Runoff Control & Land Configuration

- **Contour Farming & Terracing:** Plant and plow along the natural contours of sloping land rather than up and down. This creates natural barriers that slow down water and force it to soak into the soil. In Himachal Pradesh contour farming is practiced in 6-7 hilly districts (Shimla, Sirmour, Kangra, parts of Mandi, Solan). In addition, it is also carried out in the southern states of Karnataka, Tamil Nadu, Kerala, dryland regions of Rajasthan as well as some parts of Eastern Ghats. Contour bunding is also carried out, notably in Maharashtra, Gujarat, Tamil Nadu, Karnataka and Andhra Pradesh
- **Swales and Bunds:** Create shallow ditches (swales) or raised earth ridges (bunds) across slopes to slow, spread, and sink rainwater into the ground. In India, swales and earthen bunds mitigate severe soil erosion (which averages 16 tons/ha/year) and passively retain monsoon rain. These interventions increase groundwater recharge, attenuate peak stormwater runoff by up to 25%, and extend soil moisture availability during critical non-irrigated (rain-fed) crop phases.
- **Strip Cropping:** Alternate rows of crops with densely rooted plants or grasses to trap sediments and reduce wind and water erosion. In India, strip cropping quantitatively reduces soil loss by 40%–70%, decreases runoff, and significantly enhances Land Equivalent Ratios (LER) by 1.15 to 1.50. By alternating strips of erosion-resistant and row crops, farmers achieve higher yields and drought resilience without requiring additional land.

3. **Water Harvesting & Storage**

- **Check Dams:** Build small barriers (loose boulders, sandbags, or concrete) across streams and gullies to slow water velocity, prevent soil erosion, and allow water to percolate into the aquifer. In India, check dams are vital for water conservation, increasing groundwater recharge rates by 23% to 47% in regional aquifers. They typically retain 30% to 70% of local runoff, decrease peak stream discharges by over 35%, and can double agricultural productivity in drought-prone areas.
- **Farm Ponds:** Excavate localized ponds to capture heavy seasonal rainfall, which can be drawn upon for supplemental irrigation during dry spells. Farm ponds in India provide

vital life-saving irrigation, boosting farmers' annual incomes by 40% to over 60%. They mitigate drought risks by storing excess monsoon runoff, increase cropping intensity, and allow farmers to cultivate high-value crops and adopt supplementary aquaculture. Supplementary irrigation during critical dry spells boosts crop yields significantly. Drone-based studies indicate irrigation can raise yields by up to 39% over rainfed conditions. In regions of Karnataka and Rajasthan, yield increases range from 13% for basic crops to 80% for vegetables and pulses.

- **Rooftop Rainwater Harvesting:** Divert and store rainwater from roofs into storage tanks or recharge wells for later use. n India, Rooftop Rainwater Harvesting (RTRWH) has profound quantitative effects, particularly in managing water stress, reducing municipal dependency, and mitigating groundwater depletion. Because only 8% of India's total rainfall naturally recharges aquifers, RTRWH helps bridge the gap, potentially elevating recharge rates up to 50% Tamil Nadu is a pioneer in water conservation. It was the first Indian state to mandate rooftop rainwater harvesting (RWH) for all buildings. The quantitative effects are substantial: widespread implementation historically yielded a **50% increase in groundwater levels within five years**, while local campus studies demonstrate the systems can meet **25% to 84% of annual water demands**

4. Precision Agriculture

- **Drip and Sprinkler Irrigation:** Ditch inefficient flood irrigation. Deliver water directly to the plant root zone via drip lines to minimize evaporation and runoff. Drip and sprinkler irrigation deliver remarkable quantitative benefits compared to traditional flood methods, drastically reducing water usage by 30% to 70% and boosting crop yields by 10% to 50%. Drip is superior for targeted root delivery, while sprinklers offer cost-effective area coverage
- **Soil Moisture Sensors:** Use sensors and weather-based trackers to ensure you only irrigate when absolutely necessary, saving critical water reserves. Soil moisture sensors mitigate drought by enabling precision irrigation, which limits water waste, optimizes root development, and allows agriculture to weather dry periods. On average, these sensors **reduce agricultural water usage by 20% to 50%** and **boost crop yields by 15% to 25%** compared to traditional or scheduled watering

- **Agroforestry & Intercropping:** Plant trees (agroforestry) and mix complementary crop types on the same plot. Taller trees reduce wind speeds (which dry out soil), while mixed root depths maximize nutrient and moisture uptake efficiency.

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MULBERRY INTERCROPPING FOR SUSTAINABLE SERICULTURE AND IMPROVED SOIL HEALTH

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Abstract

Mulberry farming has powered sericulture for centuries, but a mulberry field left bare between the rows wastes land, water, and sunlight. Intercropping in mulberry changes that equation. By planting legumes, vegetables, medicinal herbs, or short-duration crops between mulberry rows, growers raise farm profitability, restore soil fertility, and move sericulture farming toward genuine sustainable agriculture. This article explains the science behind mulberry cultivation alongside companion crops, lists the best legume intercrops and vegetable options for different regions, and walks through spacing, nutrient management, and real economic numbers from field trials.

Keywords: intercropping, mulberry cultivation, sericulture farming, sustainable agriculture, soil fertility, legume.

Introduction

Sericulture supports millions of rural households across India, China, Bangladesh, and parts of Africa, yet mulberry farming alone often returns modest profits per acre compared to the labour and irrigation it demands. Farmers who rely only on leaf and cocoon income absorb every price swing in the silk market without a backup. Intercropping in mulberry gives that backup. It

puts the unused space between mulberry rows to work, growing pulses, vegetables, or fodder while the mulberry matures.

Sericulture research stations across South Asia have tested it in real fields for over two decades, comparing sole mulberry against mulberry paired with cowpea, chickpea, cauliflower, and other crops. The results consistently favour the intercropped plots, both in mulberry leaf quality and in net farm income. This article lays out what intercropping in mulberry actually involves, which crops perform best, how to manage spacing and nutrients, and what kind of returns a farmer can realistically expect.

What is Intercropping in Mulberry?

Intercropping means growing two or more crops on the same piece of land during the same season, arranged so each crop uses a different layer of light, root depth, or growing window. In mulberry farming, this usually means planting a shorter, faster crop in the alleys between mulberry rows.

Mulberry is planted in rows, commonly spaced between 90 cm and 150 cm depending on whether the system is rainfed or irrigated. Until the bushes form a full canopy, roughly 60 to 90 cm of open soil sits between each row for most of the year. A legume, vegetable, or fodder crop fills that space, drawing on sunlight and moisture that would otherwise go to weeds.

The practice differs from mixed cropping, where seeds of different crops are simply scattered together without planned rows. Intercropping in mulberry is deliberate: rows are measured, planting dates are timed around mulberry pruning cycles, and crop choice depends on soil type, irrigation access, and the silkworm rearing calendar. Done correctly, the intercrop and the mulberry support each other rather than compete.

Why Farmers should adopt Intercropping

Sericulture income depends on cocoon price, leaf yield, and the number of rearing cycles a farmer can manage each year. Any one of those factors can swing low in a bad season. Intercropping spreads that risk across a second harvest that does not depend on silkworm rearing at all.

Three practical pressures push farmers toward this system:

- **Land is limited** Most mulberry holdings in India run between half an acre and three acres. Leaving 40 percent of that land bare for most of the year is not an option for a family farm trying to cover input costs.

- **Soil degrades under repeated leaf harvest** Mulberry is pruned and harvested four to six times a year in irrigated systems. That repeated defoliation pulls heavily on soil nitrogen, and continuous monocropping without organic input speeds up fertility decline.
- **Input costs keep rising** Fertilizer, irrigation, and labour costs have climbed steadily in most sericulture regions. A second income stream from the same plot, the same irrigation line, and largely the same labour force improves the return on every rupee or dollar spent.

Farmers who have shifted to intercropping report it as one of the few changes that improves both income and soil condition at the same time, rather than trading one for the other.

Scientific Principles Behind Mulberry Intercropping

Nitrogen fixation Legume intercrops such as cowpea, green gram, and black gram host Rhizobium bacteria in their root nodules. These bacteria convert atmospheric nitrogen into a form plants can use, adding usable nitrogen to the soil that the following mulberry flush can draw on. Field studies on mulberry paired with alfalfa found a marked rise in beneficial soil bacteria, including nitrogen-fixing genera such as Bradyrhizobium and Rhizobium, in the rhizosphere of the intercropped plots compared to sole mulberry.



Fig 1: Mulberry Plantation

Light and root stratification Mulberry has a relatively open canopy in its first two to three years and deep, woody roots. Low-growing legumes and vegetables occupy the shallow root zone and intercept light that would otherwise hit bare soil, so the two crops are not drawing from the same resource pool at the same depth.

Organic matter cycling Legume residues left on the surface after harvest decompose and feed soil microbial activity, raising organic carbon over several seasons. This is the same principle behind green manuring, applied inside an existing perennial system instead of a dedicated fallow.

Microclimate moderation A living ground cover reduces soil surface temperature and slows evaporation, which matters most during the hot months between irrigation cycles in semi-arid sericulture tracts.

These mechanisms explain why trial after trial shows higher mulberry leaf protein, chlorophyll content, and sugar levels in intercropped plots compared to sole mulberry, which translates directly into better silkworm growth and stronger cocoons.

Best Intercrops for Mulberry Plantations

Legumes

Cowpea, green gram, black gram, soybean, horse gram, and chickpea are the most studied and most recommended group. They fix nitrogen, mature quickly, and tolerate the partial shade of young mulberry rows. Cowpea in particular has shown strong leaf yield response in tree mulberry systems, alongside solid grain returns.

Vegetables

Cauliflower, cabbage, red amaranth, spinach, brinjal, onion, and potato all work well as intercrops, especially on irrigated plots near urban vegetable markets. Cauliflower has recorded the highest benefit to cost ratio among vegetable intercrops in field trials, helped by strong market demand and a short growing window.

Medicinal Crops

Ashwagandha, aloe vera, asparagus, and turmeric suit drier tracts and command premium prices through contract buyers or local Ayurvedic processors. These crops need less frequent attention than vegetables, which suits farmers managing a tight silkworm rearing schedule.

Fodder Crops

Lucerne, guinea grass, and hedge lucerne support farmers who also keep dairy animals. The fodder crop draws on the same irrigation already running to the mulberry, cutting the cost of buying feed separately.

Short-Duration Crops

Black gram, green gram, and mustard fit into the narrow 50 to 70 day windows between mulberry pruning cycles, making them the safest choice for farmers nervous about timing conflicts with leaf harvest.

Benefits of Intercropping

- **Increased income:** A second crop on the same land, often without extra land rent or new irrigation infrastructure.
- **Better land utilization:** Alley space that would sit idle for eight to ten months a year is put into production.
- **Soil fertility improvement:** Nitrogen fixation and organic residue build long-term fertility rather than depleting it.
- **Weed suppression:** A planted ground cover out-competes weeds for light and moisture, cutting weeding labour by a noticeable margin.

- **Moisture conservation:** Ground cover reduces direct evaporation from the soil surface between irrigation cycles.
- **Biodiversity enhancement:** A mix of root systems and flowering periods supports more beneficial insects and soil organisms than a single-crop block.
- **Reduced production risks:** If cocoon prices fall or a rearing cycle fails, the intercrop still delivers income.

Table1 : Suitable Intercrops and its key benefits

Intercrop	Category	Duration (days)	Key Benefit
Cowpea	Legume	60–75	Nitrogen fixation, fodder and grain
Chickpea	Legume	90–100	High benefit:cost, soil nitrogen
Green gram	Legume	60–65	Quick turnover, low input need
Cauliflower	Vegetable	90–110	Highest market return among vegetables
Cabbage	Vegetable	80–100	Strong urban market demand
Spinach	Vegetable	30–40	Fast cash crop, multiple cuttings
Potato	Vegetable	90–100	Good in cooler tracts
Turmeric	Medicinal	240–270	Premium price, low maintenance
Lucerne	Fodder	Continuous (cut every 25–30 days)	Pairs sericulture with dairy income

Recommended Spacing and Crop Management

Mulberry spacing sets the limits for any intercrop plan. For irrigated bush mulberry, a row spacing of 90x90 cm or 5x3 feet is common. Tree mulberry, grown for higher single-tree leaf yield, is usually spaced wider, often 2.5 to 3 meters between rows.

1. Leave a 20 to 25 cm buffer on either side of the mulberry row before sowing the intercrop, so root competition stays minimal near the mulberry base.

2. Sow legumes and vegetables in the center of the alley, in two or three lines depending on row width.
3. Time sowing around the pruning cycle. Sow the intercrop right after a mulberry harvest, when the canopy is lowest and light reaches the ground freely.
4. Stop intercropping at least three weeks before the next leaf harvest for taller vegetables that might shade the mulberry or interfere with picking.
5. Rotate the intercrop type every one or two seasons. Running the same legume in the same alley for years invites a buildup of root-specific pests.

Nutrient and Irrigation Management

Mulberry under repeated leaf harvest is a heavy nitrogen feeder, typically needing 300 to 350 kg of nitrogen per hectare per year in irrigated systems, split across pruning cycles. Intercropping changes this calculation only slightly, but a few adjustments matter:

- Apply farmyard manure or compost at 10 to 15 tonnes per hectare annually, split between mulberry and the intercrop rows. The intercrop benefits directly, and the residue left behind feeds the mulberry root zone afterward.
- Reduce nitrogen fertilizer to the intercrop itself when using legumes. Legumes fix their own nitrogen, so a starter dose of 15 to 20 kg N per hectare is enough; anything more suppresses nodulation.
- Apply phosphorus and potassium based on a soil test, since legumes draw more heavily on phosphorus than mulberry does.
- Share the irrigation schedule. Most intercrops listed above tolerate the same 7 to 10 day irrigation interval used for mulberry, so a separate watering line is rarely needed.
- Avoid herbicide use on the intercrop rows if the goal is organic farming certification or premium market access; manual or mechanical weeding keeps the system clean.

Common Mistakes Farmers Should Avoid

- Planting tall or sprawling crops too close to mulberry rows. Crops like maize or pumpkin shade young mulberry and compete heavily for water.
- Skipping crop rotation in the alley. Repeating the same legume year after year builds up nematode and root pathogen pressure.
- Over-fertilizing the intercrop with nitrogen. This pushes leafy growth in legumes at the cost of nodulation and pod yield, and wastes input money.

- Ignoring the silkworm rearing calendar. Vegetable harvest and mulberry leaf harvest sometimes fall in the same week. Plan ahead so labor is not stretched across both at once.
- Using chemical pesticides on the intercrop without checking compatibility. Some pesticide residues on mulberry leaves are toxic to silkworms even at low concentrations, so any spray near mulberry rows needs a sericulture-safe label.
- Treating intercropping as a one-time decision. Soil, market price, and rainfall change. Reassess the intercrop choice every one to two years.

Expert Tips for Maximum Profit

- Match the intercrop to your nearest market first, not just to agronomic suitability. A high-yielding vegetable with no nearby buyer earns nothing.
- Keep a simple seasonal calendar mapping mulberry pruning dates against intercrop sowing and harvest dates, so labour planning stays realistic.
- Test soil nitrogen and organic carbon every two years to confirm the intercropping is actually building fertility, not just maintaining the status quo.
- Where possible, contract with a local Ayurvedic or organic buyer for medicinal intercrops before planting, since these crops often depend on a specific buyer rather than open market sale.
- Start with one intercrop on a small section of the plot for the first season before committing the full holding, especially if switching from a long-standing sole mulberry system.

Future Scope of Intercropping in Sustainable Sericulture

Sericulture is under pressure from land fragmentation, water scarcity, and competition from other high-value crops in many traditional mulberry tracts. Integrated farming models that combine mulberry, legumes, vegetables, and sometimes livestock fodder offer one of the more realistic paths to keep sericulture farming attractive to the next generation of farmers.

Research institutes in India and Bangladesh continue to test new intercrop combinations, including medicinal plants suited to drier mulberry tracts and short-duration oilseed crops. As organic certification programs expand into sericulture supply chains, legume-based intercropping will likely become a standard recommendation rather than an optional add-on, since it supports both soil health claims and crop diversification requirements that organic buyers increasingly ask for.

The direction is clear: mulberry plots that function as integrated, multi-crop systems will outperform single-purpose mulberry blocks on both income and soil resilience over the next decade.

Conclusion

Intercropping in mulberry is not a complicated technique, and it does not require new land, new irrigation systems, or expensive equipment. It asks a farmer to use the space already sitting between mulberry rows more deliberately, with crop choices grounded in real field trial data rather than guesswork.

The returns are measurable: extra net income ranging from 20 to 45 percent depending on crop choice and market access, measurable gains in soil nitrogen and organic matter, lower weeding costs, and no loss in cocoon quality when managed correctly. For a sericulture sector facing tighter margins and rising input costs, that combination of farm profitability, soil health, and reduced risk is hard to ignore. Farmers who start with a small trial plot this season, matched to their local soil and market, are likely to find the case for intercropping convincing within a single growing cycle.

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JAL KUMBHI: A THREAT TO WETLAND AND ITS SUSTAINABLE MANAGEMENT

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Introduction

Water hyacinth or *Jal Kumbhi (Eichhornia crassipes)* is an aquatic plant. It is native of Amonzon Basin of South America and from there, it spread to other countries. This plant bear attractive purple flower and that's the reason the botanists and plant lover helped in its spread in different countries. In India it was introduced in late 19th century by British colonizers and botanophile. There is another Jal Kumbhi (*Pistia stratiotes),* known with different names like water cabbage, water lettuce, Nile Cabbage and Shellflower. Both the plant species are aquatic and float at the surface water. These species are alien invasive in nature. The alien invasive species can be defined that those species (*Flora and Fauna*) that invade the habitat outside of their natural occurrence. The Jal Kumbhi is considered in world's worst the among 100 most invasive plant species. These invasive species are contemplated second largest threat to biodiversity on Earth.

Green Menace: The Jal kumbhi has posed a serious threat to wetland across the India. Among them are, famous lakes namely Dal Lake in Kashmir, Loktak lake in Manipur, Vembanad Lake in Kerala, Hussainsagar Lake, in Hyderabad, Telangana are invated, in Assam 30% fishing activity affected in peak months of Jal Kumbhi prolifreation. There is hardly any state where this plant has not clogged the big or small water reservoirs. According to TERI (The Energy and Resources Institute), 2.5 -3 million metric tonnes of Jalkumbh, collectively produced. In some water bodies produce more than 200 tonnes per hectare Jal Kumbhi are reported.

Jal Kumbhi Growth: Since, it is invasive species, its multiplication happens at exponential rate and double in mass just a week's time. "According to the Indian Agricultural Research Institute,

water hyacinth spreads at a rate of nearly 2 hectares per day in some riverine ecosystems." Its rapid proliferation well narrated that it grows faster than your to-do-list. The rapid multiplication of Jal Kumbh is attributed its unique reproduction methods. It multiplied sexually produced seeds as well as vegetative propagation. The plant strive well under stress conditions like temperature fluctuations, P^H, nutritional changes. Its growth flourish in nutri-rich water particularly untreated sewerage water and rain water flow down to these structures.

Ecological threat: Jal Kumbhi make a thick mat over surface of water body and in some cases mat is so dense, multi-layer of Jal Kumbhi has seen. This thick mat inhibits the sunlight penetration and reduce level of oxygen in water. This directly harms the aquatic life while clogging life of native species. No doubt Jal Kumbhi limit the evaporation due to thickly covered water surface. However, in state of Rajasthan where summer temperature rose to above $40C^{0,}$ in this situation these water bodies act as cooling the atmosphere. The balance of biodiversity is severely affected particularly aquatic life. Those bird species feed on aquatic organism are also suffer due to surface of water covered by this plant. Thus, Jal Kumbhi can be designated as an ecosystem nuisance.

Non- ecological impacts: The Jal Kumbhi infestation disrupt the fishing activities and in Assam upto 30 per cent fishing activities suffered is reported. The boating and local transportation come to halt in severely infected water bodies. The irrigation is also negatively affected. It is also reported that a few cows died while eating Jal Kumbhi.

Sustainable Usage: The massive production of Jal Kumbhi can be used sustainably to produce valuable products.

Industrial Use: In many countries, the rapid multiplication of this plant successfully utilized as raw material for small industries for various types goods manufacturing. The Thailand and Kenya are front running countries; those have established the industry to use this aquatic weed. In Thailand entire communities in Patham Thani earn livelihoods making basket and mats for domestic use and also for export purpose. In Kenya through cooperatives, women are manufacturing namely Kisumu craft furniture and earning livelihood from the sales these goods. Out of 2.5 -3 matric tonnes bio mass production of Jal Kumbhi, hardly 1 per cent effectively utilized. Its use can be scaled up by following usage:

Raw material for biodegradable packing and paper: It is reported the Jal Kumbhi in rich in cellulose (50%) and one kilogram dry matter of Jal Kumbhi used in production can substitute about 700 grams of plastic based material used for plastic manufacturing. The cellulose rich

biomass of this plant need to used for making packing material and paper making of various categories. The Packing material made form this plant would be most appropriate for the packing like fruits, vegetables, glass as thes items required soft packing.. **Base for natural fibre composites used in automotive interiors:** With natural adhesives, pulp of Jal Khumbi can be mixed to use as alternative to MDF (Medium Density Fiberboard) and plywood products in a sustainable way to serve growing need of wood. The natural fibres can be used to woven household items such as wearable accessories, baskets, diaries, art surface etc. This shows meaningful mixing the instinctual creativity, functionality and accountability.

A feedstock for biogas and bio-ethanol Production: Presently, maize, sugarcane juice and broken grains of rice used for bio-ethanol production and biomass of this notorious weed can be better alternative for bio-ethanol and biogas production. It is environmental friendly source for these products. Further, CSIR- NEERI (National Environmental Engineering Research Institute) developed the techniques and methods for bio-coal pellets conversion form water hyacinth bio-mass. These pallets are more reliable source energy and emit lesser pollutants. The International Journal of Life Cycle studies found that biomass mass of Jal Kumbhi based products exhales less CO_2 upto 40-50% than to plastic base material.

Source of Compost manure: Jalkumbhi's bio-mass is abundant in Nitrogen and Potassium and these elements are important plant nutrients. Thus, compost of Jal Kumbhi promotes soils health. It can be appeared good alternative than traditional composts required for organic and natural farming.

Ayurvedic usage: Water hyacinth contains a number of medicinal properties. Its extracts possess anti-cancer, anti-fungal, anti-inflammatory and antibacterial compounds. These constituents can be used to treat various health aliments. Besides this, *Pistia stratiotes* has been used in various medicines for the treatment of enzema, leprosy, ulcers, piles, stomach disorders. Throat and mouth inflammation (Tyagi and Mala, 2015). There is urgent need to intensify research to make more useful Jal Kumbhi.

Sustainable Management of Jal Kumbhi: The various options reported in literature to utilize Jal Kumbhi in sustainable manner. However, small fraction of total bio-mass generated by this plant is being utilized. Hence, it necessitates more scientific solutions to be find out to save our wet-lands from this notorious plant. The Following approaches are being used to manage this plants. **Biological Control:** Successful biological control of hyacinth by Neochetina eichhorniae

reported. The Weevils and larve of this insect feed on leaves and petioles, creating scars and tunnel that reduce the plant vigour, increase susceptibility to pathogens and accelerate plant decay. The biological control of Jal Kumbhi with this bio-agent has been tried in Karnataka and Kerala. However, this insect is effective against *Eichhornia crassipes* not another species PIstia stratiotes. Other method to manage the Jal Kumbhi with microbial consortia. The microbial consortia act in a way to deprive of nutrients availability to Jal Kumbhi and due to lack of nutrients in water hyacinth plant start wilting and slowly plants wither out. The biological control method followed in Indore to manage the Jal Kumbhi.

Manual and Mechanical Management: It appears that manual and mechanical management of Jal Kumbhi is only answer to get rid of this plant to-date. Other means of management of this plant are very localized and are also need some work to be done manually.

Story of Jal Kumbhi Management of Mansarover Jheel of Bhilwara: The Bhilwara district located in South-eastern region of Rajasthan. It is popularly known as textile city. The district receives annual rainfall ranges from 580 to 635 mm. The district has over 480 water bodies and among them, four are quite big located around the city. One of the biggest water body is Mansarover Lake. It spread over 40 bigas (about 8 hectares). This particular lake falls inside the city and heavily infested with *Pistia strateiotes.* The photo 1 shows the surface view of this lake the lake which is fully covered by this plant. The Bhilwara administration took the decision to weed out this plant.



Photo1: Mansarover Lake Bhilwara, Rajasthan

A wider consultations made to all concerned institutions both technical and other players to get this job done in eco-friendly way. All options looked into but ultimately tender given to a private agency. The agency took manual and mechanical methods to clean the lake. I viewed

whole process of weeding out thick mat of water lettuce. The mat was so thick even dog can walk on this. Two months' time taken to remove plant mass and other debris. The small boats were used to brought plants at shore with help of ropes. To lift biomass near the bank of lake JCBs, topline cranes and dumper trucks are used. Latest view of the lake is given in Photo 2. This was a huge task and another six months are critical to watch for regenerations. It brought the cheers on face of residents of city as they look this place of recreation.



Photo 2: Mansarover Lake after cleaning

The way forward: There is an urgent need to view the seriousness of this problem critically and this issue become more analytical where water is scar like in the western Rajasthan. The following are suggestions for way forward:

1. Stop the flow of untreated sewerage water or any other polluted water to the water bodies. This action will restrict the multiplication of Jal Kumbhi.
2. Action plan to be drawn at district level to remove Jal Kumbhi. on basis of severeness of infestation in the water bodies to be categorized and action priority line to be drawn to eradicate the Jal kumbhi.
3. Regular monitoring of water bodies to be planned to see the infestation and timely action plan if required.
4. Jal Kumbhi based small industries to be incentivized, particularly biogas and ethanol production.
5. Conversion of Jal Kumbhi into composed manure and bio-coal pallets formations to be made mandatory where biomass production is enough.
6. There is need to periodically water to be drawn out to remove the silt and garbage.
7. In larger water bodies recreation facilities to be created like water fountains, boating etc.

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WASTEWATER MICROBIOLOGY FOR SUSTAINABLE IRRIGATION TRANSFORMING WASTE INTO A RESOURCE FOR CLIMATE-RESILIENT AGRICULTURE

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Abstract

Freshwater scarcity has emerged as one of the greatest challenges to global agriculture due to rapid population growth, urbanization, industrialization, and climate change. Sustainable management of water resources has therefore become essential for ensuring future food security. Treated wastewater is increasingly recognized as an alternative irrigation source, but its safe utilization depends largely on microbiological processes. Wastewater microbiology focuses on the beneficial microorganisms that degrade organic pollutants, remove excess nutrients, and reduce disease-causing pathogens during treatment. These microbial activities convert wastewater into a safer and nutrient-rich resource suitable for agricultural use. Besides conserving freshwater, treated wastewater supplies valuable nutrients such as nitrogen, phosphorus, and potassium, reducing fertilizer requirements while improving soil fertility. However, appropriate treatment, quality monitoring, and adherence to irrigation guidelines are essential to minimize environmental and public health risks. This article explores the role of microorganisms in wastewater treatment, their contribution to sustainable irrigation, benefits to soil and crop productivity, associated challenges, and future innovations that support climate-smart agriculture.

Keywords: Wastewater, Agricultural Microbiology, Sustainable Irrigation, Beneficial Microorganisms, Biofilm, Soil Health, Water Reuse, Climate-Smart Agriculture

Introduction

Water is the foundation of agricultural productivity. Approximately 70% of the world's freshwater resources are used for irrigation, placing enormous pressure on available water

supplies. Increasing water demand, prolonged droughts, groundwater depletion, and unpredictable rainfall patterns have intensified the need for alternative irrigation sources. Traditionally regarded as waste, municipal wastewater is now viewed as a valuable resource when properly treated. It contains water, organic matter, plant nutrients, and microorganisms that can be harnessed through biological treatment processes. Instead of discharging wastewater into rivers and lakes, modern agriculture increasingly emphasizes recycling treated wastewater to conserve freshwater resources.



The success of wastewater treatment relies heavily on microorganisms. Bacteria, fungi, algae, protozoa, and archaea work together to decompose organic pollutants, recycle nutrients, and eliminate harmful pathogens. These naturally occurring microbial communities function as biological engineers, transforming contaminated water into a safer resource suitable for agricultural irrigation. Understanding wastewater microbiology is therefore essential for developing environmentally sustainable irrigation systems that support agricultural productivity while protecting soil, water, and human health.

Understanding Wastewater Microbiology

Wastewater microbiology is the study of microorganisms involved in the purification and stabilization of wastewater. Biological treatment processes depend on naturally occurring microbial communities that utilize organic pollutants as sources of carbon and energy.

Different groups of microorganisms perform specialized functions during wastewater treatment:

Bacteria

Bacteria are the most important organisms involved in wastewater purification. They decompose biodegradable organic matter, convert ammonia into nitrate through nitrification, and transform nitrate into nitrogen gas through denitrification. These reactions reduce water pollution while improving water quality.

Fungi

Fungi contribute to the breakdown of complex organic compounds such as cellulose, lignin, and industrial pollutants that are difficult for bacteria to degrade. They also play a role in reducing the organic load of wastewater.

Algae

Algae produce oxygen through photosynthesis, supporting aerobic bacteria during biological treatment. They also absorb nitrogen and phosphorus, helping to reduce nutrient pollution in treated wastewater.

Protozoa

Protozoa feed on suspended bacteria and organic particles, improving water clarity and reducing microbial populations that may interfere with treatment efficiency.

Archaea

In anaerobic treatment systems, methanogenic archaea convert organic matter into methane gas, contributing to renewable biogas production while stabilizing wastewater sludge. The interaction among these microorganisms forms a balanced ecosystem capable of efficiently purifying wastewater through natural biological processes.

Microbial Processes in Wastewater Treatment

Wastewater treatment involves several interconnected microbial processes that gradually remove contaminants.

Hydrolysis

Complex organic materials such as proteins, carbohydrates, and fats are broken down into simpler compounds by extracellular enzymes produced by microorganisms.

Aerobic Decomposition

Aerobic bacteria utilize dissolved oxygen to oxidize organic matter into carbon dioxide,

water, and microbial biomass. This process significantly lowers the Biological Oxygen Demand (BOD) of wastewater.

Nitrification

Specialized bacteria such as *Nitrosomonas* and *Nitrobacter* convert ammonia into nitrate, preventing ammonia toxicity and improving water quality.

Denitrification

Under oxygen-limited conditions, denitrifying bacteria convert nitrate into harmless nitrogen gas, thereby removing excess nitrogen from wastewater.

Anaerobic Digestion

In oxygen-free environments, anaerobic microorganisms degrade organic matter and produce methane-rich biogas, which can be utilized as a renewable energy source.

Together, these biological processes produce treated wastewater that is substantially safer for agricultural reuse.

Importance of Treated Wastewater in Sustainable Irrigation

The reuse of treated wastewater offers several agricultural and environmental advantages.

Conservation of Freshwater Resources

Using treated wastewater for irrigation reduces dependence on freshwater sources such as rivers, reservoirs, and groundwater aquifers. This becomes particularly important in water-scarce regions where irrigation competes with domestic and industrial demands.

Natural Nutrient Supply

Unlike freshwater, treated wastewater often contains essential plant nutrients including nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients. These nutrients can partially substitute chemical fertilizers, reducing production costs.

Improvement of Soil Fertility

Organic matter present in treated wastewater improves soil aggregation, increases water-holding capacity, enhances microbial activity, and promotes long-term soil health.

Support for Circular Economy

Recycling wastewater transforms waste into a productive agricultural input, reducing pollution while promoting efficient utilization of natural resources.

Impact of Wastewater Microorganisms on Soil Health

When properly treated wastewater is applied for irrigation, beneficial microorganisms

influence the soil ecosystem in several positive ways. Beneficial bacteria contribute to nutrient cycling by decomposing organic residues and releasing nutrients into plant-available forms. Soil microbial diversity increases, leading to improved biological activity and enhanced nutrient availability. Microorganisms also stimulate the formation of stable soil aggregates through the production of extracellular polysaccharides, improving soil aeration and water infiltration. Healthy microbial communities contribute to disease suppression by competing with soil-borne pathogens and producing antimicrobial compounds that inhibit harmful microorganisms. Consequently, microbiologically active soils become more productive, resilient, and sustainable over time.

Potential Risks Associated with Wastewater Irrigation

Although treated wastewater offers numerous benefits, improper treatment or management can pose certain risks. Untreated or poorly treated wastewater may contain pathogenic bacteria, viruses, protozoa, and helminths capable of causing diseases in humans and animals. Industrial wastewater may introduce heavy metals such as cadmium, lead, mercury, and chromium into agricultural soils. Continuous accumulation of these metals can affect crop quality and food safety. Excessive sodium and dissolved salts may increase soil salinity, reducing crop productivity in sensitive soils. Emerging contaminants including pharmaceutical residues, antibiotics, and microplastics have become growing concerns because of their potential effects on soil microorganisms and ecosystem health. Therefore, wastewater intended for irrigation should always undergo adequate treatment and quality assessment before agricultural use.

Safe Management Practices for Agricultural Reuse

Sustainable wastewater irrigation requires appropriate management practices that protect both agricultural productivity and public health.

Important recommendations include:

- Use only adequately treated wastewater that complies with national or international quality standards.
- Monitor microbial indicators such as *Escherichia coli* and fecal coliform bacteria regularly.
- Periodically analyze heavy metals, salinity, nutrient levels, and pH.

- Adopt drip or subsurface irrigation systems whenever possible to minimize contact between irrigation water and edible plant parts.
- Observe appropriate withholding periods before harvesting fresh produce.
- Encourage integrated nutrient management to avoid excessive nutrient accumulation.
- Follow guidelines issued by the World Health Organization (WHO), Food and Agriculture Organization (FAO), and national regulatory agencies.

Proper management significantly reduces health risks while maximizing agricultural benefits.

Future Perspectives

Rapid advances in agricultural microbiology and biotechnology are improving the safety and efficiency of wastewater reuse. Modern treatment technologies increasingly employ microbial biofilms, membrane bioreactors, constructed wetlands, and microbial consortia to achieve superior contaminant removal. Researchers are also exploring beneficial microbial inoculants that can further enhance nutrient recovery and soil fertility following wastewater irrigation. Artificial intelligence, biosensors, and molecular diagnostic tools are enabling real-time monitoring of microbial communities and water quality, improving treatment efficiency and risk assessment. As climate change intensifies water scarcity, wastewater recycling will become an increasingly important component of climate-smart agriculture and integrated water resource management.

Conclusion

Wastewater microbiology demonstrates how naturally occurring microorganisms can transform polluted water into a valuable agricultural resource. Through biological degradation, nutrient recycling, and pathogen reduction, microbial communities make treated wastewater suitable for sustainable irrigation while conserving limited freshwater resources.

When supported by appropriate treatment technologies, regular quality monitoring, and scientifically based management practices, wastewater reuse offers multiple benefits, including improved soil fertility, reduced fertilizer consumption, enhanced water security, and greater environmental sustainability. Although challenges related to pathogens, heavy metals, and

emerging contaminants remain, continuous advances in microbiology and wastewater treatment technologies are improving the safety of agricultural water reuse.

In the face of increasing water scarcity and climate change, wastewater microbiology represents a powerful example of how biological processes can contribute to resilient, resource-efficient, and environmentally responsible agriculture. Harnessing the potential of beneficial microorganisms today will help secure sustainable food production for future generations.

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HOW GLOBAL WARMING INFLUENCES PLANT PATHOGENS

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Abstract

Global warming has emerged as one of the most significant environmental challenges affecting agriculture worldwide. Rising temperatures, altered rainfall patterns, increased atmospheric carbon dioxide concentrations, and frequent extreme weather events are reshaping plant-pathogen interactions in complex ways. Plant pathogens, including fungi, bacteria, viruses, and nematodes, are highly sensitive to climatic factors, and even slight changes in environmental conditions can significantly influence their survival, reproduction, dispersal, and virulence. These changes have resulted in the emergence of new diseases, shifts in pathogen distribution, increased epidemic frequency, and enhanced crop vulnerability. The changing climate also affects host physiology and resistance mechanisms, often weakening plant defence systems and making them more susceptible to infection. Understanding the relationship between global warming and plant pathogens is essential for developing sustainable disease management strategies. This article explores how global warming influences plant pathogens, its impact on agriculture, and possible adaptation measures to mitigate future risks.

Introduction

Agriculture forms the backbone of food security and economic stability in many countries. However, agricultural productivity is constantly threatened by plant diseases caused by diverse pathogens. Traditionally, the occurrence and severity of plant diseases have been strongly linked to environmental conditions. Temperature, humidity, rainfall, and wind patterns determine whether pathogens can infect and spread effectively. Global warming, characterized by the gradual increase in Earth's average surface temperature due to greenhouse gas

accumulation, is altering these environmental parameters. According to scientific reports, the global mean temperature has increased by approximately 1.1°C since the pre-industrial period, with projections suggesting further increases in the coming decades. Such climatic shifts create favorable conditions for many plant pathogens while disrupting established ecological balances. The relationship between climate and disease development is often explained through the disease triangle, which consists of the host, pathogen, and environment. Global warming primarily alters the environmental component, but its indirect effects on hosts and pathogens can intensify disease outbreaks. As a result, understanding the implications of climate change on plant pathology has become increasingly important for researchers, farmers, and policymakers.

Influence of Global Warming on Plant Pathogens

1. Expansion of Geographic Distribution

One of the most evident effects of global warming is the expansion of pathogen ranges into new geographical areas. Temperature acts as a limiting factor for many pathogens. As regions become warmer, pathogens that were once restricted to tropical or subtropical areas can move into temperate zones. For instance, rust diseases in wheat, such as stem rust caused by *Puccinia graminis*, have shown changes in distribution due to shifting climatic conditions. Similarly, bacterial wilt caused by *Ralstonia solanacearum* is spreading into higher altitudes where cooler temperatures previously limited its survival. This geographic expansion poses a serious threat because crops in newly affected regions may lack resistance, leading to severe yield losses.

2. Increased Pathogen Survival and Overwintering

Warmer winters are reducing the natural mortality of many pathogens. Traditionally, cold temperatures help suppress pathogen populations by killing spores, eggs, or dormant structures. With milder winters, these survival structures remain viable and can initiate infections earlier in the growing season. For example, fungal pathogens like *Sclerotinia sclerotiorum* and insect-transmitted viruses can persist longer under warmer conditions. This extended survival increases primary inoculum levels and enhances disease pressure in subsequent seasons.

3. Faster Pathogen Reproduction and Life Cycles

Temperature significantly affects pathogen metabolism and reproduction. Rising temperatures can shorten generation times, allowing pathogens to complete more life cycles within a season. Many fungal pathogens, including *Alternaria* and *Fusarium* species, produce

spores more rapidly under warm conditions. Increased reproduction means greater inoculum availability, faster disease progression, and a higher probability of epidemics. In some cases, pathogens that previously produced one generation per season may produce multiple generations, intensifying disease severity.



4. Enhanced Virulence and Aggressiveness

Global warming may influence the genetic adaptability of pathogens. Rapid reproduction and mutation rates can lead to the emergence of more aggressive strains capable of overcoming host resistance. For instance, new races of *Phytophthora infestans*, the causal agent of late blight in potato, have evolved with greater adaptability under changing climatic conditions. Increased virulence complicates breeding efforts and reduces the effectiveness of resistant cultivars. This evolutionary advantage allows pathogens to adapt faster than crops, creating a continuous challenge for plant breeders.

5. Altered Host Susceptibility

Climate change not only affects pathogens but also the plants they infect. Heat stress, drought stress, and irregular nutrient uptake weaken plant immunity, making crops more vulnerable to diseases. Elevated carbon dioxide levels can alter plant tissue composition, affecting the nutritional environment for pathogens. Stress-induced physiological changes may reduce the production of defensive compounds such as phytoalexins and pathogenesis-related proteins. For example, rice plants under heat stress have shown increased susceptibility to blast disease caused by *Magnaporthe oryzae*.

6. Changes in Disease Epidemiology

Global warming alters rainfall intensity, humidity, and wind movement, all of which influence disease spread. Increased rainfall and humidity favor many foliar pathogens by providing prolonged leaf wetness essential for spore germination. Heavy rainfall can also facilitate soilborne pathogen movement. Windstorms may carry spores over long distances, introducing diseases into previously unaffected areas. Diseases like downy mildew, powdery mildew, and anthracnose are expected to show increased incidence under changing weather patterns.

7. Impact on Vector-Borne Diseases

Many plant viruses depend on insect vectors such as aphids, whiteflies, and leafhoppers. Global warming directly affects vector populations by increasing their survival, reproduction, and migration. Warmer temperatures can accelerate insect life cycles, leading to larger populations and increased virus transmission. For example, Tomato Yellow Leaf Curl Virus spread has intensified due to the expanded range of whitefly populations. This creates a combined threat where both vector and pathogen benefit from climatic changes.

8. Emergence of New Diseases

Changing climatic conditions may create opportunities for previously minor pathogens to become major threats. Novel pathogen-host interactions may arise when crops are introduced into new environments or when pathogens adapt to new hosts. For example, diseases that were once sporadic may become endemic due to favorable temperatures and humidity. The unpredictability of such emergences makes disease forecasting difficult. Emerging diseases can cause sudden and severe economic losses because farmers may not be prepared to manage them effectively.

Impact on Agricultural Production

The influence of global warming on plant pathogens directly affects crop productivity and food security. Increased disease incidence reduces yield quantity and quality. Farmers face higher production costs due to increased fungicide applications, resistant variety development, and disease monitoring. Smallholder farmers are particularly vulnerable because they often lack access to advanced disease management technologies. Major staple crops such as rice, wheat, maize, and pulses are increasingly at risk from climate-driven disease outbreaks. In addition to economic losses, excessive pesticide use to combat rising disease pressure can harm the environment and human health, creating a broader sustainability concern.

Strategies to Manage Climate-Driven Plant Diseases

To address the growing challenge of plant pathogens under global warming, several strategies must be adopted:

Development of Climate-Resilient Varieties: Breeding crops with durable resistance to multiple pathogens is essential.

Improved Disease Forecasting Systems: Climate-based predictive models can help farmers take preventive actions.

Integrated Disease Management (IDM): Combining cultural, biological, and chemical methods reduces disease risks sustainably.

Surveillance and Early Detection: Monitoring pathogen movement and emergence helps contain outbreaks.

Crop Diversification: Mixed cropping systems reduce the spread of host-specific pathogens.

Soil Health Management: Healthy soils improve plant vigor and resistance.

Use of Biological Control Agents: Beneficial microbes can suppress pathogen populations naturally.

Policy Support and Farmer Education: Governments and institutions must strengthen extension services to educate farmers on climate-adaptive disease management.

Conclusion

Global warming is profoundly transforming plant disease dynamics across the world. Rising temperatures, altered precipitation patterns, and increased atmospheric carbon dioxide are

creating favorable conditions for pathogen survival, multiplication, and spread. At the same time, crop plants are becoming increasingly vulnerable due to environmental stress. These combined effects threaten agricultural sustainability and global food security.

The challenge is not merely the increase in known diseases but also the emergence of new pathogens and more aggressive strains. This evolving scenario demands continuous research, improved surveillance, and innovative disease management strategies. Sustainable adaptation measures, combined with climate-smart agricultural practices, will be essential to protect crops from future disease threats.

Understanding how global warming influences plant pathogens is critical for ensuring resilient agricultural systems in an era of climate uncertainty. The future of food production will depend on our ability to anticipate, adapt, and respond effectively to these changing plant health challenges.

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FOOD INK: THE SECRET INGREDIENT BEHIND 3D-PRINTED FOOD

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Abstract

Three-dimensional (3D) food printing is an emerging additive manufacturing technology that creates edible structures layer by layer from a digital model. At the heart of this technology lies the concept of food ink, a formulated, food-grade material that governs whether a product can be successfully printed at all. Food inks must satisfy two fundamental requirements: they must flow smoothly through a printer nozzle under pressure, and they must solidify quickly after deposition to retain the intended shape. The composition of food ink, typically comprising carbohydrates, proteins, fats, and hydrocolloids, directly determines its rheological behaviour, texture, and structural fidelity. This article examines the science of food inks, exploring their classification, the role of rheology, the impact of key ingredients, and their transformative applications in personalized nutrition and healthcare, while identifying the key challenges that must be resolved before 3D-printed food can fulfil its remarkable potential.

Keywords: food ink, 3D food printing, rheology, hydrocolloids, personalized nutrition, extrusion-based printing

1. Introduction

Three-dimensional printing, which is also known as additive manufacturing, produces three-dimensional objects using a digital model, and its utilisation has been observed across various industries, including the food industry (Domzalska & Jakubczyk, 2025). Three-dimensional food printing technology is a significant innovation that has the potential to revolutionise the culinary market, offering a unique opportunity to create complex and aesthetic dishes that go beyond the limitations of traditional cooking methods (Domzalska & Jakubczyk, 2025). The global population is projected to reach 9.7 billion by 2050, and the combined effects

of population growth, climate change, water shortages, and the problem of food waste present a significant threat to global food security; given these challenges, 3D food printing technology could prove crucial in ensuring a food supply for a growing population (Domzalska & Jakubczyk, 2025).

In food 3D printing, instead of non-edible materials, the filament uses a formalized food ink, and the ink is inserted into the extruder, which then forces the ink, either viscous or watery, into the nozzle (Neamah & Tandio, 2024). The actuators move the nozzle in each direction to create specific paths, and important parameters required for successful printing include temperature, extrusion rate, nozzle height, nozzle diameter, extruder moving speed, and slicer software (Neamah & Tandio, 2024). After the food has been printed, post-processing such as baking, frying, toasting, or steaming is sometimes necessary for certain types of food (Neamah & Tandio, 2024). Researchers have also begun to look for unusual food ink sources such as insects, algae, bacteria, and fungi (Neamah & Tandio, 2024).

The 3D food printing process can be broken down into different steps: the desired object is initially digitally created using 3D scanning or computer-aided design (CAD); raw materials, including gels, pastes, or powders, are carefully selected; the printer then draws the prepared material into syringes or cartridges; a series of layers of food are created; and once the food has been printed, it can be further processed to improve its texture, shape, or taste (Domzalska & Jakubczyk, 2025). This article examines the science of food inks, from their classification and rheological requirements to their applications in personalized nutrition and medicine.

2. What Is Food Ink? Classification and Core Composition

Food-grade material, called food ink, is a key component of 3D food printing technology, and the properties of these materials must allow them to flow through the nozzle and stabilise once deposited on the surface (Domzalska & Jakubczyk, 2025). The properties of the ink can therefore control the viscosity and flavour of the food-grade materials, and additional ingredients incorporated into the base products to improve their physical properties or provide nutritional benefits can be divided into four main categories: carbohydrates, proteins, fats, and food viscosity enhancers (Domzalska & Jakubczyk, 2025). Food inks have been developed to personalise 3D-printed food, and the food ink market offers many possibilities, including changing texture, taste, satiety, and appearance while contributing to changing eating habits (Domzalska & Jakubczyk, 2025).

Printing materials can be divided into three main categories: native printing materials such as cheese, alternative materials such as insects, and non-native ingredients such as meat (Domzalska & Jakubczyk, 2025). Some printing materials can be easily extruded through nozzles without additional flow enhancers and exhibit a stable structure after printing, whereas changes in physical and rheological properties may be necessary when using non-native materials to achieve the required printability and smooth extrusion (Domzalska & Jakubczyk, 2025). A widely used classification of food inks distinguishes two primary categories: non-natively extrudable inks, which include plant-based inks derived from fruits and vegetables and meat-based inks, and natively extrudable inks, which encompass dairy-based, hydrogel-based, and confectionary-based inks (Domzalska & Jakubczyk, 2025). During the past few years, cake, chocolate, cheese, mashed potato, dough, ice cream, peanut butter, and blends of fruits and vegetables have been successfully printed (Neamah & Tandio, 2024).

3. The Rheology of Food Ink: Why It Matters

The main parameter affecting extrusion-based 3D-printing processes is the rheology of the food ink, and a printable material needs rheological properties that allow extrusion through the nozzle and a fast stabilisation once the material has been deposited to guarantee the fidelity of the shape (Maldonado-Rosas et al., 2022). Two main criteria therefore determine printability: the ink must flow easily through the narrow printer nozzle, and it must solidify quickly after deposition to support subsequent layers (van der Sman et al., 2025). The yield stress showed a strong correlation with the printing force, and moderate correlations were found between printing accuracy, yield stress, loss tangent (tan delta), and the strain-thinning exponent (van der Sman et al., 2025). The yield stress also correlated with the strain-thinning exponent, suggesting that higher yield stress inks require stronger strain or shear thinning to be printable (van der Sman et al., 2025).

Food inks designed for 3D-printing applications must possess shear-thinning flow characteristics in order to be easily extruded from the syringe outlet; otherwise, an increment in friction forces within the syringe barrel could occur, resulting in rough-surfaced, uneven 3D prints (Nikolaou et al., 2025). All studied samples in a comprehensive starch-based formulation study displayed pseudoplastic characteristics, meaning a decrease in viscosity values with an increase in shear rate, which are considered essential for extrusion-based 3D food printing (Nikolaou et al., 2025). The relationship between the storage modulus (G prime) and the loss

modulus (G double prime) plays a critical role in determining the suitability of food inks for 3D printing, as these materials must withstand the shear forces encountered during extrusion while also being able to recover their shape after deposition (Nikolaou et al., 2025). A study investigating pea-based paste food inks found that all inks sharing the same macronutrient formulation mapped to a master curve after scaling with the elastic plateau modulus, demonstrating the independence of rheological properties from the nutrient composition (Bugday et al., 2024). The study showed that observing the independence of the rheological properties from the nutrient composition and the scalability of the rheology by the water content provided a step forward in developing formulations with various nutrient content at desired flow properties, which promises personalized nutrition (Bugday et al., 2024). Furthermore, the extrusion force and the buildability were controlled by the macronutrient composition, and varying the water content according to a ratio of the total water holding capacity (WHC) of dry ingredients was an effective hydration method (Bugday et al., 2024).

4. Key Ingredients in Food Ink Formulation

4.1 Hydrocolloids: The Structural Architects

Hydrocolloids play a central role in food ink formulation as structuring and thickening agents, and to ensure the stability of inks during printing and storage, various types of stabilising and thickening substances are added to the inks, mainly hydrocolloids (Domzalska & Jakubczyk, 2025). Hydrocolloids have been commonly used to modify the desired soft texture and consistent viscoelastic properties of 3D-printed food, as well as improve printability and structural stability (Chao et al., 2024). Hydrocolloids used in 3D food printing include starch, methyl cellulose, xanthan gum, guar gum, alginate, pectin, agar, carrageenan, and gellan gum, which are composed of hydrophilic polymers rich in functional groups that enable extensive water absorption and swelling (Domzalska & Jakubczyk, 2025).

Among all tested hydrocolloid types, formulations containing kappa-carrageenan (KC) consistently demonstrated superior viscoelastic behaviour with a storage modulus (G prime) greater than 4000 Pa, optimal tan delta values between 0.096 and 0.169, and yield stress conducive to stable extrusion (Nikolaou et al., 2025). Kappa-carrageenan formulations also achieved high structural fidelity with 93 to 96 percent accuracy and favourable textural attributes such as increased hardness and chewiness (Nikolaou et al., 2025). In contrast, xanthan gum formulations displayed the weakest viscosity profile compared to the other hydrocolloids, a

feature possibly attributed to the rigid, rod-like structure of xanthan gum that aligns more easily under shear compared to a random-coil structure, resulting in an enhanced shear-thinning behaviour (Nikolaou et al., 2025).

4.2 Starch: The Backbone of Many Food Inks

Starch has been widely explored as a base material for 3D food printing due to its natural abundance, its ability to develop a gel-like structure upon heating, and its favourable shear-thinning and viscoelastic properties in the gelatinized state (Nikolaou et al., 2025). Starch is primarily composed of two polysaccharides: amylose, which is a primarily linear polymer composed of glucose units linked by alpha-1,4-glycosidic bonds, and amylopectin, which is a much larger, highly branched molecule due to the presence of both alpha-1,4- and alpha-1,6-glycosidic linkages (Nikolaou et al., 2025). The botanical variations between starch sources are particularly important when evaluating starches for 3D food printing applications, as different starch sources can significantly affect key functional properties such as gelatinization, viscosity, structural integrity, and printability (Nikolaou et al., 2025). As a printed material, starch alone does not constitute a suitable food ink, often necessitating the incorporation of additional components such as proteins and hydrocolloids to enhance its mechanical properties, minimise syneresis, and improve printability (Nikolaou et al., 2025). Starch-based food inks prepared from corn starch showed higher viscosity values compared to potato starch-based inks, and the observed differences between these two starch types may be attributed to variations in amylose content, where potato starch has a lower amount, phospholipid content, and granule morphology (Nikolaou et al., 2025). Fourier Transform Infrared (FTIR) analysis revealed that gel strengthening in composite starch-based inks was primarily driven by non-covalent interactions, such as hydrogen bonding and electrostatic effects (Nikolaou et al., 2025).

4.3 Proteins and Fats: Nutritional and Functional Contributors

Protein concentrates from alternative sources, such as legumes including soy, pea, and fava bean, cereals including rice and corn, and microbial or plant-based materials, are being increasingly investigated for their nutritional and functional roles in 3D food printing formulations (Nikolaou et al., 2025). Plant-based proteins such as soy or pea protein isolates can be precisely structured through 3D food printing to replicate the fibrous texture of animal meat, while allowing for the incorporation of specific micronutrients or functional ingredients to enhance the nutritional profile of the final product (Nikolaou et al., 2025). Protein supply in food

inks can be obtained from animals, plants, and alternative sources, which provide important different protein patterns in terms of composition and functional properties (Chao et al., 2024). The direct suitability of fruits and vegetables for 3D printing is limited by their inherent flow and viscosity properties, which can be enhanced by adding appropriate additives such as starch, hydrocolloids, or hydrogels (Domzalska & Jakubczyk, 2025). The high water content of fruit and vegetable products reduces the viscosity of edible inks, and two methods can be used to reduce the moisture content of these food materials: the first involves adding significant thickeners including proteins, starches, and hydrocolloids, and the second involves using various dehydration techniques to reduce the moisture content (Domzalska & Jakubczyk, 2025). The integration of empirical measurements and computational simulation through Computational Fluid Dynamics (CFD) provided a robust framework for evaluating and optimising printable food gels, and these findings contribute to the advancement of personalized and functional 3D-printed foods through data-driven formulation design (Nikolaou et al., 2025).

5. Applications of Food Ink Technology

5.1 Personalized Nutrition and Healthcare

3D food printing in food production offers the opportunity to create personalised products for consumers, which can help solve food availability issues, increase supply-chain efficiency, and enable products to take on a variety of complex shapes (Domzalska & Jakubczyk, 2025). Printing food technologies are considered a potential solution for producing customized foods such as military food and astronaut food, making this technology of strategic as well as consumer importance (Neamah & Tandio, 2024). Research exploring inks developed for personalized nutrition found formulations that were either carbohydrate-rich, protein-rich, or fibre-rich, confirming that 3D food printing can tailor macronutrient composition to individual requirements (van der Sman et al., 2025).

3D food printing is a promising technique widely used in customized food development, and it can be used to re-formulate the food ink by combining more than one type of food material to ensure high calorie and nutrient intake, improve sensory quality, and prevent malnutrition (Chao et al., 2024). Understanding the functional properties of macronutrient compounds is therefore essential to design food ink that meets personalized nutrient requirements (Chao et al., 2024). Personalized food with nutritional customization should be reduced in saturated fat, cholesterol, sugar, and salt contents while being enriched in protein, unsaturated fatty acid,

essential micronutrients, other bioactive compounds, and pre- or pro-biotics to ensure sufficient calorie needs and necessary nutrient absorption to prevent malnutrition and degenerative chronic diseases (Chao et al., 2024).

5.2 Food for Elderly Patients with Dysphagia

Elderly individuals commonly experience the risk of dysphagia, or difficulties in eating and swallowing food safely, which is caused by physiological changes during aging development, including lost dentures, reduced salivary secretion ability (xerostomia), impaired anatomical coordination, muscle frailty, stroke, and other neurological diseases (Chao et al., 2024). Dysphagia in the elderly is increasingly recognized as a concerning healthcare issue that makes them suffer from the risk of malnutrition, starvation, dehydration, sarcopenia (decreased skeletal muscle mass), and altered gastrointestinal conditions (Chao et al., 2024). Three-dimensional printed food construction is uncomplicated, quick, automated, and consistent; it starts from the preparation of food ink by formulating food ingredients into targeted structures such as dough, puree, or gelling forms, then designing the desired food shape using printing-related software, and performing the printing process by extrusion and deposition of food ink layer by layer (Chao et al., 2024). Owing to the feasibility of food ink customization, 3D food printing can be used to develop a new version of personalized food with nutrition-added value, softening in texture, consistent viscoelasticity, improved functional properties, and visual appeal to provide more options, facilitate safe oral intake and satiety, as well as improve the healthy mealtime experience for the elderly (Chao et al., 2024). The food standard guidelines have been established and used to categorize texture-modified foods to ensure easy eating and safe swallowing for the elderly with swallowing difficulties (Chao et al., 2024). The production of personalized food using 3D printing may provide more food options, facilitate safe oral intake, and increase calorie intake to improve the healthy mealtime experience for the elderly (Chao et al., 2024).

5.3 Innovative and Novel Food Products

In 2006, the Fab@Home 3D printer was developed as an open-source printer that could create moulds using various printing materials, and it was initially used to make chocolate, Nutella, and icing shapes, after which researchers at the University of Exeter, TNO, Stratasys, and elsewhere developed 3D printing using other food materials (Domzalska & Jakubczyk, 2025). Three-dimensional printers may become the future technology allowing people to print

and eat (Domzalska & Jakubczyk, 2025). Recent advances add a new dimension from 3D to 4D printing by inserting smart materials that can change colour or shape when stimulated, with applications including identification of product decomposition by changing colour, smaller packaging, better control of dimensional stability after dehydration, and alteration of structure for artificial tissues (Neamah & Tandio, 2024). The integration of artificial intelligence (AI) with 3D food printing is transforming the food industry by enabling the production of personalized, nutritious, and sustainable food products, and AI-driven innovations in food design, process optimization, and quality control are paving the way for a future where food is tailored to individual needs and produced efficiently and sustainably (Neamah & Tandio, 2024).

6. Current Challenges and Future Directions

The printable food ink material still lacks standardization and a superior extrusion process compared to other 3D printing industries, and one of the major limitations that needs to be resolved is the standardisation of food printing safety (Neamah & Tandio, 2024). An understanding of the mechanical properties of 3D-printed food is also crucial for consumer satisfaction, as they are related to the texture of food products, and a clear relationship between rheological properties and printability has not yet been studied in sufficient depth (Maldonado-Rosas et al., 2022). A study on pea-based inks found that moderate correlations between printing accuracy and rheological parameters were attributed to inhomogeneity of the inks imparted by imperfect mixing and hydration, and these issues merit further investigation in the context of 3D food printing (van der Sman et al., 2025).

Printing parameters such as the nozzle diameter, printing speed, and temperature of the process significantly affect the quality of the final 3D-printed product, and selecting appropriate printing parameters, such as process temperature and printing speed, and using the proper nozzle diameter and height, significantly impacts the quality, precision, and stability of the final printed product (Domzalska & Jakubczyk, 2025). Fruit juices and beverages can be enriched with bioactive chemicals and probiotics, but designing them for 3D printing is a significant challenge because these beverages could be destabilised when lipophilic compounds and probiotics are added, which poses a significant obstacle to the broader application of 3D printing (Domzalska & Jakubczyk, 2025). Overall, the critical variables for all types of food to be printed lie in their rheological and physical properties, and since many foods have unprintable properties, some

additives and flow enhancers are added to the food to alter its properties and improve printability (Neamah & Tandio, 2024).

Conclusion

Food ink is the secret and defining ingredient behind the success or failure of any 3D-printed food product. As research demonstrates, the formulation of a food ink, whether based on starch, protein, hydrocolloids, or combinations thereof, directly controls the rheological properties that govern both printability and the final product's texture and nutritional value. From soft foods for elderly patients with dysphagia, to personalized nutrient-dense meals for athletes and patients, to future applications in space exploration and military nutrition, food ink science is at the frontier of food technology. Overcoming the persistent challenges of standardization, safety, and the relationship between ink composition, rheology, and print fidelity will be decisive in enabling 3D food printing to fulfil its transformative potential and reshape the global food landscape.

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FROM ATMOSPHERE TO EARTH: THE SCIENCE OF CARBON SEQUESTRATION

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Introduction

Every breath we take, every crop we grow, and every degree of warming our planet experiences is tied to a single, restless element: carbon**.** It drifts through the air as carbon dioxide, gets pulled down by a leaf during photosynthesis, becomes part of a stem, a root, or a grain, and eventually returns to the atmosphere when that plant decays or is burned. Carbon sequestration, the process of capturing and storing carbon dioxide (CO2) from the atmosphere, has become a crucial strategy in addressing climate change and mitigating the impacts of greenhouse gas emissions. Since the industrial era began, however, humans have been pulling carbon out of the ground as coal, oil, and gas and pushing it into the sky faster than the Earth's natural systems can absorb it. The result is the warming climate we are all living through today.

Every soil carries a kind of memory, a natural baseline of organic carbon it held under its original vegetation, long before conversion to farmland. To understand how much carbon a soil could sequester, we first have to know how much it used to hold. When farming or grazing reduces the carbon going into the soil, or speeds up the carbon leaving it, compared to what natural vegetation would have provided, soil carbon declines steadily over time. This creates a carbon deficit between the soil's present stock and its original, pre-conversion level. That deficit, though, is really just unused storage capacity. It represents an opportunity: change the land use or management to add more carbon or lose less of it, and that gap can begin to close. Converting cropland back to forest or grassland is one way to do this, since deeper, denser root systems rebuild organic matter faster than annual crops typically allow. Creating or restoring wetlands and ponds achieves something similar on an even larger scale, because waterlogged, low-oxygen soils slow decomposition and let carbon accumulate rather than escape.

Understanding the Carbon Cycle

It moves constantly between four great reservoirs: the air above us, the oceans, every living thing, and the rock and soil of the Earth's crust. Its journey through plants is where the story gets interesting: a leaf pulls carbon dioxide from the air and, through photosynthesis, turns it into sugars that build roots, stems, leaves, and grain. That should be the end of the story: the plant dies, is eaten, or decomposes, and most of that carbon simply returns to the atmosphere through respiration and decay, picking up its journey again.

On a global scale, soils hold roughly two to three times more carbon than the atmosphere and about four times more than all living plants and animals combined. This makes soil the largest terrestrial carbon reservoir on the planet, and it explains why soil scientists have found themselves at the centre of the climate change conversation.

Carbon Sequestration?

In the simplest terms, carbon sequestration is the process of capturing carbon dioxide from the atmosphere and storing it in a form that keeps it out of the air for a long period of time. Scientists usually group sequestration approaches into three broad categories.

Biological Sequestration

Biological carbon sequestration is simply this natural process at work: carbon dioxide drawn out of the air and stored in living systems, whether that's a forest canopy, a grassland, a wetland, or the soil beneath a farmer's field. Photosynthesis does the heavy lifting here, converting atmospheric carbon into biomass and, eventually, into stable soil organic matter. It's the oldest form of carbon capture there is, predating any human intervention by millions of years, and it remains the most widespread. What makes it especially significant for agriculture is that it's also the one form of sequestration farmers can shape directly, not through expensive technology, but through the everyday choices they make about how to manage their land.

1. Oceanic Carbon Sequestration

Beneath the waves, an enormous and largely invisible process is constantly moving carbon out of reach of the atmosphere. Tiny marine organisms called phytoplankton absorb carbon dioxide near the surface through photosynthesis, just as land plants do. When they die or are eaten, much of that carbon sinks slowly toward the ocean floor as organic debris, often nicknamed "marine snow." Scientists call this the biological pump, and it transports billions of tonnes of carbon into the deep ocean every year, effectively taking it out of circulation for

centuries. Interestingly, cold, nutrient-rich waters, including those near the poles, tend to absorb far more carbon dioxide than warmer regions, making them disproportionately important carbon sinks. The catch is that this absorption comes at a cost: as oceans take up more carbon dioxide, their water becomes more acidic, creating serious challenges for shell-forming marine life.

2. *Terrestrial Carbon Sequestration*

- ***Soil System***

On land, soil captures carbon mainly in one of two forms. The first is soil organic carbon, built up from decomposing roots, residues, and microbial matter, the kind of carbon farmers can directly influence through their management choices. The second, less familiar form is inorganic carbon, stored as mineral carbonates. In arid and desert regions, carbon dioxide dissolved in water reacts with calcium and magnesium in the soil over thousands of years, forming a hardened mineral layer known as "caliche." While soil organic carbon typically survives a few decades before cycling back into the atmosphere, these carbonate minerals can lock carbon away for tens of thousands of years, making them one of the most durable, if slow-forming, carbon vaults nature has to offer.

- ***Forest System***

Forests are often held up as carbon superheroes, and rightly so; trees capture enormous amounts of carbon in wood, leaves, and roots. But forest carbon storage is more delicate than it looks. Large herbivores browsing through a forest can quietly shift the balance: selective feeding reduces plant biomass, trampling compacts the soil and squeezes out oxygen, and animal waste adds its own carbon dioxide back into the system. Under the wrong conditions, a forest that would otherwise be busily absorbing carbon can tip into releasing more than it stores, a reminder that even well-established ecosystems need to stay in ecological balance to keep functioning as sinks.

- ***Grassland System***

While forests tend to get the spotlight, grasslands and rangelands are proving to be surprisingly resilient carbon stores in their own right, particularly in regions increasingly hit by drought and wildfire. Unlike trees, grasslands keep most of their carbon below ground, in roots and soil rather than in above-ground wood and leaves. That turns out to be a major advantage during fires: when a grassland burns, the flames consume surface vegetation, but the carbon stored underground stays largely intact. Forests may have a higher overall storage capacity, but

as climate extremes make tree-based sinks less predictable, grasslands are emerging as a sturdier, if quieter, contributor to long-term carbon storage.

Geological Sequestration

If soil and forests are nature's way of storing carbon, geological sequestration is humanity's engineered answer to the same problem. The idea is refreshingly direct: catch carbon dioxide right where it's being produced a power plant chimney, a steel factory, a cement kiln before it ever reaches the atmosphere, then pump it deep underground where it can stay locked away for good. This approach goes by a more technical name in scientific circles: carbon capture and storage, or CCS.

The first (physical): the gas is simply contained within rock cavities, whether that's a vast natural pore space in a saline aquifer or a man-made cavern. Think of it as carbon dioxide being tucked into naturally occurring underground rooms, sealed in by layers of impermeable rock above.

The second (chemical): it involves carbon dioxide actually changing form. Depending on the underground conditions, carbon dioxide can dissolve into salty formation water or reservoir oil much like sugar dissolves in tea, break down into charged ionic particles, react with surrounding minerals to form solid, stable carbonate rock, or simply stick, through a process called adsorption, onto the surface of coal seams. That last mechanism is particularly elegant: carbon dioxide has a stronger natural attraction to coal than methane does, so when it's injected into a coal bed, it displaces the methane already sitting there and takes its place — occasionally even allowing that displaced methane to be captured and used as a resource.

Technological (Engineered) Sequestration

Not all carbon capture happens in soil or underground rock; some of the most exciting work is happening in labs, where scientists are asking a different question entirely: instead of just storing carbon dioxide, can we put it to work? This shift in thinking has opened up a handful of striking innovations. In one, carbon dioxide is used as a raw ingredient to manufacture graphene, the ultra-thin, ultra-strong material found in smartphone screens and other advanced electronics. It's still a niche application, limited to specific industries, but it offers a glimpse of a future where captured carbon isn't just buried and forgotten, but transformed into something genuinely useful.

Other approaches focus purely on capture, particularly the challenge of pulling carbon dioxide straight out of thin air. Direct air capture plants do exactly this, using specialised

technology to filter carbon dioxide from the atmosphere itself, rather than from a smokestack or factory. It's an appealingly simple idea, but at present it's also an expensive one, costing anywhere from $500 to $800 to remove a single tonne of carbon, a price tag that keeps it from being scaled up widely for now. A gentler, more targeted alternative comes from molecular engineering, where scientists design custom compounds that behave like highly specific chemical filters, built to seek out and latch onto carbon dioxide molecules and nothing else. Together, these technologies represent agriculture and industry's next frontier: not simply reducing emissions, but reimagining carbon dioxide as a raw material with a second life.

Methods by Which Carbon is locked in soil

Soil organic carbon builds up when the amount of carbon added to the soil, through roots, crop residues, manures, and microbial by-products, exceeds the amount lost through decomposition and erosion. Several mechanisms determine how long that carbon stays locked away.

- ✓ **Physical protection:** Carbon trapped inside soil aggregates, the small crumb-like clusters of soil particles, is shielded from the microbes and enzymes that would otherwise break it down.
- ✓ **Chemical stabilisation:** Organic molecules can bind tightly to clay particles and metal ions, forming complexes that resist microbial decomposition for long periods.
- ✓ **Biochemical recalcitrance:** Some organic compounds, such as lignin or the carbon in biochar, are inherently difficult for microbes to break down, allowing them to persist for very long durations.
- ✓ **Depth placement:** Carbon stored deeper in the soil profile is generally less exposed to oxygen, temperature swings, and disturbance, and therefore decomposes more slowly than carbon near the surface.

Turning Farms into Carbon Sinks

Agricultural soils across the world have lost a significant share of their original carbon stock due to decades of intensive tillage, residue burning, and monocropping. The encouraging part of this story is that the same land that lost carbon can be managed to regain much of it. A number of practices, many of them already familiar to Indian farmers in some form, have been shown to rebuild soil carbon while also improving yields and resilience to drought.

Practice	How it Locks Away Carbon
Zero / minimum tillage	Leaves soil structure undisturbed, slowing decomposition of organic matter and protecting carbon bound inside soil aggregates.
Cover cropping	Keeps living roots in the soil round the year, continuously feeding root exudates and biomass to soil microbes that build stable humus.
Agroforestry & shelterbelts	Trees fix atmospheric carbon into woody biomass and deep root systems while enriching topsoil with leaf litter.
Organic manuring / composting	Adds stable, humified carbon directly to the soil and improves aggregation, which physically shields carbon from microbial attack.
Biochar application	Converts crop residue into a highly stable, charcoal-like form of carbon that can persist in soil for centuries.
Integrated nutrient management	Balanced fertilisation boosts root and shoot biomass, increasing the amount of carbon returned to the soil each season.

Environmental Benefits of Carbon Sequestration

✓ A Brake on Global Warming

Of all the reasons to care about carbon sequestration, its role in slowing global warming is the most direct. Nature already does a remarkable share of this work on its own; roughly 45 per cent of the carbon dioxide humans emit is naturally absorbed by ecosystems, leaving the rest to accumulate in the atmosphere. That leftover carbon dioxide doesn't simply disperse harmlessly; it acts as a heat-trapping blanket around the planet, intensifying the greenhouse effect and pushing global temperatures upward. The downstream consequences are already familiar and well documented: more frequent droughts, shifting and often reduced rainfall, melting polar ice, rising sea levels, worsening floods, and, of direct concern to agriculture, declining crop productivity that threatens food security in vulnerable regions. Every tonne of carbon successfully sequestered is, in effect, a tonne kept out of this warming equation.

✓ Why Forests Remain Non-Negotiable

This is precisely why forests occupy such a central place in climate strategy. Trees and

other vegetation together capture around a quarter of global carbon emissions, making forests one of the planet's largest and most reliable natural carbon sinks. As the link between rising carbon dioxide and climate change has become impossible to ignore, protecting existing forest cover and actively promoting afforestation have moved from being purely conservation goals to recognised climate strategies in their own right. Maintaining and expanding forest cover keeps this carbon-capturing capacity intact, safeguarding environmental stability for both the near term and generations to come.

✓ **Calmer, Safer Oceans**

Carbon sequestration also has a quieter, less visible benefit playing out beneath the ocean's surface. The upper layer of the world's oceans absorbs close to 30 per cent of the carbon dioxide released from burning fossil fuels, a service that comes at a cost. As oceans take up more carbon dioxide, their waters grow steadily more acidic, making it harder for shell-forming marine organisms to build and maintain their protective structures. By capturing carbon before it ever reaches the ocean, sequestration efforts help ease this acidification pressure, protecting marine ecosystems and, in turn, the coastal communities and fisheries that depend on healthy seafood populations for their livelihoods.

✓ **Cutting Emissions at the Source**

Finally, technology is steadily closing the gap on emissions that can't be avoided outright. Continuing advances in carbon capture are making it increasingly possible to intercept carbon dioxide directly from coal-fired power plants and industrial smokestacks before it ever reaches the atmosphere, then store it safely deep underground or beneath the ocean floor. Alongside this, researchers are also refining carbon mineralisation techniques, which use specialised mineral catalysts to convert captured carbon dioxide into stable, rock-like carbonates, a way of locking carbon away not just temporarily, but for the very long term. Together, these advances show that reducing atmospheric carbon dioxide isn't only about prevention; it's increasingly about smarter, more permanent forms of cleanup as well.

Challenges on the Ground

Despite this promise, scaling up soil carbon sequestration is not without difficulty. Carbon gains built up over years of careful management can be lost quickly if tillage resumes or residues are burned, meaning the benefits are reversible unless practices are sustained. Measuring soil carbon accurately and cheaply across millions of small farm plots remains

technically challenging, which complicates efforts to verify and reward farmers for their contribution. Saturation is another concern: soils cannot absorb carbon indefinitely, and once a new equilibrium is reached, further gains slow considerably. Finally, many of these practices require an initial investment of time, labour, or money that smallholder farmers may find difficult to bear without institutional or policy support.

The Road Ahead

The future of carbon sequestration in agriculture will likely combine several threads at once: wider farmer adoption of conservation practices, better and cheaper soil carbon monitoring tools including remote sensing and modelling, carbon credit markets that fairly compensate farmers for verified carbon gains, and continued research into materials like biochar that can lock carbon away for centuries rather than years. As young soil scientists, this is a field where research still has enormous ground to cover, from refining regional carbon sequestration potential estimates to designing practices suited to the diverse agro-climatic zones of India.Carbon sequestration is, in the end, a reminder of something soil scientists have always known: that the ground beneath our feet is not an inert backdrop to farming, but a living, breathing system capable of shaping the future of our climate.

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HARMFUL CONSEQUENCES OF CARBIDE RIPENING IN MANGOES

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Introduction

Artificial ripening of fruits such as mango, banana, and sapota has been widely practiced for commercial purposes for many years. In order to obtain better market prices and supply fruits early to consumers, some farmers and traders harvest mangoes before they reach full maturity and induce ripening artificially using calcium carbide. During transportation to distant markets, packets of calcium carbide are often placed along with unripe fruits to accelerate the ripening process.

However, the use of calcium carbide adversely affects both fruit quality and consumer health. Fruits harvested before proper maturity do not develop their natural flavour, sweetness, aroma, and nutritional quality. Although the outer peel of such mangoes may turn yellow and appear attractive, the inner pulp often remains unripe, hard, fibrous, and sour. As a result, consumers are misled by the external appearance while receiving fruits of inferior quality.

Calcium carbide becomes highly dangerous when it comes into contact with atmospheric moisture, as it releases acetylene gas. This gas may contain toxic impurities such as phosphine and arsine, which are harmful to human health. Consumption of fruits ripened using calcium carbide can lead to several serious health problems including mouth ulcers, stomach irritation, liver dysfunction, kidney disorders, and even cancer upon prolonged exposure. In addition, inhalation of acetylene gas can adversely affect the central nervous system, causing symptoms such as headache, dizziness, weakness, confusion, memory loss, and in severe cases prolonged unconsciousness or coma.

Considering the severe health hazards associated with its use, both the Central and State Governments have banned the use of calcium carbide for artificial ripening of fruits. As per G.O. Rt. No. 288 dated 19-03-2012, the practice is strictly prohibited.

Further, under the Prevention of Food Adulteration (PFA) Act, 1954 and the Prevention of Food Adulteration Rules, 1955, Rule 44(AA), the use of calcium carbide for ripening fruits is illegal. Any individual found violating these regulations is liable for punishment, including imprisonment up to three years along with a monetary fine.

Therefore, farmers, traders, and consumers should promote and adopt safe and scientific ripening methods such as ethylene-based ripening chambers, which ensure better fruit quality and protect public health.

Differences Between Carbide Ripened Mangoes and Ethylene Ripened Mangoes

S. No.	Particulars	Carbide Ripened Mangoes	Ethylene Ripened Mangoes
1	Appearance	Fruits ripen unevenly with patchy yellow and green colour. The outer peel may appear attractive, but the inner pulp often remains unripe and hard.	Fruits ripen uniformly with a natural golden-yellow colour similar to naturally ripened mangoes. The pulp develops properly and evenly
2	Aroma	Produces an unpleasant or chemical-like smell due to the release of acetylene gas and impurities. Such fruits may also cause health discomfort.	Develops a pleasant natural aroma and flavour, making the fruits more appealing and acceptable to consumers.
3	Taste	Fruits are generally sour, less juicy, fibrous, and lack natural sweetness because they are harvested before maturity.	Fruits become naturally sweet, juicy, and tasty as ripening occurs gradually under controlled conditions.
4	Shelf Life	Shelf life is very short. Fruits usually spoil within 2–3 days	Fruits have comparatively longer shelf life and maintain

		after ripening due to improper physiological development.	better quality during storage and marketing
5	Sugar Content	Sugar accumulation is poor, and fruits contain about 10–13% lower sugar content than naturally ripened fruits.	Sugar development is better, and fruits show only about 7–10% reduction in sugar content compared to naturally ripened fruits.
6	Safety	Harmful to human health. Calcium carbide may contain toxic impurities such as arsenic and phosphorus compounds that can cause ulcers, neurological disorders, kidney and liver damage.	Comparatively safer when recommended concentrations of ethylene are used. Ethylene is a natural plant hormone involved in the normal ripening process.
7	Cost of Ripening	Cost may become higher due to fruit spoilage, health risks, and legal restrictions associated with calcium carbide use.	More economical and profitable because of better fruit quality, reduced wastage, and consumer acceptance.

Precautions While Ripening Mangoes with Ethylene

Ethylene is a natural plant hormone that plays an important role in the ripening of climacteric fruits such as mango, banana, and sapota. Ripening mangoes with ethylene is considered a safe, scientific, and eco-friendly method when compared to harmful chemicals like calcium carbide. Proper use of ethylene not only improves fruit quality but also ensures consumer safety and environmental protection.

For safe ripening, mangoes should be ripened either in scientifically designed ethylene ripening chambers or by using naturally produced ethylene under controlled conditions. The use of approved ethylene-based ripening technology helps in achieving uniform colour development, better flavour, improved sweetness, and enhanced market quality.

During ripening, mangoes are generally exposed to ethylene gas at a concentration of 100–150 ppm inside ripening chambers. The chambers should be maintained at an optimum

temperature of 12–24°C along with proper ventilation and humidity management. Under these controlled conditions, mangoes ripen uniformly within 4–5 days without affecting their internal quality.

After completion of ripening, the fruits should preferably be packed in paper covers or paper-based packaging materials. Paper covers help absorb excess moisture nearly three times more effectively, thereby reducing fungal growth, minimizing spoilage, and extending shelf life during storage and transportation.

Important Precautions

- Only mature and healthy mangoes should be selected for ripening.
- Damaged, diseased, or immature fruits should be removed before storage in ripening chambers.
- Recommended ethylene concentration should not be exceeded.
- Proper temperature and humidity should be maintained throughout the ripening period.
- Adequate air circulation should be ensured inside the chamber for uniform ripening.
- Fruits should never be ripened using calcium carbide or other harmful chemicals.
- Ripened fruits should be stored and transported carefully to avoid bruising and post-harvest losses.

Conclusion

Ethylene ripening is a safe, scientific, and government-approved technology for ripening mangoes, which helps produce fruits with superior quality, better flavour, attractive appearance, uniform ripening, and extended shelf life. The adoption of recommended ethylene ripening methods not only safeguards consumer health but also minimizes post-harvest losses and supports environmentally sustainable fruit handling and marketing practices.

On the other hand, ripening mangoes with calcium carbide adversely affects fruit quality and poses serious health risks to consumers. Carbide-ripened fruits often develop poor taste, uneven ripening, and reduced storage life. Therefore, farmers, traders, and fruit handlers should strictly avoid the use of calcium carbide and instead adopt approved ethylene-based ripening techniques for the safe production, handling, and marketing of quality mangoes.

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PRECISION FERMENTATION: THE FUTURE OF SUSTAINABLE FOOD PRODUCTION

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Introduction

Imagine a world where your morning glass of milk never came from a cow, where the cheese on your pizza was grown in a steel tank, and where the egg white in your cake batter was brewed rather than laid. This is not science fiction anymore. It is happening right now, quietly, in fermentation tanks across the world, through a technology called precision fermentation. For most of us, the word fermentation brings to mind idli batter, curd, or perhaps a bottle of wine. We know it as an old, comforting process, something our grandmothers understood long before scientists gave it a name. Precision fermentation takes this ancient art and gives it a modern, exact twist. Instead of letting microbes ferment sugars into alcohol or acid the way they naturally would, scientists now program microorganisms, usually yeast or bacteria, to produce a very specific protein or molecule that we want. The microbe becomes a tiny, living factory, brewing exactly what is asked of it, nothing more and nothing less.

What Exactly Is Precision Fermentation

Fermentation itself is nothing new. Humans have used yeast and bacteria for thousands of years to make bread, curd, idli batter, and wine. Precision fermentation takes this ancient biological process and gives it a modern, molecular upgrade. Instead of relying on microbes to simply convert sugars into alcohol or acid, scientists genetically engineer microorganisms such as yeast, fungi, or bacteria to act as microscopic factories that produce one specific, high value molecule.

That molecule could be a milk protein like whey or casein, an egg protein like ovalbumin, a fat, a vitamin, an enzyme, or even the heme protein that gives plant based burgers

their meaty taste. The engineered microbe is grown in a bioreactor, much like beer is brewed, and the target molecule is harvested and purified afterward. In essence, precision fermentation separates the nutrient we want from the animal we traditionally needed to get it.

How Does It Actually Work

The process begins with identifying the gene responsible for a particular protein we are interested in. This could be the gene that makes whey protein in milk, or the gene that produces heme, the molecule that gives meat its bloody, savoury flavour. Scientists insert this gene into a host microorganism, often a common and well studied yeast strain. Once inserted, the yeast is placed in a fermentation tank along with sugar, water, and a few nutrients. As the yeast multiplies, it starts expressing the inserted gene and producing the desired protein, almost like a factory assembly line, except the workers are microscopic and the raw material is sugar rather than steel. Once the fermentation is complete, the protein is separated, purified, and used as an ingredient in food products. The rest of the process, from there, is much like any other food manufacturing step. What makes this different from traditional fermentation is precisely this element of control. Farmers ferment food to preserve it or change its flavour, letting nature do most of the work. Precision fermentation, on the other hand, is engineered from the very first step to produce one exact molecule, in a way that is repeatable, scalable, and consistent every single time.

Why the World Is Turning to This Idea

Our food systems today face a genuine crisis of scale. The global population is expected to cross nine billion by 2050, and with it comes a growing appetite for protein, especially dairy and meat products. Traditional animal farming, however, is resource hungry. It takes enormous amounts of land, water, and feed to raise livestock, and the methane emissions from cattle alone are a significant contributor to climate change. Dairy farming, while central to rural livelihoods in a country like India, also faces pressures from land scarcity, water stress, and the ethical questions increasingly being raised around animal welfare. Precision fermentation offers an alternative path. Producing whey protein through fermentation, for instance, requires a fraction of the land and water compared to raising a dairy herd, and it can be done in urban or semi-urban facilities rather than sprawling farmland. Because the process happens in controlled tanks, it is also far less vulnerable to droughts disease outbreaks, or seasonal disruptions that regularly

affect conventional agriculture. For a country that experiences erratic monsoons and periodic livestock disease outbreaks, this kind of resilience is not a luxury, it is a necessity.

Comparing the Footprint

Parameter	Conventional Dairy	Precision Fermentation
Land use	Very high (pasture and fodder)	Minimal (bioreactor footprint only)
Water use	High	Substantially lower
Greenhouse gases	High methane and CO2 output	Much lower, mainly from energy use
Production time	Months to years	Days
Disease risk	Vulnerable to livestock outbreaks	Contained, controlled environment

Real Products Already on Shelves

This is not merely a laboratory promise. Companies around the world have already brought precision fermented products to market. Whey protein made without a single cow has been used in ice creams and protein shakes. Egg white proteins produced through fermentation are being tested in baked goods. Heme, the molecule responsible for the meaty taste and aroma in plant based burgers, is produced using precision fermentation and has become one of the most talked about ingredients in the alternative protein industry. Even rennet, the enzyme traditionally extracted from a calf's stomach to make cheese, is now largely produced through fermentation, a change that has quietly transformed the cheese industry over the past few decades without most consumers ever noticing.

What This Means for Indian Agriculture

For students and researchers in agricultural biotechnology, precision fermentation opens up a genuinely exciting frontier. India has a strong base in fermentation technology already, built over decades of expertise in producing enzymes, antibiotics, and vaccines through microbial fermentation. Extending this expertise toward food proteins is a natural next step, and one that fits well within the country's existing biotechnology and biomanufacturing capacity. There is also a meaningful opportunity here for seaweed and marine biomass to enter the picture, since certain algal and seaweed derived sugars can serve as low cost feedstock for fermentation, turning coastal biomass that is otherwise underutilised into a genuine input for next generation

food production. This kind of thinking, connecting India's rich coastal resources with cutting edge fermentation technology, could allow the country to build a sustainable protein industry that does not depend entirely on imported technology or feedstock. At the same time, questions around affordability, regulatory approval, and consumer acceptance remain very real. Precision fermented proteins are currently more expensive to produce than their conventional counterparts, largely because the technology is still young and the infrastructure is still being built out. Regulatory frameworks in India and across much of the world are also still catching up with this new category of food, working out how to classify and approve products that are neither purely plant based nor animal derived in the traditional sense.

The Science Behind the Microbial Factories

At the heart of precision fermentation lies a deceptively simple genetic engineering principle: identify, insert, and express. Scientists first isolate the gene sequence coding for the target protein, often from an animal genome, and then optimise its codon usage so that the chosen microbial host can read and translate it efficiently. This optimised gene, along with promoter and terminator sequences that switch expression on and regulate its level, is assembled into an expression vector and introduced into the host cell through transformation.

Saccharomyces cerevisiae, the same yeast used in bread and beer making for millennia, remains the most popular chassis organism because its genetics are extremely well understood, it grows quickly, and it is already recognised as safe for food use by regulators in many countries. Filamentous fungi such as *Trichoderma reesei* are favoured when very high protein yields are required, since they naturally secrete large quantities of protein into their growth medium, simplifying downstream purification considerably. Bacterial hosts such as *Escherichia coli* are used for smaller molecules like vitamins and certain enzymes, though extra purification steps are usually needed to remove bacterial endotoxins before the product is food safe.

Once engineered, these microbial strains are grown in bioreactors ranging from a few litres in a research laboratory to hundreds of thousands of litres in an industrial facility. Precise control over temperature, pH, dissolved oxygen, and nutrient feeding ensures that the microbes remain healthy and productive throughout the fermentation cycle, which typically lasts anywhere from two to seven days depending on the organism and target molecule. This tight process control is what gives the technology its name, precision fermentation, distinguishing it from traditional, less controlled fermentation practices.

From Bioreactor to Consumer: The Downstream Journey

Producing the target molecule is only half the story. After fermentation is complete, the microbial cells and the surrounding liquid, called the fermentation broth, must be processed to isolate a pure, food grade ingredient. This downstream processing typically involves separating the cells from the liquid through centrifugation or filtration, followed by a series of purification steps such as chromatography, ultrafiltration, and precipitation to isolate the target protein from thousands of other cellular components.

The purified protein is then tested extensively for safety, purity, and functional properties before it is dried into a stable powder or concentrated liquid form suitable for use as a food ingredient. This purified ingredient can then be blended with plant based fats, sugars, minerals, and flavourings to recreate the taste, texture, and nutritional profile of the original animal derived product. The entire journey, from a single engineered cell to a finished food ingredient, can take as little as one to two weeks, compared to the months or years required to raise livestock.

Regulatory Landscape and Food Safety

Because precision fermentation involves genetically engineered microorganisms, regulatory scrutiny is understandably rigorous. In most jurisdictions, the finished protein or ingredient is assessed rather than the microorganism itself, since the engineered microbe is typically removed during purification and does not end up in the final product. Regulatory bodies evaluate the purified ingredient for compositional equivalence to its conventional counterpart, checking that it is free from allergenic residues, toxins, or unintended by products.

such as the United States, Singapore, and several members of the European Union have already approved multiple precision fermentation derived ingredients for commercial sale, including whey protein and heme. In India, the Food Safety and Standards Authority of India, along with the Genetic Engineering Appraisal Committee, would be the relevant bodies overseeing the approval of such novel food ingredients, an area of law and biosafety that is still evolving as the technology matures globally.

Conclusion

Precision fermentation will not single handedly solve global food insecurity or reverse climate change, but it represents a meaningful and increasingly practical piece of the puzzle. By decoupling the production of essential proteins and nutrients from the land, water, and emissions intensive practices of conventional animal agriculture, it offers a genuinely sustainable path

forward, one bioreactor at a time. As the technology matures and costs fall, the food on our plates a decade from now may look remarkably familiar, even though the way it was made will have changed entirely

A Quiet Revolution Worth Watching

Precision fermentation will not replace traditional farming overnight, and it should not be seen as an enemy of the dairy farmer or the livestock owner. Rather, it represents an additional tool, one that can ease the pressure on land and water while meeting the protein demands of a growing population. As research continues and costs come down, it is likely that ingredients made this way will become an increasingly ordinary part of our food, much like how fermented soy sauce or vinegar became household staples over centuries, except this time the journey from laboratory to kitchen table is happening within a single generation rather than several. The next time someone tells you their protein shake or ice cream was brewed rather than milked, do not be surprised. The microbes have been doing this work for thousands of years already. We have simply learned, at last, to ask them for exactly what we need.

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MICROPROPAGATION: FAST-TRACK MULTIPLICATION OF ELITE CROPS

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Introduction

Imagine a economically important plant is in a vulnerable situation to become extinct, and a last piece of it growing in a dense forest. Is there any possibilities to save this last piece of plant and prevent it from extinction? Is it believable that from this single piece thousands of healthy, uniform plants can be regenerated in a year. Isn't it amazing, yet this can be achieved through a **micropropagation**, a modern technology in plant tissue culture. As the world today faces lots of biodiversity issues due to human activities (like deforestation, natural habitat destruction, overexploitation of natural resources etc..) which affects the agriculture. The demand for quality planting material is of serious concern, so micropropagation is one of best solution for fast and reliable method of multiplying elite crop varieties. From this technique **1,80,000 sugarcane plantlets** can be produced in a **single year**, such a remarkable technique right?

DID YOU KNOW ?

Shikonin, a famous vegetable dye that produces colour from red to blue was the first plant chemical that was produced on a commercial scale using plant tissue culture back in the 1970s

"Through modern micropropagation, science has found a way to not just cultivate, but to conserve the fragile green blueprints of our planet."

WHAT IS MICROPROPAGATION?

Clonal propagation of genetically identical individual by asexual method from somatic tissue or organ. **Micropropagation** is a technique in plant tissue culture wherein rapid multiplication of plant tissue which is undergone in a sterile condition using a suitable nutrient medium and maintained under a controlled environment. The small plant tissue which is used as a starting material is called as **explant**. Shoot tip, root tip, axillary bud, meristem, node, leaf, embryo, endosperm, anther, ovary, ovule etc can be used as a explant. It is a botanical cloning process that multiplies a single super plant into thousands of exact, disease free twins. The explants are cultured in a nutrient rich medium containing macronutrients, micronutrients, vitamins, sugars, growth regulators in a particular concentration. A single tissue develop into a whole plant when placed in a controlled condition of temperature, relative humidity and light. In vitro multiplication of plants – micropropagation because of miniaturization it has become an industrial technology and is adopted word wide to regenerate orchids, ornamentals, medicinal, fruits and tree crops.

TOTIPOTENCY:

"ONE TINY CELL CREATES AN ENTIRE GREEN WORLD"

Micropropagation is based on a basic principle called as **totipotency** – potential ability of a single cell of plant to divide and grow into a complete new plant. This unique property forms the foundation of plant tissue culture and modern biotechnology. It demonstrates one of the nature's most fascinating principles: **every living plant cell carries the complete genetic blueprint needed to create an entire plant.**

STAGES OF MICROPROPAGATION:

Micropropagation of a plant cell involves five stages:

Stage 0 – It is **preparatory stage**, where a small, clean, healthy explants are collected. These explants are sterilized to remove the pathogens that could contaminate the growth.

Stage 1 **– Initiation of aseptic cultures**. The collected explants are surface sterilized. Transfer of plant tissue (root, shoot, node, leaf, meristem etc) into a suitable nutrient rich medium for further division and growth. The objective of this stage is to establish a contamination free culture.

Stage 2 – **Multiplication of shoots**. The multiple axillary shoots formed are repeatedly subcultured in a cytokinin rich medium to increase the plant count exponentially.

Stage 3 – **Rooting** of in vitro formed shoots. The shoots formed are separated and placed in rooting media rich in auxin like IAA, IBA for root formation. Adventitious roots develop, producing complete plantlet capable of independent growth.

Stage 4 – **Acclimatization**. The process of transfer of in vitro regenerated plants to greenhouse condition or field condition to expose the micropropagated plant to natural environment.

STEPS IN MICROPROPAGATION:

1. **SELECTION OF ELITE MOTHER PLANT:**

Mother plant with desirable character such as high yield, superior quality, and disease resistance are selected. An explant is excised from this mother plant.

2. **EXPLANT STERILIZATION:**

The collected explants are washed in running water to remove dust and dirt. The explants are treated with fungicide like Bavistin to remove microorganisms. The explants are taken to a sterile workspace (laminar air flow chamber) and are surface sterilized with 0.1 % mercuric chloride or 0.6 % sodium hypochlorite for 15 minutes with intermittent stirring. Then rinse the tissue with 70 % ethanol and then wash the tissue with distilled water for 3 – 4 times.

3. **CULTURE ESTABLISHMENT:**

The sterilized explant are inoculated on a culture tube with suitable nutrient medium using forceps.

4. **INCUBATION:**

The culture tubes are incubated in a culture room with controlled environment (25^0 C Temperature, 90-95 % Relative humidity and 2000 lux light with 16 hours light and 8 hours dark condition)

5. **SHOOT MULTIPLICATION:**

After 3-4 weeks of incubation multiple shoots will be developed. These shoots are repeatedly subcultured in cytokinin rich medium to increase the count.

6. **ROOT INDUCTION:**

The multiple shoots are separated and placed in a rooting medium rich in auxin like IBA for vigorous and healthy root formation.

7. **HARDENING:**

The in vitro developed plants are transferred from lab condition to greenhouse or field condition through primary and secondary hardening. Hardening is done to expose the

regenerated plant to natural environment to shift the heterotrophic mode of nutrition to autotrophic mode.

Each step require careful monitoring to ensure healthy plant development.

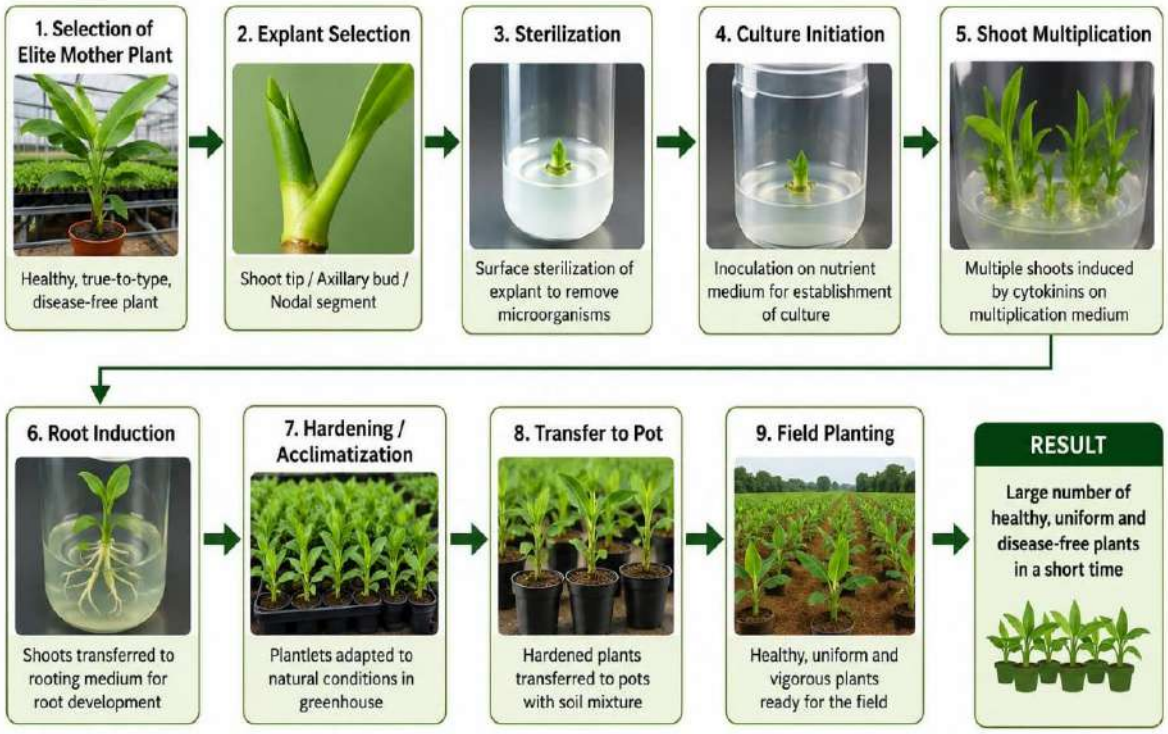
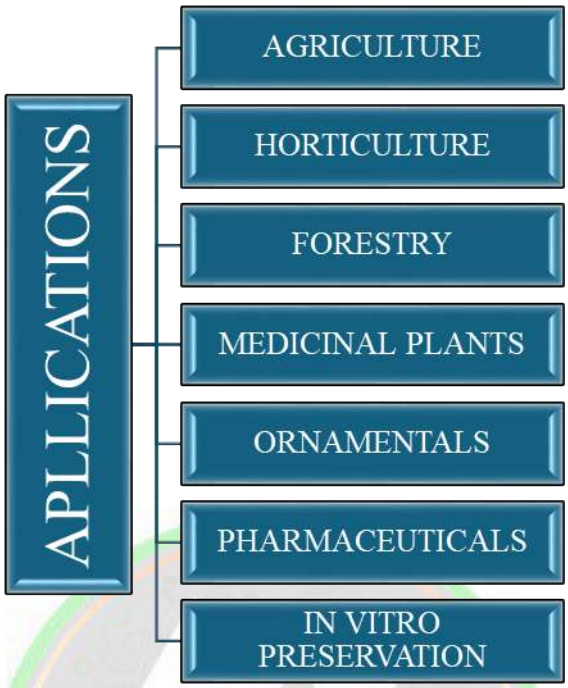


Figure 2. Steps involved in micropropagation

ADVANTAGES OF MICROPROPAGATION:

1. In short time large number of plants can be regenerated from a single tissue
2. A very small piece of plant tissue is enough to initiate aseptic culture.
3. Rate of multiplication in vitro is much faster than in vivo method of propagation
4. It is impossible in plants in which in vivo propagation is difficult or impossible.
5. Year round production is possible.
6. Virus or disease free planting material can be obtained, so planting material can be exported without any quarantine problem.
7. In vitro production can be better planned by storing the cultures at low temperature in the season of low market demand.
8. Micropropagated plants acquire new desirable traits.
9. Quick dissemination of newly released varieties to farmers.
10. Conservation and multiplication of endangered species.

11. Genetic stability can be maintained.



CONVENTIONAL VS. MICROPROPAGATION: FROM SOIL TO SCIENCE—THE EVOLUTION OF PLANT PROPAGATION

FEATURE	CONVENTIONAL	MICROPROPAGATION
Propagation method	Cutting, grafting, seed	Small plant tissue (explant)
Condition of growth	field	laboratory
Multiplication rate	Slow	Very rapid
Time required	Less number of plants in Several Months to years	Large number of plants in few months
Genetic uniformity	Show variation (especially seed)	True to type
Seasonal dependance	Season bound	Throughout the year
Disease status	Spread through planting material	Virus and disease free plants can be produced
Cost	Lower initial investment	Higher initial investment

CHALLENGES:

Despite of these advantages there are limitations in this technology. Establishing tissue culture laboratories require high investment and skilled personnel. Sterile condition should be maintained throughout the production process to prevent from contamination. Some species are difficult to culture and improper culturing of these species leads to genetic variation. Proper hardening and environment condition should be maintained for successful regeneration.

Conclusion

Micropropagation has brought up new revolution in the field of agriculture through rapid multiplication of elite crop varieties while ensuring genetic uniformity and plant health. It bridges the gap between scientific innovation and practical farming by providing high quality planting material that boosts productivity and farm income. As demand for quality planting material rises, micropropagation remain as a cornerstone of sustainable agriculture and an essential tool for ensuring food security by producing more in shorter time.

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SEED PRIMING IN VEGETABLE CROPS

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Abstract

Seed priming is a pre-sowing technique that controls seed hydration to initiate pre-germinative metabolic activity without permitting radicle emergence. It significantly enhances germination rate, seedling vigour, uniformity of establishment, stress tolerance, and ultimately crop yield. Seed priming is defined as controlled hydration of seeds to a level that allows pre-germinative metabolic activity to proceed while preventing actual radicle emergence.

Introduction

Good quality seed is the most critical input for crop establishment. The *Manu Smriti* affirms this with "*Subeejam Sukshetre Jayate Sampadyathe*", meaning good seed in good soil yields abundantly. Germination, the foundation of crop production, proceeds through three stages: imbibition, activation (lag phase), and radicle emergence. Rapid germination promotes leaf expansion, root development, nutrient uptake, and biomass production, while poor germination reduces vigour and causes economic losses.

Seed priming is defined as controlled hydration of seeds to a level that allows pre-germinative metabolic activity to proceed while preventing actual radicle emergence. At the cellular level, priming triggers membrane repair, DNA/RNA synthesis, embryo development, endosperm modification, dormancy breakage, and pre-germination metabolism. As a result, primed seeds show faster and more uniform germination, better growth attributes, quicker emergence, and stronger stand establishment (Farooq *et al.*, 2007).

History of Seed Priming

The evolution of seed priming spans centuries of agricultural knowledge:

- Theophrastus (372–287 BC) recommended soaking cucumber seeds in milk or water for earlier, more vigorous germination (Evenari, 1984).
- Roman farmers pre-hydrated legume seeds to increase germination rate and synchronize emergence.
- Plant hormones role in seed physiology was discovered in the 1920s (Lutts *et al.*, 2016).
- Heydecker coined the term "seed priming" and demonstrated its benefit for germination under stressful conditions.

Need and Objectives of Seed Priming

The need for seed priming arises from challenges including erratic rainfall, soil salinity, temperature extremes, deteriorating seed quality, and increasing global food demand. The primary objectives are:

- Faster and improved germination under field conditions.
- Ensuring adequate food security for the world's growing population.
- Achieving successful crop establishment in diverse and stressful environments.
- Serving as an invigoration technique to improve germination uniformity across seed lots.

Factors Affecting Seed Priming

The efficacy of seed priming depends on several interacting factors:

- **Priming agent:** Type and concentration of the soaking solution (water, salts, sugars, hormones, or biostimulants) affects metabolism, membrane stability, enzyme activity, and gene expression.
- **Priming duration:** Too short a period gives insufficient benefit; too long causes nutrient leaching, membrane damage, or premature germination. In pepper, 6-day PEG priming gave fastest germination but 60% abnormal seedlings vs. 0% at 4 days.
- **Priming temperature:** Higher temperatures accelerate priming effects but increase risk of seed damage; optimal temperature varies by crop species.
- **Aeration:** Adequate oxygen supports aerobic respiration and ATP production; excessive aeration causes oxidative stress. Aerated PEG priming improved onion germination (Bujalski *et al.*, 1989).

- **Seed condition:** Seed size, maturity, moisture content, dormancy, vigour, and health all influence the response to priming treatment.

Methods of Seed Priming

- **Hydropriming:** Simple, low-cost, eco-friendly; seeds soaked in pure water then re-dried. Improves water uptake efficiency and initiates early metabolic phases without chemicals.
- **Halopriming:** Seeds soaked in inorganic salt solutions (NaCl, KNO_3, $CaCl_2$, $CaSO_4$). KNO_3 (5%) and NaCl (5%) enhanced seedling vigour in tomato (Venkatasubramanian & Umarani, 2007); 150 ppm KNO_3 improved onion germination.
- **Osmopriming:** Seeds soaked in osmotic solutions (PEG, mannitol, sorbitol, glycerol) at -1 to -2 MPa water potential. Allows slow imbibition and early germination stages while preventing radicle protrusion. PEG significantly enhanced soybean emergence and yield (Arif *et al.*, 2008).
- **Biopriming:** Combines seed hydration with inoculation of beneficial microorganisms (*Bacillus spp., Pseudomonas spp., Trichoderma spp.*) for growth promotion and disease suppression. Pumpkin seeds bioprimed with Azospirillum + Phosphobacteria + *P. fluorescens* showed improved yield and quality.
- **Hormonal priming:** Treatment with hormones (GA3, auxins, cytokinins, salicylic acid, polyamines) to break dormancy and enhance cell division, elongation, and differentiation. KNO_3 improves yield and fruit quality in vegetable crops.
- **Solid matrix priming (SMP):** Seeds incubated with a moist insoluble matrix (vermiculite, peat moss, diatomaceous earth) allowing slow, controlled imbibition. A cost-effective alternative to osmopriming with better aeration (Paparella *et al.*, 2015).
- **Nutrient priming:** Seeds soaked in macro/micronutrient solutions (zinc, phosphorus, boron, manganese) to boost germination, seedling resilience, and stress tolerance while supporting protein synthesis and cell elongation.
- **Nanopriming:** Emerging technique using nanoparticles (<100 nm: AgNPs, ZnNPs, TiO_2NPs, carbon nanotubes) to enhance water/nutrient uptake, antioxidant activity, photosynthetic efficiency, and stress tolerance (Johnson & Puthur, 2021).

Application in Vegetable Crops

The table below summarizes priming applications and benefits documented across major vegetable crops (Srivastava *et al.*, 2022):

S.No.	Crop	Priming Type	Key Advantage
1.	Okra	Hydro / Bio-priming	Rapid, uniform germination; improved stem length and diameter.
2.	Onion	Hydro / Halopriming (NaCl)	Shorter germination duration; enhanced germination %.
3.	Tomato	GA3 / Hydropriming	Improved vigour and viability; germination up by 30.56%.
4.	Cherry Tomato	KNO3	Better antioxidant ability; improved osmotic stress tolerance.
5.	Vegetable Pea	Hormonal / Halo-priming	Better seedling growth, chlorophyll, relative water content.
6.	Chilli	Osmopriming /][Hydropriming	Reduced pathogens; uniform germination.
7.	Brinjal	Osmopriming	Higher fruit yield, more leaves, reduced days to flowering.
8.	Capsicum	Osmo / Solid matrix	Improved germination over non-primed seeds.
9.	Cowpea	Osmopriming	Maintained water content; enhanced antioxidant activity.
10.	Carrot	Osmopriming (PEG)	Increased germination rate.
11.	Radish	Osmopriming (KNO3)	Improved seed quality parameters.
12.	Tomato	Nanopriming (ZnO+TiO2)	Increased germination; promoted ROS scavengers (SOD, POD, CAT).

Limitations

Standardization difficulty: Optimal priming conditions (duration, concentration, temperature) vary greatly across crop species and seed lots, making universal protocols difficult.

Reduced shelf life: Primed seeds have a shorter storage life than non-primed seeds as pre-germinative metabolism has already begun; handling and transport must be carefully managed.

- **Risk of over-priming:** Excessive treatment causes membrane deterioration, nutrient leaching, and premature radicle protrusion before sowing.
- **Species specificity:** A priming treatment beneficial for one crop may be ineffective or harmful for another, requiring crop-specific optimization.
- **Scale-up challenges:** Commercial-scale priming using osmotic agents or biological inoculants requires specialized equipment and quality control systems.

Conclusion and Future Prospects

Seed priming is a versatile, scientifically validated, and cost-accessible pre-sowing technique that controls seed hydration and regulates the metabolic activity needed for germination. It encompasses chemical, physical, biological, and nanotechnological approaches, each suited to particular crops and environments. Seed priming not only improves uniform germination across diverse vegetable crops under non-supporting conditions but also reduces soil-borne and seed-borne diseases, offering dual agronomic and phytosanitary benefits. As global food demand intensifies and climate becomes increasingly unpredictable, the adoption of appropriate seed priming technologies offers a practical, low-cost, high-impact pathway to sustainable vegetable production and food security.

Future developments in seed priming focus on novel materials and approaches including endophytes, biostimulants, biochar, and nanoparticles, offering improved nutrient uptake, disease resistance, and soil health benefits. Integration of priming with sustainable practices like crop rotation, intercropping, and organic farming will further enhance food security. As climate change intensifies drought, heat, and salinity stresses, priming techniques that build stress tolerance will become indispensable. Research into molecular mechanisms of priming-induced stress memory and epigenetic regulation opens further transformative possibilities. AI-assisted optimization of priming protocols across diverse crops and environments is another promising frontier.

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ROLE OF BACTERIOCIN IN DISEASE DIAGNOSIS

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Abstract

Bacteriocins are ribosomally synthesized antimicrobial peptides produced by bacteria that exhibit potent and highly specific activity against closely related or pathogenic microorganisms. Beyond their well-established role in food preservation and antimicrobial therapy, bacteriocins have emerged as promising tools in disease diagnosis owing to their target specificity, rapid binding kinetics, and compatibility with modern biosensing technologies. This review highlights the classification, structural diversity, and mechanisms of action of bacteriocins, emphasizing their ability to recognize specific bacterial receptors and biomarkers. Recent advances demonstrate their application in the diagnosis of infectious diseases, including *Staphylococcus aureus*, *Listeria monocytogenes*, *Mycobacterium tuberculosis*, and uropathogenic *Escherichia coli*, through biosensors, microfluidic platforms, and molecular detection systems. Furthermore, alterations in bacteriocin-producing microbial communities have been associated with microbiome dysbiosis, inflammatory bowel disease, colorectal cancer, and other chronic disorders, suggesting their potential as non-invasive biomarkers for disease monitoring and early diagnosis. The integration of bacteriocin-based probes with nanotechnology, genomics, and point-of-care diagnostic platforms offers improved sensitivity, specificity, and reduced turnaround time compared with conventional diagnostic methods. Despite challenges related to stability, standardization, and clinical validation, bacteriocins represent a promising next-

generation diagnostic approach with broad applications in precision medicine and personalized healthcare. Continued research and technological advancements are expected to accelerate their translation from experimental studies to routine clinical diagnostics.

Introduction

The discovery of antibiotics in the twentieth century fundamentally transformed medicine by providing clinicians with potent weapons against infectious diseases. However, decades of overuse and misuse have driven the emergence of **multidrug-resistant (MDR)** bacterial strains, which the **World Health Organization (WHO)** now classifies as one of the gravest threats to global public health. In parallel, diagnostic medicine faces its own crisis: delays in identifying causative pathogens, lack of sensitivity in conventional culture-based methods, and the rising prevalence of polymicrobial and opportunistic infections challenge the speed and accuracy of clinical decision-making.The scope of bacteriocin-based diagnostics extends well beyond infectious disease. Emerging evidence implicates dysregulated bacteriocin production in inflammatory bowel disease, colorectal cancer, neurodegenerative disorders linked to gut dysbiosis, and systemic inflammatory syndromes. The microbiome, now understood as a central orchestrator of health and disease, produces a complex network of bacteriocins that serve as regulatory signals. Mapping this bacteriocinome, as some researchers have termed it, may provide a new landscape of biomarkers for disease states that were previously accessible only through invasive or complex diagnostic modalities.

MILESTONES IN BACTERIOCIN RESEARCH:

Year	Milestone	Significance
1925	Discovery of colicin by Gratia	First identification of a bactericidal substance from bacteria
1953	Term 'bacteriocin' coined	Formal classification framework established
1969	Nisin approved by FAO/WHO	First commercial bacteriocin application; food safety benchmark
1988	Lantibiotic classification proposed	Distinguished post-translationally modified bacteriocins

2005	BAGEL tool development	Bioinformatic mining of bacteriocin gene clusters
2013	Microbiome bacteriocinome described	Diagnostic and ecological significance of human-associated bacteriocins
2020+	Bacteriocin-based biosensors	Integration into point-of-care diagnostic platforms for pathogen detection

CLASSIFICATION AND STRUCTURAL DIVERSITY OF BACTERIOCINS:

Bacteriocins are classified according to their producing organisms, molecular characteristics, mode of action, and post-translational modifications. The most widely accepted classification system, initially proposed by Klaenhammer (1993) and subsequently refined by Cotter, Ross, and Hill (2005) and others, divides bacteriocins into major classes, particularly for those produced by Gram-positive bacteria, especially lactic acid bacteria.

Class I: Lantibiotics:

Lantibiotics (lanthionine-containing antibiotics) are small peptides, typically less than 5 kDa, characterized by the presence of unusual amino acids generated through extensive post-translational modifications. These include lanthionine (Lan), methyllanthionine (MeLan), dehydrobutyrine (Dhb), and dehydroalanine (Dha). Nisin (produced by *L. lactis*), mersacidin (*Bacillus sp.*), actagardine, and lacticin 3147 are prominent examples. Lantibiotics are further subdivided into Type A (elongated, amphipathic, pore-forming, e.g., nisin, subtilin) and Type B (globular, enzyme-inhibiting, e.g., mersacidin).

Their biosynthesis involves a pre-peptide containing a leader sequence that guides post-translational modification enzymes (LanB, LanC, LanM) and subsequent cleavage and export. The complex biosynthetic machinery, encoded in BGCs, has been a valuable target for genomic mining and expression studies relevant to diagnostics.

Class II: Non-Modified Bacteriocins:

Class II bacteriocins are small (less than 10 kDa), heat-stable, non-lantibiotic peptides. They are further subdivided into: Class IIa (pediocin-like, containing the consensus YGNGV motif, highly active against *Listeria monocytogenes*), Class IIb (two-peptide bacteriocins requiring complementary peptides for activity, e.g., lactococcin G), Class IIc (circular

bacteriocins with N-to-C terminus cyclization, e.g., gassericin A), and Class IId (single peptide, non-pediocin-like, e.g., lacticin Q). Class IIa bacteriocins have particular diagnostic relevance because their anti-Listeria activity and receptor-specificity enable highly sensitive and selective pathogen detection.

Class III: Large Heat-Labile Bacteriocins:

Class III bacteriocins are large proteins (more than 30 kDa), heat-labile, and often possess bacteriolytic activity (murein hydrolases). Examples include helveticin J, enterolysin A, and millericin B. While not as commonly exploited in diagnostics due to their size and lability, their enzymatic activity has been harnessed in cell-lysis-based biosensor designs.

Colicins and Microcins (Gram-Negative Bacteriocins):

Bacteriocins of Gram-negative bacteria are typically classified separately. Colicins, produced by *E. coli* and related species, are large proteins (30–100 kDa) that kill sensitive bacteria through multiple mechanisms: pore formation in the inner membrane (e.g., colicins A, B, E1, Ia, Ib), DNase activity (colicins E2, E7, E8, E9), RNase activity (colicins E3, E4, E5, E6, cloacin DF13), or inhibition of murein synthesis (colicin M). Microcins are smaller peptides (less than 10 kDa) with activity against Gram-negative organisms, produced by Enterobacteriaceae; examples include microcin J25 (a lasso peptide) and microcin B17. Their structural uniqueness and high specificity make them attractive for biosensor applications.

MECHANISMS OF ACTION AND MOLECULAR BASIS OF TARGET SPECIFICITY:

PORE FORMATION:

The most widespread mechanism of bacteriocin action is disruption of the cytoplasmic membrane through pore formation. Pore-forming bacteriocins, such as nisin, colicin A, and most Class IIa bacteriocins, insert into the lipid bilayer and create ion channels that collapse the proton motive force (PMF), leading to leakage of essential ions (K+, Mg2+), dissipation of membrane potential, and ultimately cell death. Nisin, in addition to pore formation, inhibits cell wall synthesis by complexing with lipid II, the essential precursor molecule for peptidoglycan biosynthesis.

The dual mechanism of nisin, combining lipid II binding and pore formation, is particularly instructive for diagnostics. Lipid II is a highly conserved molecular target present on virtually all Gram-positive bacterial cell surfaces, and nisin's specificity for this target has been

exploited in biosensor designs that selectively capture Gram-positive pathogens from complex clinical samples.

ENZYMATIC ACTIVITY:

Certain bacteriocins, particularly colicins and Class III bacteriocins, function as enzymes. DNase-type colicins (E2, E7, E8, E9) cleave chromosomal DNA of target cells after translocation across both membranes of the Gram-negative cell envelope. RNase-type colicins (E3, E4, E5, E6) cleave the 16S ribosomal RNA at a specific position, inactivating ribosomes. These highly specific enzymatic activities form the basis of diagnostic assays in which enzyme-linked bacteriocin reporters can generate amplifiable signals.

INHIBITION OF CELL WALL SYNTHESIS:

Mersacidin and related globular lantibiotics bind to lipid II at a different epitope than nisin, inhibiting transglycosylation without pore formation. Colicin M targets lipid II outside the cell, hydrolytically cleaving it to block peptidoglycan synthesis. Vancomycin, though not a bacteriocin, shares this lipid II-targeting mechanism, and bacteriocins with similar specificity have been investigated as alternatives in MDR pathogen detection.

BACTERIOCINS AS BIOMARKERS IN DISEASE:

CONCEPT OF BACTERIOCIN BIOMARKERS:

A biomarker is a measurable indicator of a biological state or condition. In the context of bacteriocins, biomarker utility operates at two distinct levels: (i) the presence or absence of bacteriocin-producing or bacteriocin-sensitive strains in the microbiome as indicators of disease states (ecological biomarkers), and (ii) the direct detection of specific bacteriocins or their biosynthetic genes in clinical samples as markers of infection, dysbiosis, or pathogenic activity. Both modalities are clinically significant and are explored in the following sections.

BACTERIOCINS AS INDICATORS OF MICROBIOME DYSBIOSIS:

The human microbiome, comprising trillions of microorganisms colonizing the gut, skin, oral cavity, and urogenital tract, is now recognized as a critical determinant of health. The composition of the microbiome, including its bacteriocin-producing components, shifts dramatically in disease states. Metagenomic studies have consistently demonstrated that bacteriocin gene cluster abundance and diversity are altered in conditions such as inflammatory bowel disease (IBD), irritable bowel syndrome (IBS), colorectal cancer (CRC), type 2 diabetes, obesity, and neurodegenerative disorders.

In a landmark study, Sherlock et al. and subsequent investigators used shotgun metagenomics to demonstrate that individuals with CRC had significantly reduced abundance of bacteriocin gene clusters from Firmicutes, particularly those of *Lactobacillus* and *Ruminococcus species*, compared to healthy controls. Conversely, bacteriocin gene clusters from potentially pathogenic *Fusobacterium nucleatum* and *Peptostreptococcus anaerobius* were enriched in CRC-associated microbiomes, providing a bacteriocin-based compositional signature with diagnostic utility.

BACTERIOCINS IN INFECTIOUS DISEASE DIAGNOSIS:

STAPHYLOCOCCAL INFECTIONS:

Staphylococcus aureus, including methicillin-resistant *S. aureus* (MRSA), is a leading cause of nosocomial and community-acquired infections. Bacteriocins such as lysostaphin, epidermin, and Pep5 (produced by Staphylococcal species themselves) have been incorporated into detection systems. Lysostaphin, a glycylglycine endopeptidase, specifically cleaves the pentaglycine cross-bridges of *S. aureus* cell walls and is used in rapid lysis-based detection assays coupled with luminometry and PCR. Its exquisite specificity for *S. aureus* over other Staphylococcal species enables species-level discrimination without cross-reactivity.

LISTERIOSIS DIAGNOSIS:

Listeria monocytogenes, the causative agent of listeriosis, a severe foodborne and clinical infection, is particularly amenable to bacteriocin-based detection given the high sensitivity of this organism to Class IIa bacteriocins. Pediocin PA-1, nisin, and listeriocin 743A have been employed as capture and lysis agents in biosensor formats. The N-terminal consensus sequence (YGNGV) of Class IIa bacteriocins binds specifically to the mannose phosphotransferase system (PTS) II Man receptor of *Listeria*, forming the molecular basis of this diagnostic specificity.

TUBERCULOSIS AND MYCOBACTERIAL INFECTIONS: *Mycobacterium tuberculosis (Mtb)* presents unique diagnostic challenges due to its slow growth, complex lipid-rich cell wall, and intracellular lifestyle. Lantibiotics, owing to their ability to interact with lipid II (present in mycobacteria as decaprenyl-phosphate-linked precursors), have been investigated as probes for mycobacterial cell wall integrity. Modified nisin variants with enhanced specificity for mycobacterial lipid II analogs have been explored in electrochemical biosensor formats, though this remains an emerging area requiring further validation.

URINARY TRACT AND GASTROINTESTINAL INFECTIONS:

Colicin-based probes have been designed for the detection of uropathogenic *E. coli* (UPEC) in urine samples. By conjugating colicin receptor-binding domains (RBDs) to fluorescent nanoparticles or electrochemical transducers, researchers have developed lateral flow and microfluidic assays capable of detecting UPEC at concentrations as low as 10^2 CFU/mL, matching or exceeding the sensitivity of standard culture methods while reducing turnaround time from 18–72 hours to less than 2 hours.

BACTERIOCINS IN INFLAMMATORY DISEASE:

Chronic inflammatory diseases, including IBD (comprising Crohn's disease and ulcerative colitis), rheumatoid arthritis, and psoriasis, are associated with distinct microbiome alterations. The bacteriocin profile of the gut microbiome in IBD patients is markedly different from that in healthy individuals. Specifically, nisin-like lantibiotics from *Lactococcus* and *Lactobacillus species* are depleted in IBD, while colicin-producing *E. coli* strains are enriched. The diagnostic significance of this shift lies in its potential as a non-invasive biomarker panel derivable from fecal metagenomics.

Furthermore, bacteriocins themselves can modulate inflammatory signaling cascades. Nisin has been shown to downregulate NF-κB activation in macrophages in vitro, while certain microcins have been demonstrated to influence toll-like receptor (TLR) signaling. The presence or absence of immunomodulatory bacteriocins in the gut may thus serve as indirect markers of the inflammatory status of the host, with implications for monitoring disease activity and treatment response.

BACTERIOCINS AND CANCER BIOMARKER DISCOVERY:

The relationship between bacteriocins and cancer is bidirectional and complex. On one hand, bacteriocins produced by certain probiotic bacteria have demonstrated in vitro and in vivo anticancer properties, including induction of apoptosis in cancer cell lines. On the other hand, the metagenomic bacteriocin signature of the tumor microbiome and associated gut microbiome differs significantly from that of healthy individuals, offering a potential diagnostic window.

Nisin and its modified derivatives have been reported to selectively induce apoptosis in head and neck squamous cell carcinoma (HNSCC) cells, and the presence of nisin-producing *L. lactis* in the oral microbiome may serve as a negative predictive marker for oral malignancy. Similarly, the loss of bacteriocin diversity in colorectal cancer-associated microbiomes, as

assessed by BGC metagenomics, has been proposed as an early detection biomarker, potentially implementable in a stool-based, non-invasive screening format.

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ORGANIC FARMING AS A STRATEGY FOR CONSERVATION OF INDIGENOUS LIVESTOCK GENETIC RESOURCES

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Introduction

Organic farming is a holistic agricultural production system that promotes ecological balance, biodiversity, animal welfare, and environmental sustainability while minimizing the use of synthetic fertilizers, pesticides, antibiotics, and genetically modified organisms (FAO, 2015; IFOAM, 2023). Livestock is an integral component of organic farming, contributing to nutrient recycling, soil fertility, farm diversification, and sustainable rural livelihoods. Organic livestock production emphasizes natural feeding, preventive healthcare, free-range grazing, and species-specific management practices that closely align with the biological characteristics of indigenous livestock breeds (IFOAM, 2023). These breeds, developed over centuries through natural and farmer-led selection, possess unique genetic traits such as adaptability to local climates, resistance to endemic diseases and parasites, efficient utilization of low-quality feed resources, and tolerance to environmental stress. Consequently, indigenous breeds are particularly well suited to organic farming systems, where productivity is balanced with ecological sustainability and animal welfare rather than solely maximizing production (FAO, 2015).

The rapid expansion of intensive livestock production has led to the widespread replacement of indigenous breeds with high-yielding exotic and crossbred animals. Although

these breeds offer higher production under intensive management, they often require substantial external inputs, including concentrate feeds, veterinary interventions, and climate-controlled housing. This trend has resulted in a significant decline in indigenous livestock populations and erosion of valuable animal genetic resources worldwide (FAO, 2015). Organic farming provides an economically and environmentally sustainable alternative by promoting the utilization and conservation of locally adapted breeds capable of thriving under low-input production systems. Thus, organic farming plays a vital role in conserving indigenous livestock breeds while simultaneously enhancing biodiversity, supporting rural livelihoods, improving ecosystem resilience, and ensuring sustainable livestock production.

Indigenous Livestock Breeds and Their Importance

Indigenous livestock breeds are domesticated animal populations that have evolved over generations under specific agro-climatic conditions through natural selection and traditional breeding practices. India possesses one of the richest reservoirs of animal genetic resources globally, with numerous indigenous breeds of cattle, buffalo, sheep, goats, pigs, poultry, camels, horses, and yaks (NBAGR, 2023). Examples include Kangayam, Gir, Sahiwal, Red Sindhi, Tharparkar, Ongole, Pulikulam, Bargur, Hallikar, Vechur cattle; Murrah, Surti, and Toda buffaloes; Mecheri, Deccani, and Nellore sheep; Jamunapari, Barbari, Black Bengal, Kanni Adu, Salem Black, and Osmanabadi goats; and Aseel, Kadaknath, Nicobari, and Ghagus poultry.

These indigenous breeds possess several adaptive traits that make them highly suitable for organic farming. They efficiently utilize crop residues and natural grazing resources, exhibit greater resistance to local diseases and parasites, tolerate heat and drought conditions, and require comparatively lower management inputs than exotic breeds (Leroy et al., 2018). Besides their productive roles, indigenous livestock contribute significantly to cultural heritage, traditional farming practices, ecosystem management, and livelihood security for millions of smallholder farmers. Conserving these breeds is therefore essential for maintaining biodiversity, ensuring future breeding options, and strengthening climate-resilient livestock production systems.

Principles of Organic Farming Supporting Breed Conservation

Organic farming is based on four internationally accepted principles proposed by IFOAM: **health, ecology, fairness, and care** (IFOAM, 2023). These principles naturally complement the conservation of indigenous livestock breeds because they emphasize sustainable

resource use, animal welfare, biodiversity conservation, and reduced dependence on external inputs.

Organic livestock production encourages free-range grazing, natural mating, balanced nutrition using locally available feeds, preventive health management, and minimal use of synthetic chemicals. Indigenous breeds fit these production systems exceptionally well because they evolved under similar environmental conditions and possess natural adaptability. Their ability to maintain acceptable production under low-input management makes them economically viable for organic farmers while reducing production costs and environmental impacts.

Mechanisms through which Organic Farming Conserves Indigenous Breeds

Organic farming contributes to indigenous breed conservation through several complementary mechanisms. First, it creates market demand for products derived from native breeds, encouraging farmers to maintain purebred populations. Second, organic certification often rewards environmentally friendly and welfare-oriented production systems that favor locally adapted animals. Third, indigenous breeds require fewer veterinary drugs and synthetic inputs, making them economically attractive under organic production systems.

Furthermore, integrated crop–livestock farming promotes efficient recycling of nutrients through farmyard manure and compost production. Indigenous cattle, buffaloes, sheep, and goats provide high-quality manure that improves soil fertility, soil microbial activity, and crop productivity. This integration reduces dependence on chemical fertilizers while maintaining ecological balance. Consequently, organic farming not only conserves indigenous breeds but also strengthens sustainable agricultural ecosystems.

Ecological Benefits of Indigenous Breeds in Organic Farming

Indigenous livestock play an essential role in maintaining ecosystem health within organic farming systems. Their grazing habits contribute to grassland management, seed dispersal, nutrient cycling, and biodiversity conservation. Mixed grazing by cattle, sheep, and goats helps control invasive weeds while promoting desirable pasture species. Farmyard manure and urine enrich soil organic matter, improve water-holding capacity, and stimulate beneficial microbial populations.

Compared with intensive livestock systems, indigenous breeds generally produce lower environmental impacts because they rely on locally available feed resources and require fewer external inputs. Their superior adaptability also reduces energy requirements associated with climate-controlled housing and intensive management. Thus, conservation of indigenous breeds through organic farming contributes significantly to climate-smart agriculture and environmental sustainability.

Economic Benefits to Farmers

Organic farming creates premium markets for milk, meat, eggs, ghee, curd, and other products obtained from indigenous breeds. Consumers increasingly prefer products from native animals because of their perceived nutritional quality, medicinal value, ethical production methods, and absence of chemical residues. Premium pricing improves farm income and enhances the economic viability of conserving indigenous livestock.

Indigenous breeds also reduce production costs through lower feed requirements, fewer disease outbreaks, reduced veterinary expenses, and longer productive life. Farmers practicing integrated organic farming benefit from multiple income sources including milk, manure, vermicompost, biogas, breeding stock, and value-added products such as Panchagavya and Jeevamrutham. This diversified income structure enhances farm resilience and livelihood security.

Animal Welfare and Organic Farming

Animal welfare is a central component of organic livestock production. Organic standards require animals to have adequate space, access to open areas, natural behavior, appropriate nutrition, and preventive healthcare. Indigenous breeds naturally adapt to these welfare-oriented systems because they evolved under free-range or semi-intensive conditions.

Compared with exotic breeds, indigenous livestock generally experience lower stress, improved reproductive performance, and fewer metabolic disorders under organic management. Their superior disease resistance reduces reliance on antibiotics and promotes healthier production systems. Consequently, organic farming simultaneously enhances animal welfare and supports long-term conservation of valuable genetic resources.

Challenges in Conserving Indigenous Breeds through Organic Farming

Despite its advantages, several challenges limit the widespread adoption of indigenous breeds in organic farming. Lower production compared with specialized commercial breeds

often discourages farmers seeking immediate economic returns. Limited availability of certified organic markets, inadequate price premiums, poor breeding infrastructure, and insufficient awareness among consumers also constrain conservation efforts.

Additional challenges include declining grazing lands, indiscriminate crossbreeding, climate change, weak marketing networks, and inadequate policy support. Strengthening breeding programmes, farmer cooperatives, organic certification systems, value-chain development, and consumer awareness is essential to overcome these limitations and ensure sustainable conservation.

Future Prospects

Future conservation strategies should integrate organic farming with modern breeding technologies, genomic characterization, community-based breeding programmes, and digital livestock management. Government support through financial incentives, organic certification assistance, conservation breeding farms, and marketing infrastructure will further encourage farmers to maintain indigenous breeds.

Research on climate resilience, disease resistance, nutritional quality of indigenous livestock products, and ecosystem services will provide additional scientific evidence supporting conservation. Integration of indigenous breeds into climate-smart agriculture, agroecology, and circular bioeconomy models will further enhance their importance in sustainable food systems.

Conclusion

Organic farming provides a scientifically sound and economically viable approach for conserving indigenous livestock breeds while promoting sustainable agriculture, biodiversity conservation, animal welfare, and rural livelihoods. Indigenous breeds possess valuable adaptive traits including disease resistance, heat tolerance, efficient utilization of local feed resources, and longevity that make them particularly suitable for low-input organic production systems. Their integration into organic farming strengthens ecological sustainability through improved nutrient recycling, reduced chemical inputs, enhanced soil fertility, and conservation of animal genetic resources.

Expanding organic livestock production, strengthening conservation breeding programmes, improving market incentives, and creating greater consumer awareness can significantly enhance the long-term conservation of indigenous breeds. A coordinated approach involving farmers, researchers, policymakers, breeding organizations, and certification agencies

will ensure that indigenous livestock continue to contribute to food security, climate resilience, and sustainable agricultural development.

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THE TOUCH-ME-NOT PLANT (*MIMOSA PUDICA* L.): A REMARKABLE EXAMPLE OF PLANT SENSITIVITY AND ITS ECOLOGICAL SIGNIFICANCE

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Abstract

The Touch-Me-Not plant (*Mimosa pudica* L.), popularly known as Lajwanti, Chuimui, or the Sensitive Plant, is one of the most fascinating examples of rapid plant movement in nature. Unlike most plants, *Mimosa pudica* exhibits a unique touch-induced leaf-folding response known as **thigmonasty (seismonasty)**, which is mediated through rapid changes in turgor pressure within specialized motor organs called pulvini. Native to tropical America, the species is now widely distributed across tropical and subtropical regions, including India. Besides attracting scientific interest for its remarkable movement, the plant has ecological, medicinal, and agricultural significance. As a leguminous species, it forms symbiotic associations with nitrogen-fixing bacteria and contributes to soil improvement under suitable conditions. Traditionally, the plant has been used in Ayurveda and folk medicine for treating wounds, gastrointestinal disorders, and inflammation. Modern pharmacological studies have reported antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and hepatoprotective activities, although most evidence is based on laboratory and animal experiments. In some ecosystems, however, *Mimosa pudica* behaves as an invasive weed, competing with native vegetation and cultivated crops. This article discusses the origin, botanical characteristics, physiology of rapid movement, ecological role, agricultural importance, medicinal potential, and management strategies of this remarkable plant.

Keywords: *Mimosa pudica*, Sensitive Plant, Touch-Me-Not, Thigmonasty, Seismonasty, Pulvinus, Plant Physiology, Medicinal Plant

Introduction

Plants are generally regarded as sessile organisms that respond slowly to environmental changes. However, a few exceptional species possess the ability to exhibit rapid movements in response to external stimuli. Among these, *Mimosa pudica* L., commonly known as the **Touch-Me-Not Plant**, is perhaps the most widely recognized. The plant instantly folds its leaflets and droops its petioles when touched, shaken, heated, or exposed to sudden environmental disturbances. This rapid movement has fascinated botanists, physiologists, and plant biologists for centuries and continues to serve as an important model for understanding plant signaling, electrophysiology, and adaptive responses.

Belonging to the family **Fabaceae (subfamily Caesalpinioideae; mimosoid clade)**, *Mimosa pudica* is commonly known as **Lajwanti**, **Chuimui**, **Sensitive Plant**, **Sleeping Grass**, and **Shame Plant**. The specific epithet *pudica*, meaning "shy" or "modest" in Latin, reflects its characteristic response to touch. Besides its botanical uniqueness, the species has long been valued in traditional medicine and is increasingly studied for its pharmacological properties. At the same time, its aggressive spread in disturbed habitats has raised concerns regarding its weed potential in agricultural ecosystems.

Origin and Distribution

Mimosa pudica is native to the tropical regions of **Central and South America**, particularly Brazil and neighbouring countries. Owing to its ornamental appeal and medicinal importance, it was introduced into many tropical and subtropical regions across Asia, Africa, Australia, and the Pacific Islands. Today, the species is naturalized in more than 100 countries and is widely distributed throughout the humid tropics.

In India, *Mimosa pudica* is commonly found in almost all states, particularly in regions receiving moderate to high rainfall. It thrives in roadsides, grasslands, wastelands, orchards, tea plantations, forest margins, and cultivated fields with well-drained soils. The species prefers warm temperatures (25–35°C), high humidity, and full sunlight but can also tolerate partial shade. During the monsoon season, rapid seed germination and vigorous vegetative growth allow the plant to colonize disturbed habitats efficiently. In several agricultural ecosystems, it is considered a troublesome weed because of its ability to form dense colonies that compete with crops and native vegetation.

Taxonomy

Kingdom	Plantae
Division	Tracheophyta
Class	Magnoliopsida
Order	Fabales
Family	Fabaceae
Genus	*Mimosa*
Species	*pudica*

Botanical Characteristics

Mimosa pudica is a perennial herb that often behaves as an annual under cultivated conditions. The plant generally grows to a height of **30-100 cm**, depending on environmental conditions. The stem is slender, creeping or ascending, branched, and armed with small recurved prickles that provide protection against herbivores.

The leaves are bipinnately compound and highly sensitive to mechanical stimulation. Each leaf consists of one or two pairs of pinnae bearing numerous small, oblong leaflets arranged opposite each other. At the base of each leaflet and petiole lies a swollen structure known as the **pulvinus**, which functions as the motor organ responsible for rapid leaf movement. The pulvini contain specialized parenchymatous motor cells that regulate changes in turgor pressure during movement.



Figure1. Touch me not Plant

Flowering generally occurs during the rainy season. The flowers are small, pink to purple, and arranged in globose inflorescences approximately 1–2 cm in diameter. Pollination is mainly accomplished by insects such as bees and butterflies. The fruit is a flat, bristly pod containing three to five brown seeds. Seed production is abundant, and the seeds exhibit considerable longevity in soil, contributing to the plant's persistence in natural and agricultural habitats.

Scientific Basis of Leaf Folding Movement

The most fascinating characteristic of *Mimosa pudica* is its ability to fold its leaves within one to two seconds after receiving an external stimulus. This rapid movement is classified as **thigmonasty**, a non-directional movement triggered by touch or mechanical stimulation. When the movement is induced by vibration or shaking, it is often referred to as **seismonasty**. Unlike tropic movements, which depend on the direction of the stimulus and involve growth, nastic movements are independent of stimulus direction and result from reversible physiological changes rather than permanent growth.

The movement is controlled by a specialized swollen structure called the **pulvinus**, located at the base of each leaflet, pinna, and petiole. The pulvinus consists of motor cells that regulate water movement across their membranes. Upon stimulation, mechanoreceptors generate an electrical signal known as an **action potential**, which rapidly propagates through the vascular tissues to adjacent pulvini.

This electrical impulse triggers the opening of ion channels, leading to the rapid efflux of potassium (K^+) and chloride (Cl^-) ions from the motor cells. As ions leave the cells, water follows osmotically, causing a sudden decrease in turgor pressure in the lower half of the pulvinus. Consequently, the leaflets fold inward and the petiole droops downward. Once ion concentrations are restored through active transport, water re-enters the motor cells, turgor pressure is re-established, and the leaves gradually reopen within 10–20 minutes under normal environmental conditions.

This remarkable response represents one of the fastest reversible movements observed in higher plants and serves as a valuable model system for studying plant electrophysiology, mechanosensing, signal transduction, and cellular water relations.

Biological Functions of Leaf Movement

The rapid folding of leaves is considered an adaptive survival strategy that has evolved to

protect the plant from environmental stress and herbivory.

1. Protection Against Herbivores

When the leaves suddenly collapse, the plant appears wilted or damaged, reducing its attractiveness to grazing animals and phytophagous insects. Experimental studies have shown that herbivores often avoid plants displaying this rapid defensive response.

2. Reduction in Mechanical Damage

The folding response minimizes the exposed leaf surface during heavy rainfall, strong winds, or accidental physical disturbances, thereby reducing the likelihood of tissue injury.

3. Water Conservation

Although not its primary function, temporary leaf closure may reduce transpiration under certain stressful environmental conditions by decreasing the exposed leaf area.

4. Defence Against Insects

The sudden movement may startle or dislodge small insects feeding on the foliage, thereby reducing insect damage.

Ecological Importance

Mimosa pudica plays several beneficial ecological roles in natural and managed ecosystems.

1. Improvement of Soil Fertility

Being a member of the family Fabaceae, *Mimosa pudica* develops symbiotic associations with nitrogen-fixing bacteria in root nodules. These bacteria convert atmospheric nitrogen into biologically available forms, contributing to nitrogen cycling and improving soil fertility, particularly in nutrient-deficient soils.

2. Soil Conservation

Its spreading growth habit forms a protective ground cover that helps reduce soil erosion caused by rainfall and surface runoff. This characteristic is particularly useful on slopes and degraded lands.

3. Support for Pollinators

The attractive pink globular flowers produce nectar and pollen that attract bees, butterflies, and several beneficial insects, thereby supporting pollinator diversity.

4. Contribution to Biodiversity

The plant provides microhabitats for numerous insects and soil microorganisms and contributes to ecological interactions within grassland and roadside ecosystems.

Agricultural Importance

The agricultural significance of *Mimosa pudica* is both beneficial and detrimental, depending upon its population density and habitat.

Beneficial Aspects

1. Nitrogen Enrichment

As a leguminous plant, *Mimosa pudica* contributes to biological nitrogen fixation through symbiotic rhizobia, which may improve soil nutrient status under suitable ecological conditions.

2. Indicator of Soil Disturbance

The species frequently colonizes disturbed lands and therefore serves as a useful biological indicator of degraded soils requiring ecological restoration.

3. Educational and Research Importance

Mimosa pudica is one of the most widely used experimental plants in plant physiology laboratories for demonstrating action potentials, turgor movement, osmosis, membrane transport, and plant signalling.

Negative Agricultural Impact

Despite its ecological benefits, uncontrolled spread of *Mimosa pudica* may create several agricultural problems.

1. Competition with Crops

Dense infestations compete aggressively with crops for sunlight, moisture, nutrients, and space, leading to reduced crop growth and productivity.

2. Weed Infestation

The species frequently invades tea plantations, orchards, sugarcane fields, coconut plantations, rubber plantations, and other perennial cropping systems where it becomes difficult to eradicate.

3. Hindrance in Farm Operations

Its prickly stems interfere with hand weeding, harvesting, intercultural operations, and movement of farm workers.

4. Persistent Seed Bank

The plant produces numerous seeds capable of remaining viable in soil for several years, making long-term management difficult after establishment.

Phytochemical Composition

Phytochemical investigations have revealed that *Mimosa pudica* contains a wide range of biologically active compounds responsible for its medicinal properties. The major phytoconstituents reported from different plant parts include alkaloids, flavonoids, tannins, phenolic compounds, terpenoids, glycosides, saponins, steroids, coumarins, and essential amino acids. The non-protein amino acid **mimosine**, commonly found in several *Mimosa* species, has also been detected and is considered one of the important bioactive constituents. These phytochemicals contribute to the antioxidant, antimicrobial, anti-inflammatory, and wound-healing activities reported in experimental studies.

Medicinal Importance

Mimosa pudica has been used for centuries in **Ayurveda, Siddha, Unani, and traditional folk medicine**. Almost every part of the plant, including leaves, roots, stems, and seeds, has been utilized for various therapeutic purposes.

1. Wound Healing Activity

Extracts of *Mimosa pudica* have shown significant wound-healing activity in laboratory animals by promoting collagen synthesis, angiogenesis, and faster tissue regeneration. These findings support its traditional use in treating cuts and wounds.

2. Anti-inflammatory and Analgesic Activity

Experimental studies have demonstrated that leaf and root extracts possess anti-inflammatory and pain-relieving properties by suppressing inflammatory mediators. However, well-designed human clinical trials are still limited.

3. Antioxidant Activity

The presence of flavonoids and phenolic compounds enables the plant to neutralize reactive oxygen species (ROS), thereby reducing oxidative stress in experimental models.

4. Antimicrobial Activity

Several laboratory investigations have reported inhibitory effects of *Mimosa pudica* extracts against selected bacterial and fungal pathogens, suggesting its potential as a natural antimicrobial agent.

5. Antidiabetic Potential

Animal studies indicate that certain extracts may help reduce blood glucose levels and improve antioxidant defence mechanisms. Nevertheless, sufficient clinical evidence in humans is not yet available to recommend its therapeutic use for diabetes.

6. Gastrointestinal Disorders

Traditional medicine has employed the plant for treating diarrhoea, dysentery, piles, and intestinal inflammation. Some pharmacological studies support these uses, although further scientific validation is required.

Research and Educational Importance

Because of its unique physiological behaviour, *Mimosa pudica* has become an internationally recognized experimental plant.

It is extensively used for studying:

- Plant electrophysiology
- Action potential generation in plants
- Mechanoreception and signal transduction
- Turgor pressure regulation
- Osmosis and membrane transport
- Plant defence mechanisms
- Environmental stress physiology
- Plant behaviour and adaptive responses

The species continues to serve as an important teaching model in schools, colleges, and research laboratories throughout the world.

Management of *Mimosa pudica* in Agricultural Fields

Although the plant possesses ecological and medicinal importance, excessive infestation may interfere with crop production. Therefore, integrated management practices are recommended.

1. Mechanical Control

Young plants should be manually uprooted before flowering and seed formation to prevent replenishment of the soil seed bank.

2. Cultural Practices

Maintaining optimum crop density, crop rotation, mulching, and proper field sanitation

suppress the establishment of *Mimosa pudica*.

3. Chemical Control

Where infestations become severe, selective herbicides recommended by agricultural universities or local extension agencies may be used judiciously. Herbicide application should always follow national recommendations to minimize environmental impacts.

4. Integrated Weed Management (IWM)

Combining mechanical, cultural, and chemical methods provides the most effective and environmentally sustainable strategy for long-term management.

Future Research Perspectives

Despite considerable research, several aspects of *Mimosa pudica* require further investigation.

Future studies should focus on:

- Molecular mechanisms regulating rapid leaf movement.
- Genetic improvement for stress tolerance studies.
- Clinical evaluation of medicinal compounds.
- Identification of novel bioactive molecules.
- Role in sustainable agriculture and ecological restoration.
- Application in biomimetic engineering and biosensor development.

Conclusion

The Touch-Me-Not plant (*Mimosa pudica* L.) is one of nature's most remarkable examples of rapid plant movement and physiological adaptation. Its characteristic thigmonastic response has made it a model organism for studying plant signalling, electrophysiology, and water relations. Besides its scientific significance, the plant contributes to ecological sustainability through nitrogen fixation, soil conservation, and support of pollinators. Traditional medicinal systems have long recognized its therapeutic value, while modern pharmacological research has demonstrated promising antioxidant, antimicrobial, anti-inflammatory, and wound-healing activities. However, most medicinal claims still require validation through well-controlled clinical trials. Although beneficial in many respects, *Mimosa pudica* may behave as a troublesome weed under favourable environmental conditions, emphasizing the need for integrated management. Continued multidisciplinary research will further enhance our

understanding of this extraordinary plant and its potential applications in agriculture, medicine, and plant science.

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PESTICIDE POLLUTION IN AQUATIC ECOSYSTEMS: WATER, SEDIMENT, AND FISH

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Abstract

Pesticides are extensively used in agriculture to enhance crop production, but their widespread application has raised serious environmental and public health concerns. Persistent pesticides, particularly organochlorine (OCPs) and organophosphorus pesticides (OPPs), enter aquatic ecosystems through agricultural runoff, atmospheric deposition, and improper disposal. These contaminants accumulate in water, sediments, and aquatic organisms, resulting in bioaccumulation and biomagnification along the food chain. Studies from India and other countries have documented pesticide residues in rivers, lakes, sediments, and edible fish species. Sediments act as long-term reservoirs, while fish serve as important indicators of aquatic contamination and human exposure. Consumption of contaminated fish and water may lead to adverse health effects, including cancer, endocrine disruption, reproductive disorders, immune dysfunction, and neurological problems. Despite regulatory restrictions, many pesticide residues persist due to their environmental stability. This review summarises the occurrence, distribution, bioaccumulation, and health risks associated with pesticide residues in aquatic ecosystems. It highlights the need for regular monitoring and sustainable pest management practices to protect environmental and human health.

1. Introduction

A pesticide is a chemical used by farmers to control weed growth or to prevent crop damage from insects, rodents, and moulds, thereby increasing food production. It is also used on

food crops after harvest to prolong their storage life. Small amounts of these pesticides found in foods are called residues (Aktar *et al.,* 2009). Pesticides can be classified by toxicity as extremely dangerous, highly dangerous, moderately dangerous, or slightly dangerous. According to their median lifetime, they are classified as permanent, persistent, moderately persistent and not persistent. Based on their chemical structure, they are classified into several groups, such as organochlorines, organophosphates, organosulfur compounds, organonitrogen compounds, carbamates, and synthetic pyrethroids. Pesticides are also classified based on target organisms as algicides, acaricides, avicides, insecticides, herbicides, fungicides, bactericides, miticides, nematicides, rodenticides, molluscicides, lampricides, piscicides, ovicides, larvicides, and plant growth regulators (EPA, 1965). Agriculture, public health, structural pest control, industry, green area servicing, and the maintenance of water reservoirs are the main activities in which pesticides are currently employed (Garcia et al., 2012). Pesticides are characterised by low polarity, high lipophilicity, and low aqueous solubility, and as a result, they have the potential for bioaccumulation in the food chain, posing a great threat to human health and the environment (Afful *et al.,* 2010).

2. Absorption of pesticides & toxicity

Pesticides are mainly absorbed through dermal, respiratory and oral pathways. Although absorption through the skin is prominent in the work environment, the general population are more at risk through ingestion and inhalation. Pesticides are distributed throughout the human body via the bloodstream and are eliminated through urine, faeces and exhaled air (Garcia et al., 2012). Pesticides are linked to a wide range of human health hazards, causing short-term and long-term impacts. Pesticides can cause many types of cancer in humans. Some of the most prevalent forms include leukaemia, non-Hodgkin's lymphoma, brain, bone, breast, ovarian, prostate, testicular and liver cancers. OCPs and OPPs are implicated in a wide range of adverse human and environmental effects, including reproductive and congenital disabilities (Edwards et al., 1987), immune system dysfunction, endocrine disruption, and cancer, compared with other groups of pesticides (Adeyemi *et al.,* 2008). WHO estimated that as many as 3 million people per year are poisoned worldwide by pesticides, resulting in hundreds of thousands of deaths, with agricultural workers constituting 75%. (Someshekar *et al.,* 2015; Garcia et al., 2012).

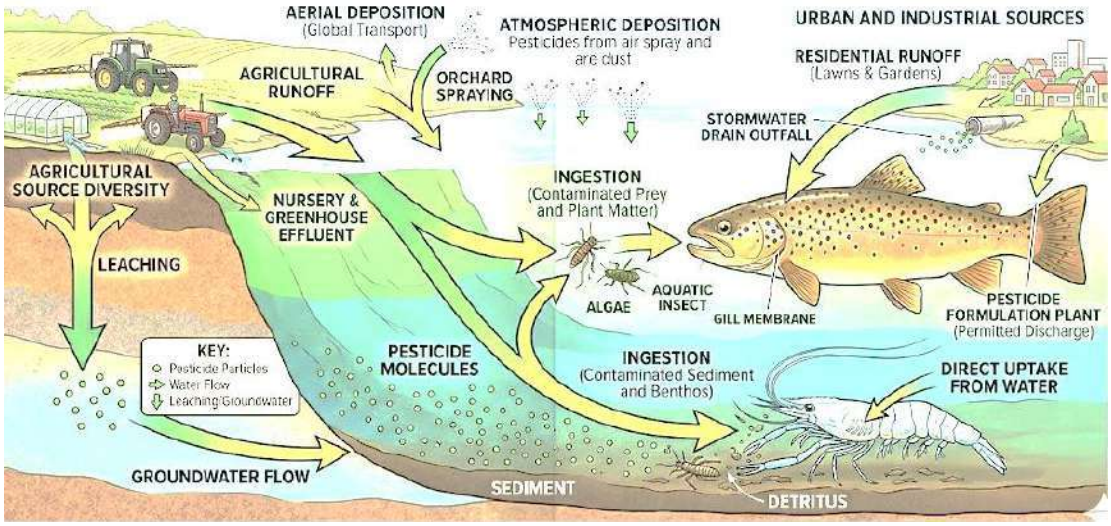


Fig. 1. Source & Pathway of Pesticides Entering into the Fish/Shellfish

3. Banned and restricted pesticides in India

The list of pesticides banned for manufacture, import and use in India include aldicarb, aldrin, benzene hexachloride, calcium cyanide, chlorbenzilate, chlordan, chlorofenvinphos, copper acetoarsenite, dibromochloropropane, dieldrin, endrin, endosulfan (Supreme Court of India, 2011), ethyl mercury chloride, ethyl parathion, ethylene dibromide, heptachlor, lindane (gamma-HCH), maleic hydrazide, menazon, metoxuron, nitrofen, paraquat dimethyl sulphate, pentachloro nitrobenzene, pentachlorophenol, phenyl mercury acetate, sodium methane arsonate, TCA, tetradifon and toxaphene, because of their highly toxicity and environmental persistence (Directorate of Plant Protection Quarantine and Storage, 2011). Aluminium phosphide, DDT, lindane, methyl bromide, methyl parathion, sodium cyanide, methoxy ethyl mercuric chloride (MEMC), monocrotophos, fenitrothion, diazinon, fenthion, and dazomet are pesticides to be restricted for use in India (Directorate of Plant Protection Quarantine and Storage, 2011). However, some OCPs, such as endosulfan, heptachlor, and HCH, are still used in some developing countries (Doong et al., 2002). Persistent organic pollutants (POPs) are of great concern due to their high bioconcentration despite bans on production and use in several countries (Iwata et al., 1994; Guruge and Tanabe, 2001).

4. Pesticide residues in water & sediments

Pesticides reach humans through food, water, air, soil, and biota, with organochlorine pesticides (OCPs) and organophosphorus pesticides (OPPs) being major contaminants of aquatic environments. Their residues degrade water quality, harm non-target aquatic organisms, and

threaten the entire food chain, including humans (Svensson et al., 1994). Numerous studies worldwide have reported pesticide contamination in rivers and lakes. Elevated levels of DDT, lindane, aldrin, cypermethrin, deltamethrin, and DDE have been detected in water bodies of Nigeria and Iran (Ize-Itamu et al., 2007; Feo et al., 2010; Kafilzadeh et al., 2012; Kafilzadeh, 2015).

In India, pesticide residues have been detected in major rivers, including the Krishna, Godavari, Hindon, Yamuna, Gomti, Ganga, Ghaggar, Ravi, and Thamirabharani. High concentrations of HCH, DDT, methyl parathion, endosulfan, chlorpyrifos, dicofol, and cypermethrin have been recorded in several river systems, indicating widespread contamination (Kaushik et al., 2008; Ghose et al., 2009; Kaushik et al., 2010; Mishra and Sharma, 2011; Leena et al., 2012; Swati Singh et al., 2015; Mahboob et al., 2015). Information on pesticide contamination in Tamil Nadu water bodies is limited. Studies from Kanyakumari district reported total OCP concentrations of 5.68–25.12 μg/L in tank waters (Jayakumar et al., 2014). In the Thamirabharani River basin, OCP residues were generally higher during post-monsoon and summer seasons due to agricultural runoff and municipal discharges. Reported total OCP concentrations ranged from 0.1 to 79.9 μg/L, with heptachlor, dieldrin, DDD, and mirex being the predominant residues (James et al., 2015; Kumarasamy et al., 2017).

Long-range transport (LRT) and extensive agricultural use are major pathways for the accumulation of organochlorine pesticides (OCPs) in aquatic sediments. Assessing pesticide residues in water and sediments is essential for evaluating environmental contamination and human exposure risks, as sediments serve as important reservoirs for pesticide accumulation and for the bioavailability of pesticides to aquatic organisms (Zhang et al., 2003). Several studies worldwide have reported higher concentrations of OCPs in sediments than in corresponding water samples. In Nigerian rivers, cis-chlordane, α-endosulfan, p,p′-DDE, and dieldrin were the predominant residues in sediments (Okoya et al., 2013). Sediments from Alexandria Harbour, Egypt, showed substantial contamination by PCBs, DDTs, and chlordane compounds (Barakat et al., 2002). In Masan Bay, China, DDT was the dominant OCP, while significant levels of PCBs and PAHs were also detected (Khim et al., 1999). Similarly, sediments from the Wu-Shi River estuary in Taiwan contained OCPs ranging from 1.73 to 71.9 ng/g, with endosulfan sulfate as the predominant residue (Doong et al., 2002). Studies from Tanzania and Nigeria also reported

notable concentrations of DDT, endosulfan, and aldrin in river and lake sediments (Mwevura et al., 2002; Shinggu et al., 2015).

In India, pesticide contamination of river sediments has been reported in several river systems. Chlorpyrifos, ethion, and dicofol were the major residues detected in the sediments of the Gomti River (Singh et al., 2015). In the Ganga River at Kolkata, endosulfan concentrations were highest in summer, whereas DDT concentrations were highest in winter (Leena et al., 2012). In the Thamirabharani River basin, Kumarasamy et al. (2012) detected 17 OCPs in bottom sediments, with concentrations ranging from 0.012 to 3938.7 ng/g (dry weight). Aldrin, dieldrin, chlordane, mirex, endosulfan, and DDT were identified as the predominant residues, indicating significant historical and ongoing pesticide contamination in the basin.

5. Pesticide residues in fish & their organs

The accumulation of pesticide residues in fish and their organs largely depends on the degree of contamination in the surrounding aquatic environment, particularly water and sediments. Since sediments serve as important reservoirs of pesticides, bioaccumulation and bioconcentration in aquatic organisms are often difficult to predict. Incidents of fish mortality in various water bodies initially prompted investigations on pesticide contamination in fish. Residues in edible fish tissues are of particular concern because they can impair immune function and pose significant health risks to consumers (Svensson et al., 1994). Pesticides adversely affect fish through haematological alterations, histopathological damage, enzyme disruption, genotoxic effects, endocrine disturbances, and changes in nutrient composition (Dutta et al., 2003; Johal et al., 2007; Saeddi et al., 2012; Ullah et al., 2014; Dey and Saha, 2014; Singh et al., 2010).

Numerous studies have reported organochlorine pesticide (OCP) residues in edible fish tissues, with DDT and its metabolites the most frequently detected compounds. Other commonly reported residues include endosulfan isomers, dieldrin, aldrin, lindane, and octachlorostyrene, occurring at concentrations ranging from trace levels to 1364 ng/g lipid (Pazou et al., 2006). DDT, HCH, and HCB have also been identified as dominant contaminants in fish muscle tissues across different aquatic environments (Yang et al., 2007; Kalyoncu et al., 2009; Kafilzadeh et al., 2012). Variations in OCP concentrations have been observed among marine, freshwater, and brackish water fish species. Brackish water fish generally showed higher OCP levels than freshwater and marine species (Sankar et al., 2006). Differences were also evident among species

with different feeding habits, with carnivorous fish often exhibiting greater pesticide accumulation due to biomagnification (Zhou et al., 2007). Studies on freshwater fish have reported widespread occurrence of HCHs, DDTs, heptachlor, aldrin, chlordane, endosulfan, and dieldrin in species such as eels, tilapia, catfish, and carp (Masan, 1993; Afful et al., 2010).

Several investigations have also documented the presence of chlorpyrifos, dicofol, ethion, endosulfan, carbofuran, and DDT residues in freshwater fish tissues. In many cases, higher residue levels were detected in carnivorous species compared to herbivorous species, indicating trophic transfer and bioaccumulation within aquatic food webs. Among the OCPs, DDTs were generally the dominant residues, followed by chlordane and HCH compounds (Henry and Kishimba, 2006; Equani et al., 2013; Ezemonye et al., 2015; Singh et al., 2005). There are few studies available on the accumulation of pesticides in different organs of the fish. Hilmy *et al. (1981) reported that the accumulation of DDT and endrin residues was the highest in the liver, intermediate in the gonads and low to non-detectable levels in the* muscle and heart of the eel and mullet.

In the silver carp *(Hypophthalmichthys molitrix),* OCPs recorded were 289.26 ng/g (wet weight), mainly consisting of DDE, c-HCH, and heptachlor, and they were found at high concentrations in the brain of silver carp, followed by the kidney, liver, heart, and gill (Zhou *et al.* 2007). On the contrary, Yang *et al.* (2007) reported that gills accumulated more OCPs due to their larger surface area per unit tissue. The accumulation of pesticide residues in different organs also varied among different fish species. Gills, liver, stomach, kidney and flesh of four fish species (*Tilapia zilli, Clarias anguillaris, Hetrotis niloticus* and *Oreochronmis niloticus*) were tested for pesticide residues and found that the concentrations of all OPPs were the highest in the organs of *Oreochronmis niloticus* and the lowest in *Hetrotis niloticus*. (Akan *et al.* 2014).

Table 1. Permissible limits for OCPs in fish/meat based products (mg/kg)

S.no	Pesticides	CAC[a]	USFDA[b]	JFCRF[c]
1	∑ Aldrin	0.2	0.3	0.05
2	∑ Heptachlor	0.2	0.3	0.01
3	∑ Endosulfan	0.2	0.2	0.5
4	∑ Endrin	0.1	-	0.01
5	∑ DDT	5	5	0.5

6	∑ BHC	0.01	0.3	0.01
7	∑ Cypermethrin	2	-	0.03
8	∑ Methoxychlor	-	0.01	0.01

[a] Codex Alimentarius Commission, 2017 (CAC, 2017); [b] United States Food and Drug Administration, 2002 (USFDA, 2002) & [c] The Japan Food Chemical Research Foundation, 2010 (JFCRF,2010)

Conclusion and future scope

The widespread presence of pesticide residues in water, sediments, and fish demonstrates the persistence of these contaminants and their ability to circulate through aquatic food webs. Evidence from numerous studies indicates that OCPs and OPPs remain major pollutants despite regulatory restrictions, posing risks to aquatic organisms and human populations through dietary exposure. Sediments function as important sinks for pesticide accumulation, while fish act as bioindicators of environmental contamination and potential health hazards. The continued detection of legacy pesticides such as DDT, HCH, aldrin, dieldrin, and endosulfan highlights the long-term consequences of pesticide use and environmental persistence. Future research should emphasise the integrated monitoring of water, sediments, and aquatic organisms, using advanced techniques for trace-level contaminant detection. Greater attention is needed on emerging pesticides, mixture toxicity, and their long-term ecological and human health impacts. Strengthening risk assessment through long-term studies and region-specific standards is essential. Adoption of integrated pest management, precision agriculture, biopesticides, and farmer awareness programs can help minimise pesticide contamination and promote sustainable environmental and public health protection.

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FARMING WITH SEAWATER: A NEW FRONTIER IN AGRICULTURE

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Abstarct

Seawater agriculture uses seawater to irrigate salt-tolerant crops either on land or on the surface of the sea. Developing seawater agriculture is an important mitigation strategy to address food insecurity due to freshwater scarcity. Traditional agriculture consumes nearly 70% of the world's freshwater. With groundwater depleting and drought occurs, humanity must look to an unconventional resource: the ocean. Covering over 70% of the Earth's surface, seawater is our most abundant water source. Farming with seawater, or halophytic agriculture, is a revolutionary frontier to feed a growing population without draining freshwater reserves. In practice, the formulation of regarding seawater agriculture should focus on four aspects: 1) Top-level design planning and optimization of resources, 2) increasing financial support as well as enhancing the capacity of science and technology, 3) strengthening environmental protection and improving the safety aspects of production, and 4) supporting the diversification of business.Increasing in world population ,mainly focuses on seawater agriculture may be a crucial driving force in delivering food security.

Introduction

The concept is based on the cultivation of halophytes, plants that naturally thrive in salty

conditions such as coastal marshes and mangrove ecosystems.it is important for arid and semi-arid regions. It also reduces the dependency on freshwater which helps to conserve rivers, lake and groundwater for future use. There are over 40 saltwater plants that can be grown via low-input aquaculture providing edible salt-tolerant products. Seawater Solutions are the first operation in the UK to grow halophytic plants on farmland. In fact, they are the first in Europe to redevelop farmland to introduce wetland ecosystems, and artificially introduce seawater. "Regenerative Seawater Agriculture (RAS) system" introduced salt-tolerant species and ecologies onto degraded land to restore the ecosystems while producing valuable agricultural products.

Need for seawater farming :

- High-value 'superfoods' (such as Samphire) for domestic and international markets
- Increased incomes in a context of diminishing market returns
- Increased yields and soil health
- Support moving towards organic, no-tillage and regenerative farming practices
- Promotion of wildlife through ecosystem restoration/creation
- Defence of their coastlines from rising sea-levels
- Significantly increased carbon capture potential of their land.

The Science Behind Saltwater Crops

Most commercial crops are glycophytes, meaning they die when exposed to high salt levels. Salt disrupts their osmotic balance, preventing roots from absorbing water and causing cellular toxicity.

Seawater agriculture relies on **halophytes**—plants naturally evolved to thrive in saline environments. These specialized plants utilize mechanisms to survive:

- **Salt Exclusion:** Roots block salt while absorbing water.
- **Salt Excretion:** Leaves pump excess salt out through specialized glands.
- **Salt Sequestration:** Plant cells store salt safely inside large vacuoles to protect metabolic processes.

Promising Crops and Technologies

Farmers and scientists are utilizing two primary methods to harvest food from the ocean: direct cultivation of wild halophytes and the engineering of salt-tolerant staples.

1. Salicornia (Sea Asparagus)

Salicornia is the poster child of seawater agriculture. It grows in pure seawater and yields crunchy, naturally salty succulent twigs. It is highly nutritious, rich in antioxidants, and its seeds can be pressed into high-quality, protein-rich cooking oil.

2. Salt-Tolerant Staples

Researchers are using selective breeding and gene-editing technologies like CRISPR to introduce halophytic traits into everyday crops. Progress is already visible in the development of sea-water rice, salt-tolerant wheat, and barley varieties that can be irrigated with diluted seawater.

3. Integrated Marine Agriculture

Innovative coastal farms use a circular system called Integrated Multi-Trophic Aquaculture (IMTA). Waste water from commercial shrimp or fish ponds—naturally rich in nutrients—is channeled to irrigate coastal halophyte fields. This filters the water safely before it returns to the ocean while producing a secondary cash crop.

Benefits of seawater farming :

- Play a role in stopping the erosion and developing carbon sinks.
- Helps in providing biofuel and animal feed production.
- The saltwater acts as a natural pesticide and with the nutrients from the sea coming in with the tides, there is little need for fertilizer, and no irrigation issues.
- Helps in restoring of marshlands, river deltas, mangroves, estuaries, coastal wetlands and desertified regions
- Create opportunities for multi-cropping as well as the development of established hydroponics and aquaculture techniques.
- **Freshwater Preservation:** Saves precious drinking water for human consumption.
- **Arid Land Reclamation:** Turns barren coastal deserts into productive green zones.

Biofuel Production: Certain oil-rich halophytes provide sustainable biomass for fuel purpose.

Case study :

A Bangladesh farmer watering Salicornia seeds just after sowing. This site has never been cultivated before and is only meters away from the ocean. While COP26 was in full swing in Glasgow and winter set in, Seawater Solutions were active in Teknaf, Bangladesh – a region heavily impacted by the Rohingya refugee crisis. In 2017 around one million refugees from the Rohingya minority in Myanmar flooded into Teknaf, resulting in a humanitarian crisis. Although

the refugees are the main victims, immense pressure was also placed on the land and communities there before the crisis.

Challenges on the Horizon

Setting up coastal irrigation infrastructure requires heavy initial capital And Farmer awareness and access to technologies require investment in training and extension services .Over-irrigation can lead to salt accumulation in the upper soil layers, leads to cause poor soil fertile if not managed properly. Furthermore, introducing unfamiliar foods like Salicornia into mainstream global diets requires a shift in consumer habits and culinary marketing .Research is needed to develop more salt- tolerant crop varieties.

Conclusion:

Seawater agriculture is an innovative approach that uses the vast resources of the oceans to support food production .Although challenge remain, advances in science and technology are making easier to implement it. It has potential to become a key component of future Agricultur.

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UTILIZATION OF DAMMER BEE CERUMEN IN COSMETIC SCIENCE

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Introduction

The global cosmetics industry is increasingly seeking natural, sustainable, and biologically active ingredients. While propolis from *Apis mellifera* (the European honeybee) has been extensively studied, a chemically distinct and potentially equally valuable product from stingless bees **cerumen** begins to attract scientific attention. Produced by dammer bees such as *Tetragonula iridipennis*, cerumen is a complex mixture of plant latex, resin, bee wax, and other bee secretions. Unlike the propolis of honeybees, which is used primarily for sealing and sanitizing the hive, cerumen serves as the primary construction material for stingless bee nests, including brood cells, storage pots, and involucrum. This article reviews the chemical composition, biological properties, and emerging cosmetic applications of dammer bee cerumen.

Chemical Composition and Botanical Origins

The chemical profile of dammer bee cerumen is remarkably complex and varies significantly depending on the botanical sources available to foraging bees. For *Tetragonula iridipennis*, foragers collect plant latex and resin from diverse species including *Artocarpus heterophyllus*, *Calotropis gigantea*, *Ficus bengalensis*, *F. religiosa*, *Mangifera indica*, *Tabernaemontana divaricata*, and *Vachellia nilotica*. Resin foragers are less numerous than nectar or pollen foragers, spending more time per foraging bout and performing fewer trips per day.

Chemically, the cerumen of Indian stingless bees is predominantly of the 'gallic acid–naringin' type, which may also contain sugars, steroids, and terpenes; the composition varies with its latex and resin sources. Studies on Australian *Tetragonula carbonaria* cerumen have identified distinct GC-MS fingerprints with a mixed diterpenic profile, featuring pimaric acid (6.31 ± 0.97% w/w), isopimaric acid (12.23 ± 3.03% w/w), and gallic acid (5.79 ± 0.81% w/w) as useful chemical markers.

Biological Activities: The Scientific Rationale for Cosmetic Use

The presence of these bioactive compounds endows dammer bee cerumen with a suite of properties highly desirable in dermatological and cosmetic applications.

Antimicrobial Activity: Terpenes, a significant component of the cerumen, provide substantial antimicrobial activities against broad-spectrum pathogens. Studies on African *Meliponula ferruginea* cerumen have confirmed its antimicrobial and anti-quorum sensing properties. This property is invaluable for cosmetic products designed for acne-prone skin or as natural preservatives in formulations.

Antioxidant Activity: The phenolic and flavonoid contents of cerumen provide antioxidant activities. Research on Australian *Tetragonula carbonaria* cerumen demonstrated antioxidant activity using Ferric Reducing Antioxidant Power (FRAP) assays, with values ranging from 5.19 ± 0.40 to 16.2 ± 0.70 mmol Fe^{2+}/kg of raw cerumen, and total phenolic content values from 3.77 ± 0.12 to 81.3 ± 2.04 mg GAE/g of raw cerumen. High-performance thin-layer chromatography (HPTLC) analysis revealed the presence of gallic acid and kaempferol in ethanolic extracts, which contribute to this antioxidant activity. These compounds neutralise free radicals, a primary cause of premature skin ageing.

Anti-inflammatory Activity: Cerumen extracts from *T. carbonaria* have been shown to inhibit 5-lipoxygenase (5-LOX), an enzyme that catalyses the production of pro-inflammatory mediators, with an IC_{50} of 19.97 ± 2.67 µg/ml. The extracts demonstrated similar potency to Trolox (IC_{50} 12.78 ± 1.82 µg/ml). This anti-inflammatory activity makes cerumen a valuable candidate for soothing irritated or sensitive skin.

Anticancer Activity: Cerumen extract has also demonstrated significant anticancer activity against several cancer cell lines, further underscoring its broad therapeutic potential.

A comprehensive review by Al-Hatamleh et al. (2020) highlights the medicinal benefits of stingless bee products—including honey, propolis, pollen, and cerumen emphasizing their

potential antioxidant properties that play a vital role in preventing and treating diseases associated with oxidative stress, microbial infections, and inflammatory disorders.

Cerumen in Cosmetic Formulations

i). Skincare and Moisturisation: The waxy, resinous nature of cerumen makes it an excellent emollient. It can form a protective, occlusive layer on the skin that locks in moisture and reduces trans-epidermal water loss. Its inherent antimicrobial and antioxidant properties provide added functional benefits beyond simple hydration. Cerumen is already finding applications in the beauty industry for artisanal products including natural lip balms, solid perfumes, and eco-friendly surfboard wax.

ii). Anti-Ageing and Anti-Wrinkle Products: The potent antioxidant and anti-inflammatory properties of cerumen position it as a promising anti-ageing ingredient. By neutralizing free radicals and reducing inflammation, it can help prevent the degradation of collagen and elastin.

iii). Anti-Acne and Clarifying Treatments: The antimicrobial and anti-inflammatory actions of cerumen make it suitable for products targeting acne, helping to combat acne-causing bacteria while soothing associated inflammation-.

Challenges and Future Perspectives

Several challenges remain. The primary obstacle is the lack of standardized information on chemical composition, as cerumen from different species and geographic locations can have vastly different profiles-. Additionally, the supply chain is underdeveloped stingless beekeeping (Meliponiculture) is less prevalent than traditional apiculture, and cerumen yield per hive is relatively low. Safety considerations also warrant attention: while generally recognized as safe, allergic contact dermatitis to bee products is documented, necessitating patch testing and appropriate concentration limits. Future research should focus on standardizing extracts, conducting rigorous human clinical trials, establishing sustainable sourcing practices through meliponiculture, and exploring advanced delivery systems to enhance stability and skin penetration.

Conclusion

Dammer bee cerumen represents a promising frontier in cosmetic science. Its unique composition a sophisticated blend of plant resins, waxes, and bee secretions confers remarkable antimicrobial, antioxidant, anti-inflammatory, and wound-healing properties. While often

confused with propolis, cerumen is a chemically and functionally distinct material with immense potential for developing multifunctional, natural skincare products.

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COVID-19 PANDEMIC AND WOMEN POULTRY FARMERS: ASSESSING LIVELIHOOD VULNERABILITY AND EMPOWERMENT IN SMALLHOLDER COOPERATIVES

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Abstract

The COVID-19 pandemic exposed the vulnerability of agricultural and livestock-based livelihoods across the world. Among the most severely affected were rural women engaged in smallholder poultry farming, whose livelihoods depend heavily on uninterrupted production, efficient market access, and stable value chains. Lockdowns, transportation restrictions, misinformation regarding poultry products, and declining consumer demand resulted in substantial economic losses and social hardships.This article presents the major findings of a field investigation conducted among women poultry farmers associated with smallholder cooperatives in Dindori district of Madhya Pradesh. The study evaluated the pandemic's influence on livelihood vulnerability and women's empowerment using scientifically validated indices. The findings demonstrate that COVID-19 affected household income, access to productive resources, marketing opportunities, financial security, workload, and psychological well-being. At the same time, women displayed remarkable resilience by maintaining poultry production under highly challenging circumstances.The article discusses practical lessons for strengthening women-led poultry enterprises through improved extension services, institutional support, digital advisory systems, credit accessibility, market resilience, and policy interventions aimed at ensuring sustainable rural livelihoods.

Keywords: COVID-19, Women Empowerment, Poultry Farming, Livelihood Vulnerability, Smallholder Cooperatives, Rural Development, Extension Education.

Introduction

Livestock farming plays a vital role in strengthening rural livelihoods, improving household nutrition, and generating employment opportunities across developing countries. Among various livestock enterprises, poultry farming has emerged as one of the fastest-growing sectors because of its relatively low investment requirements, rapid returns, and suitability for resource-poor households. For millions of rural women, particularly those belonging to tribal and economically weaker communities, poultry farming provides an important source of income and financial independence.

Women contribute significantly to feeding, watering, health care, housing management, and marketing activities in backyard and commercial poultry production systems. Their participation not only enhances household income but also strengthens food security, nutritional status, and decision-making capacity within families. Consequently, women-centred poultry cooperatives have become an effective model for promoting inclusive rural development.

However, the unprecedented outbreak of COVID-19 in 2020 created one of the most severe crises faced by the poultry sector in recent decades. Nationwide lockdowns interrupted transportation, disrupted input supply chains, restricted market access, and caused a sharp decline in consumer demand. Furthermore, widespread misinformation linking poultry products with coronavirus transmission created panic among consumers, leading to heavy economic losses for poultry producers despite the absence of scientific evidence supporting such claims.

Smallholder women poultry farmers were among the worst affected because they possessed limited financial reserves, restricted access to institutional credit, inadequate market alternatives, and heavy dependence on poultry as their primary livelihood source. Besides income loss, women experienced increased household responsibilities, reduced mobility, psychological stress, and limited access to veterinary and extension services during the pandemic.

Understanding these multidimensional impacts is essential for designing resilient livestock development programmes and strengthening women's empowerment in rural communities. The present study therefore examined the effect of COVID-19 on livelihood vulnerability and empowerment among women poultry farmers belonging to smallholder cooperatives in Dindori district of Madhya Pradesh. The findings provide valuable insights for researchers, extension professionals, policymakers, and development organizations working

towards sustainable livestock-based rural livelihoods.Study Background and Research Methodology

The poultry sector has emerged as one of the most dynamic components of Indian agriculture, contributing significantly to employment generation, nutritional security, and rural income. In tribal regions of Madhya Pradesh, poultry farming has become an important livelihood enterprise for women because it requires comparatively low investment while providing regular cash income. Women actively participate in feeding, watering, cleaning, vaccination, disease management, record keeping, and marketing of poultry birds.

The COVID-19 pandemic, however, created unprecedented challenges for this sector. Nationwide lockdowns disrupted transportation, restricted market access, interrupted feed supply, and affected veterinary service delivery. In addition, misinformation regarding the transmission of coronavirus through poultry products severely reduced consumer demand, resulting in substantial financial losses for poultry farmers.

Recognizing the importance of understanding these impacts, the present investigation was conducted in Dindori district of Madhya Pradesh. The district was purposively selected because of its large tribal population and the active participation of women in organized poultry farming through smallholder cooperatives. The study focused on members of the Rani Durgawati Murgi Palak Sahkari Samiti Maryadit, operating under the National Smallholder Poultry Development Trust (NSPDT).

An ex-post facto research design was adopted because the pandemic had already occurred and its effects could not be experimentally manipulated. A scientifically selected sample of 202 women poultry farmers from Amarpur and Samnapur blocks was included in the study using stratified random sampling techniques. Primary data were collected through personal interviews using a pre-tested and validated interview schedule.

To evaluate women's empowerment, the study employed the Women Empowerment in Livestock Index (WELI) with suitable modifications to reflect the pandemic situation. Eight dimensions of empowerment—including agricultural production, nutrition and food security, access to productive resources, control over income, access to opportunities, workload, financial impact, and mental stress—were assessed.

Similarly, livelihood vulnerability was measured through a specially developed COVID-19 Livelihood Vulnerability Index comprising indicators such as socio-demographic vulnerability, livelihood strategies, healthcare accessibility, social networking, credit accessibility, nutritional security, housing and hygiene, vocational vulnerability, and the influence of misinformation. Standard statistical procedures were used to analyse changes across different phases of the pandemic.

The adoption of standardized indices and scientifically validated methodologies ensured that the findings accurately reflected the socio-economic realities experienced by women poultry farmers during one of the most challenging periods in recent history.

Socio-economic Profile and Major Findings

The socio-economic profile of the respondents provides valuable insights into the characteristics of women involved in smallholder poultry farming in Dindori district. The findings indicate that poultry farming has become an important livelihood activity for economically weaker and tribal households, particularly for women who play a central role in managing day-to-day farm operations.

The study revealed that 75.74% of the respondents belonged to the young age group (30–40 years), indicating that rural women in their economically productive years are actively engaged in poultry farming. Educational attainment was generally low, with 63.86% having completed only primary education, while 25.74% were illiterate. None of the respondents had attained graduate-level education. These findings emphasize the need for simple, practical, and locally relevant extension programmes for capacity building.

Animal husbandry emerged as the primary occupation for 60.39% of the respondents, highlighting the sector's contribution to rural livelihoods. Nearly half (48.51%) of the respondents belonged to medium-sized families, while 78.71% lived in nuclear families. Landholding patterns showed that 65.84% were marginal farmers, confirming that poultry farming serves as an important livelihood option for resource-poor households.

Economic analysis further demonstrated the limited financial resources available to the respondents. More than half (54.45%) belonged to the low annual income category. However, poultry farming continued to contribute substantially to household income, with 63.36% earning a medium level of annual income from poultry enterprises. The majority (62.87%) maintained

flocks of 300–500 birds, reflecting the importance of cooperative-based commercial poultry production in the study area.

The COVID-19 pandemic significantly affected the livelihood security of these women. Lockdowns disrupted transportation and marketing channels, making it difficult to sell poultry birds at remunerative prices. Reduced consumer demand, largely driven by misinformation regarding poultry consumption, further aggravated economic losses. Access to feed, veterinary services, financial resources, and extension support also became increasingly difficult during the lockdown period.

The study clearly demonstrated that livelihood vulnerability increased considerably during the pandemic. Women experienced reduced access to productive resources, financial insecurity, limited marketing opportunities, and increased household responsibilities. In addition to economic losses, psychological stress increased because of uncertainty regarding income, disease risk, and family welfare.

Assessment of women's empowerment revealed that several dimensions—including access to productive resources, control over income, participation in decision-making, access to opportunities, and financial autonomy—were adversely affected during the lockdown. Nevertheless, the findings also highlighted the resilience of women poultry farmers. Despite multiple constraints, they continued poultry management, supported household food security, and contributed significantly to sustaining family livelihoods.

Overall, the results underline the importance of women-led poultry cooperatives in enhancing livelihood resilience. The experience of the COVID-19 pandemic demonstrates that strengthening extension services, institutional support, market linkages, and scientific communication can substantially reduce the vulnerability of rural women poultry farmers during future emergencies.

Practical Recommendations

The findings of the present investigation provide important lessons for strengthening the resilience of women poultry farmers against future crises. Since poultry farming is an essential livelihood enterprise for rural and tribal women, coordinated efforts from government agencies, veterinary institutions, cooperatives, financial organizations, and extension professionals are required.

The following recommendations are suggested:

1. Strengthening Women Poultry Cooperatives

Women-led poultry cooperatives should be strengthened through financial assistance, technical guidance, and institutional support. Cooperative-based production systems improve bargaining power, reduce marketing risks, and enhance collective resilience during emergencies.

2. Scientific Awareness and Risk Communication

The COVID-19 pandemic demonstrated how misinformation can severely damage the poultry industry. Regular awareness campaigns using television, radio, newspapers, mobile applications, and social media should disseminate scientifically validated information regarding poultry production and food safety.

3. Improved Extension and Veterinary Services

Digital extension services, tele-advisory platforms, mobile veterinary clinics, and village-level advisory systems should be expanded to ensure uninterrupted technical support during emergencies.

4. Access to Credit and Insurance

Easy availability of institutional credit, emergency financial assistance, and livestock insurance schemes should be ensured for women poultry farmers to reduce financial vulnerability during unexpected crises.

5. Capacity Building

Regular training programmes should be organized on scientific poultry management, disease prevention, biosecurity measures, value addition, entrepreneurship development, digital marketing, and financial management to improve farmers' adaptive capacity.

6. Strengthening Market Linkages

Development of decentralized poultry marketing systems, farmer producer organizations (FPOs), digital marketing platforms, and direct consumer linkages can minimize market disruptions during future emergencies.

Policy Implications

The study emphasizes that women should be recognized not merely as beneficiaries but as key stakeholders in livestock development programmes. Policies promoting women's participation in producer organizations, access to extension education, financial inclusion, and decision-making processes will significantly contribute to sustainable rural development.

Government programmes should integrate gender-sensitive approaches within livestock development strategies so that women receive equal opportunities for skill development, institutional support, and entrepreneurship promotion.

Conclusion

The COVID-19 pandemic highlighted both the vulnerability and resilience of women poultry farmers. While lockdowns, misinformation, and market disruptions negatively affected livelihoods and empowerment, rural women demonstrated remarkable determination in sustaining poultry production under extremely challenging circumstances.

The study concludes that strengthening extension education, improving veterinary support, promoting cooperative-based poultry farming, enhancing access to institutional credit, and ensuring effective scientific communication are essential for building resilient poultry production systems.

Investment in women poultry farmers is not merely an investment in livestock production; it is an investment in household nutrition, rural employment, women's empowerment, and sustainable agricultural development. Building resilient women-led poultry enterprises will play a crucial role in achieving inclusive growth and strengthening India's rural economy.

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AN OVERVIEW OF FELINE VIRAL DISEASES

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Introduction

Feline infectious diseases are illnesses caused by viruses, bacteria, fungi, or parasites that can spread between cats or from the environment. These diseases are a major cause of illness and death in domestic cats, especially kittens, elderly cats, and cats with weakened immune systems. Some infectious diseases are highly contagious, while others spread through direct contact, contaminated food or water, insect bites, or contact with infected animals.

Early diagnosis, proper vaccination, good hygiene, and routine veterinary care are the most effective ways to prevent these diseases. Understanding the causes, symptoms, diagnosis, treatment, and prevention of feline infectious diseases is essential for cat owners, veterinarians, and animal health professionals.

Feline Panleukopenia (Feline Distemper)

Feline Panleukopenia (FP), commonly known as **feline distemper**, is a highly contagious and life-threatening viral disease of cats caused by the **Feline Panleukopenia Virus (FPV)**, which belongs to the *Parvoviridae* family. The disease primarily affects kittens, unvaccinated cats, and immunocompromised animals because the virus attacks rapidly dividing cells in the body, particularly those in the bone marrow, intestinal lining, and developing fetus. As a result, infected cats experience a severe reduction in white blood cells, making them highly susceptible to secondary infections.

The virus spreads through direct contact with infected cats or indirectly through contaminated feces, urine, saliva, vomit, food and water bowls, litter trays, bedding, cages, and even on the hands, clothing, or shoes of people who have handled infected animals. The virus is

extremely resistant in the environment and can survive for many months, making it difficult to eliminate without proper disinfection. Pregnant cats infected with the virus can also transmit it to their unborn kittens, resulting in developmental abnormalities such as cerebellar hypoplasia.

The clinical signs of feline panleukopenia usually appear within two to seven days after infection. Affected cats commonly develop a sudden high fever, severe depression, loss of appetite, vomiting, watery or bloody diarrhea, dehydration, abdominal pain, weakness, and rapid weight loss. In many cases, kittens become severely ill within a short period, and sudden death may occur before obvious clinical signs develop. Because the virus destroys white blood cells, infected cats have weakened immune systems and are more vulnerable to bacterial infections.

Diagnosis is based on the cat's medical history, vaccination status, clinical signs, and laboratory findings. Veterinarians typically perform a complete blood count (CBC), which often reveals a marked decrease in white blood cells, a characteristic feature of the disease. Additional diagnostic tests, including fecal antigen ELISA tests and polymerase chain reaction (PCR) assays, may be used to confirm the presence of the virus.

There is no specific antiviral treatment for feline panleukopenia; therefore, therapy focuses on supportive care aimed at maintaining the cat's condition while the immune system fights the infection. Treatment generally includes intravenous fluid therapy to correct dehydration, electrolyte replacement, broad-spectrum antibiotics to prevent secondary bacterial infections, antiemetic medications to control vomiting, nutritional support, and blood or plasma transfusions in severe cases. Infected cats should also be isolated from healthy animals to prevent transmission of the virus.

Prevention is the most effective method of controlling feline panleukopenia. Routine vaccination of kittens and adult cats provides excellent protection against the disease and is considered one of the core vaccinations recommended for all cats. Good hygiene, regular cleaning and disinfection of the environment with appropriate disinfectants, quarantine of newly introduced cats, and prompt isolation of infected animals are essential measures to reduce the spread of the virus.

The prognosis for feline panleukopenia depends on the age of the cat, the severity of the infection, and how quickly treatment is initiated. Cats that receive early and intensive supportive care have a significantly higher chance of recovery, whereas very young kittens and severely affected animals often have a poor prognosis. Overall, feline panleukopenia remains one of the

most serious infectious diseases of cats, but widespread vaccination and proper disease management have greatly reduced its occurrence and improved survival rates.

Feline Upper Respiratory Infection (Cat Flu)

Feline Upper Respiratory Infection (URI), commonly known as **cat flu**, is one of the most common infectious diseases affecting domestic cats worldwide. It is a contagious disease that primarily affects the upper respiratory tract, including the nose, throat, sinuses, and eyes. The infection is most commonly caused by **Feline Herpesvirus-1 (FHV-1)** and **Feline Calicivirus (FCV)**, although bacteria such as *Chlamydia felis*, *Mycoplasma felis*, and *Bordetella bronchiseptica* may also contribute to the disease. Kittens, elderly cats, shelter cats, and cats with weakened immune systems are particularly susceptible to infection.

The disease spreads rapidly through direct contact with infected cats or indirect contact with contaminated food bowls, water dishes, bedding, litter boxes, grooming equipment, and the hands or clothing of people who have handled infected animals. Infected cats release the virus through nasal secretions, eye discharge, and saliva during sneezing or coughing. Cats infected with feline herpesvirus may remain lifelong carriers, with the virus becoming active again during periods of stress or illness.

The incubation period of feline upper respiratory infection is usually between two and ten days, after which affected cats develop a variety of clinical signs. The most common symptoms include frequent sneezing, nasal congestion, clear or thick nasal discharge, watery or sticky eye discharge, conjunctivitis, coughing, fever, lethargy, and loss of appetite. Cats infected with feline calicivirus may also develop painful ulcers on the tongue, gums, palate, or nose, making eating difficult. In severe cases, especially in young kittens, pneumonia, dehydration, and breathing difficulties may occur.

Diagnosis of feline upper respiratory infection is generally based on the cat's medical history, vaccination status, and characteristic clinical signs observed during physical examination. Laboratory tests such as polymerase chain reaction (PCR), viral isolation, bacterial culture, and cytological examination of nasal or eye secretions may be performed to identify the specific infectious agent, particularly in severe or recurrent cases.

Treatment mainly focuses on relieving clinical signs and preventing secondary bacterial infections because viral infections cannot usually be cured with antibiotics. Supportive care includes maintaining hydration through fluid therapy, providing highly palatable and nutritious

food, cleaning nasal and eye discharges regularly, and ensuring the cat rests in a warm, stress-free environment. Broad-spectrum antibiotics may be prescribed if secondary bacterial infections are suspected, while antiviral medications may be used in selected cases of feline herpesvirus infection. Nebulization and humidified air can also help reduce nasal congestion and improve breathing.

Prevention of feline upper respiratory infection relies primarily on routine vaccination against feline herpesvirus and feline calicivirus, which are included in the core vaccination schedule for cats. Although vaccination may not completely prevent infection, it significantly reduces the severity of clinical signs and the risk of complications. Maintaining good hygiene, disinfecting food bowls and litter boxes, avoiding overcrowding, isolating infected cats, reducing stress, and providing regular veterinary care are also essential measures for controlling the spread of the disease.

The prognosis for feline upper respiratory infection is generally good in healthy adult cats receiving appropriate care, with most recovering within one to three weeks. However, kittens, elderly cats, and immunocompromised animals may experience more severe disease, prolonged illness, or chronic respiratory problems. Early diagnosis, supportive treatment, and preventive vaccination play a crucial role in reducing illness and improving recovery.

Feline Infectious Peritonitis (FIP)

Feline Infectious Peritonitis (FIP) is a serious, progressive, and often fatal viral disease of cats caused by a mutation of the **feline coronavirus (FCoV)**. While feline coronavirus is common and usually causes mild intestinal disease or no clinical signs at all, in a small number of infected cats the virus mutates inside the body, allowing it to infect white blood cells and spread throughout the body. This abnormal immune response leads to widespread inflammation and the development of FIP. The disease is most commonly seen in kittens and young cats under two years of age, although cats of any age can be affected. Cats living in shelters, breeding catteries, or multi-cat households are at greater risk because feline coronavirus spreads easily in these environments.

The original feline coronavirus is transmitted mainly through the fecal–oral route. Cats become infected by ingesting virus particles present in contaminated litter boxes, food bowls, water, or the environment. However, the mutated virus that causes FIP generally develops within the infected cat and is not considered to spread directly from one cat to another. Stress,

overcrowding, poor nutrition, and weakened immunity may increase the likelihood of the virus mutating and causing disease.

FIP occurs in two major forms, known as the **effusive (wet) form** and the **non-effusive (dry) form**. The wet form is characterized by the accumulation of fluid in the abdomen or chest, causing abdominal enlargement, difficulty breathing, and weight loss. The dry form does not produce significant fluid accumulation but instead causes inflammatory lesions in organs such as the kidneys, liver, eyes, brain, and nervous system. Some cats may show features of both forms. The clinical signs of FIP vary depending on the organs affected but commonly include persistent fever that does not respond to antibiotics, loss of appetite, weight loss, lethargy, poor growth in kittens, anemia, and depression. Cats with the wet form often develop a swollen abdomen due to fluid accumulation or experience breathing difficulties because of fluid around the lungs. Cats with the dry form may develop eye inflammation, vision problems, jaundice, kidney disease, seizures, loss of balance, tremors, or paralysis if the nervous system is involved.

Diagnosing FIP can be challenging because its signs resemble those of many other diseases, and no single test can confirm every case. Veterinarians diagnose the disease by evaluating the cat's medical history, clinical signs, physical examination findings, blood tests, analysis of abdominal or chest fluid, imaging techniques such as ultrasound or radiography, and molecular tests such as polymerase chain reaction (PCR). In some cases, biopsy and histopathological examination of affected tissues are required to confirm the diagnosis.

In recent years, the treatment of FIP has improved significantly with the development of antiviral medications such as **GS-441524**, which have shown high success rates in many cats when treatment is started early. Supportive care, including intravenous fluids, nutritional support, anti-inflammatory medications when appropriate, and treatment of secondary complications, also plays an important role in recovery. Early diagnosis and prompt treatment greatly improve the chances of survival.

Prevention of FIP focuses on reducing exposure to feline coronavirus and maintaining good overall health. Good hygiene, frequent cleaning of litter boxes, avoiding overcrowding, minimizing stress, providing balanced nutrition, and regular veterinary check-ups help reduce the risk of infection. Although a vaccine against FIP has been developed, its effectiveness is limited and it is not routinely recommended in many vaccination programs.

The prognosis for cats with untreated FIP is poor because the disease is progressive and often fatal. However, the availability of effective antiviral therapy has transformed the outlook for many affected cats, with a large proportion achieving long-term recovery when diagnosed and treated promptly. Continued research and advances in antiviral treatment are improving survival rates and offering hope for cats diagnosed with this once almost universally fatal disease.

Rabies

Rabies is a highly contagious and almost invariably fatal viral disease that affects the central nervous system of all warm-blooded animals, including cats, dogs, wildlife, and humans. The disease is caused by the **rabies virus**, which belongs to the genus *Lyssavirus* in the family *Rhabdoviridae*. Although rabies is less common in cats than in some wild animals, infected cats pose a significant public health risk because the disease is zoonotic, meaning it can be transmitted from animals to humans. Once clinical signs appear, rabies is nearly always fatal, making prevention through vaccination extremely important.

The rabies virus is most commonly transmitted through the bite of an infected animal, as the virus is present in high concentrations in saliva. Less commonly, infection may occur if infected saliva comes into contact with open wounds or mucous membranes such as the eyes, nose, or mouth. Cats that are allowed to roam outdoors are at greater risk of exposure through contact with infected wildlife, including bats, foxes, raccoons, or other rabid animals, depending on the geographic region.

After entering the body through a bite wound, the virus initially multiplies in muscle tissue before traveling along peripheral nerves to the brain and spinal cord. Once it reaches the central nervous system, it causes severe inflammation of the brain and eventually spreads to the salivary glands, allowing transmission to other animals through bites. The incubation period is variable and may range from several weeks to several months, depending on the location of the bite, the amount of virus introduced, and the animal's immune status.

The clinical signs of rabies generally progress through several stages. Early signs may include fever, loss of appetite, behavioral changes, anxiety, nervousness, or unusual friendliness. As the disease progresses, affected cats may become aggressive, irritable, hypersensitive to light and sound, and prone to biting without provocation. Excessive salivation, difficulty swallowing, changes in vocalization, muscle tremors, lack of coordination, and paralysis are common in the later stages. Eventually, the disease progresses to respiratory failure, coma, and death.

Diagnosis of rabies in living animals is difficult because the clinical signs resemble those of several neurological disorders. Veterinarians usually suspect rabies based on the animal's history, vaccination status, and neurological symptoms. Definitive diagnosis is made only after death by examining brain tissue using laboratory techniques such as the direct fluorescent antibody (DFA) test or molecular diagnostic methods.

There is no effective treatment for rabies once clinical signs develop. Because the disease is almost always fatal and poses a serious risk to public health, animals showing signs consistent with rabies are managed according to local veterinary and public health regulations. If a person is bitten or exposed to a suspected rabid animal, immediate wound washing and prompt medical evaluation for post-exposure prophylaxis are essential to prevent infection.

Prevention is the most effective method of controlling rabies. Routine vaccination of cats, particularly those that spend time outdoors, provides strong protection against the disease and is legally required in many countries. Preventing contact with wild animals, keeping cats indoors whenever possible, supervising outdoor activities, and reporting suspected rabid animals to veterinary or public health authorities are also important preventive measures.

The prognosis for rabies is extremely poor because the disease is almost always fatal once clinical signs appear. However, rabies is entirely preventable through regular vaccination, responsible pet ownership, and public health measures. Continued vaccination programs, surveillance, and public awareness remain essential for protecting both animal and human health from this deadly disease.

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MICROPROPAGATION OF BAMBOO : A BIOTECHNOLOGICAL APPROACH FOR SUSTAINABLE PRODUCTION

Article ID: AG-VO6-I07-90

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Abstract

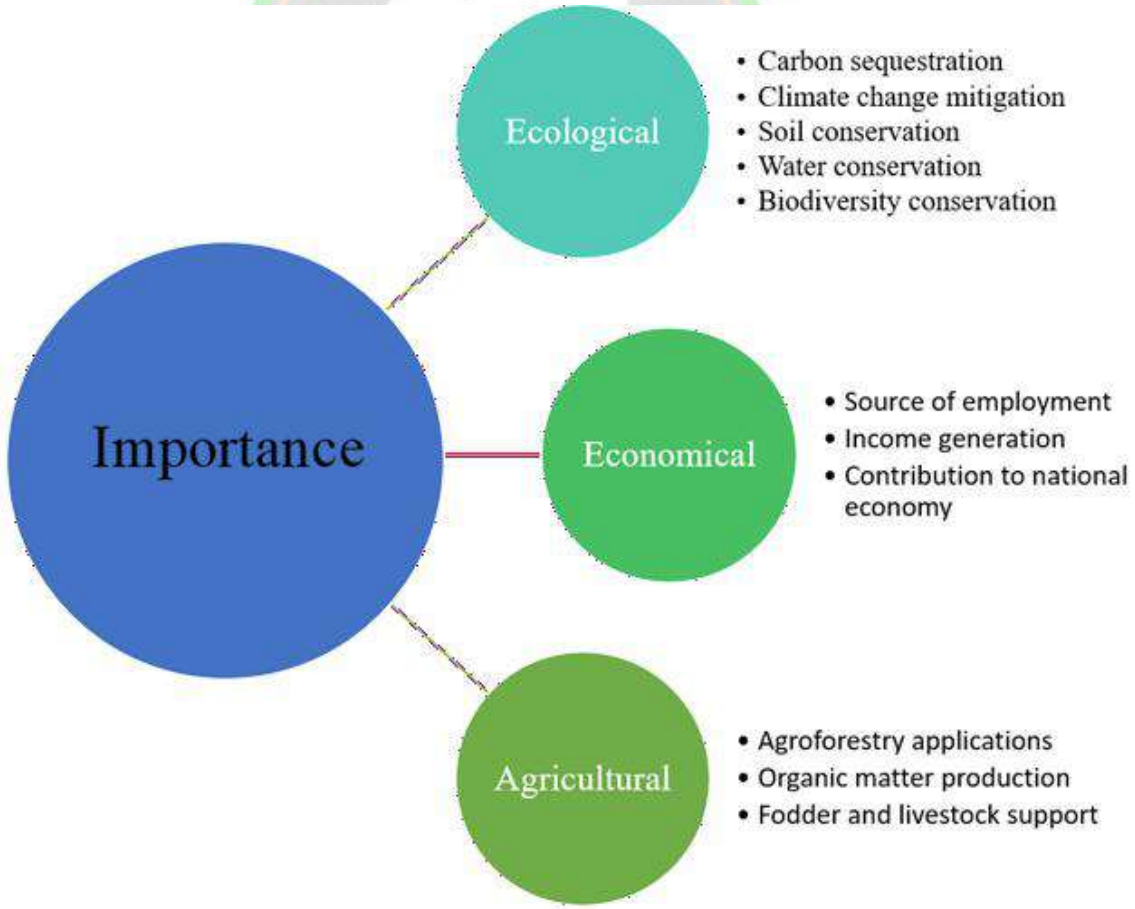
Bamboo is a fast-growing, renewable natural resource with significant ecological, economic, and industrial importance. It plays a vital role in sustainable development, carbon sequestration, environmental conservation, and the production of eco-friendly materials. However, conventional propagation methods are constrained by irregular flowering, poor seed availability, low multiplication rates, and disease transmission. Micropropagation has emerged as an efficient biotechnology tool for the rapid production of disease-free, genetically uniform planting material. Recent advances in tissue culture, including optimized nutrient media, plant growth regulators, molecular markers, and genetic transformation, have further improved propagation efficiency and plant quality. In addition, artificial intelligence and automation are being integrated into tissue culture systems to enhance culture monitoring, contamination detection, and process optimization. This review highlights recent advances in bamboo micropropagation and emphasizes its potential for sustainable cultivation, conservation, and large-scale commercial production.

Keywords: Micropropagation, Bamboo, Initiation, Propagation, Multiplication, Sterilization and Biotechnology.

Introduction

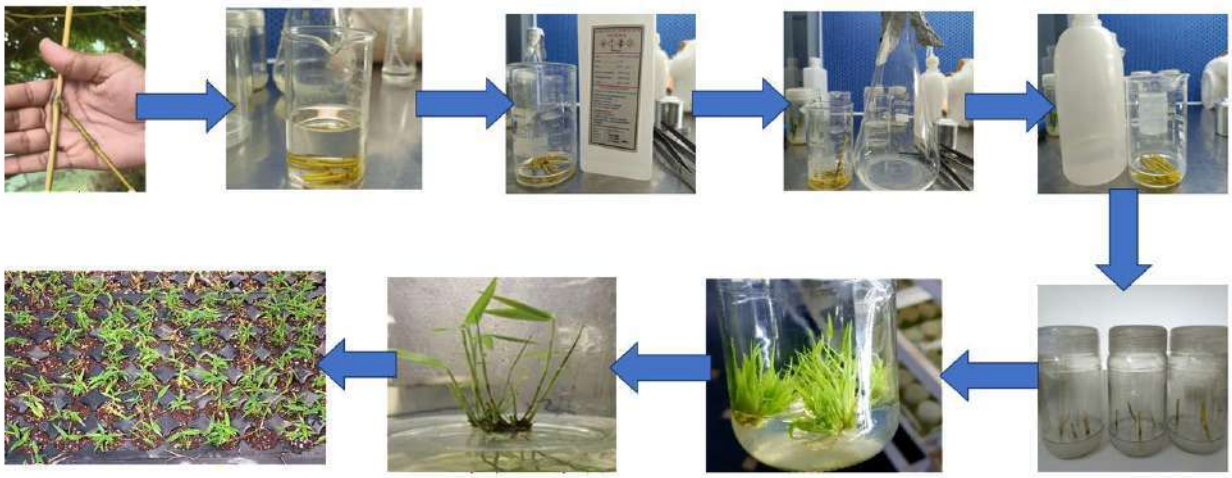
Bamboo, a giant grass belonging to the family Poaceae and subfamily Bambusoideae, is an important renewable natural resource with significant ecological and economic value. It is widely distributed in tropical, subtropical, and temperate regions and is used for construction, furniture, paper, handicrafts, bioenergy, and environmental conservation. Owing to its rapid growth, high biomass production, and ability to sequester carbon, bamboo is considered a sustainable alternative to timber. However, conventional propagation methods are limited by poor seed availability and low multiplication rates. Micropropagation offers an efficient solution by enabling the rapid production of disease-free, genetically uniform planting material, thereby supporting large-scale cultivation and sustainable bamboo-based industries.

Importance of Bamboo



Stages of Micropropagation

Micropropagation generally consists of several distinct stages. The first stage involves the selection and establishment of explants in culture. Healthy tissues are collected from selected parent plants and introduced into sterile culture media. The second stage focuses on shoot multiplication. Under the influence of suitable growth regulators, multiple shoots develop from the cultured explants. The third stage involves root induction, during which shoots are transferred to media containing auxins to stimulate root formation. The final stage is acclimatization or hardening.



Common Problems Encountered During Bamboo Micropropagation

Despite its advantages, bamboo micropropagation faces several challenges. Contamination remains one of the most persistent problems and can occur at any stage of culture. Tissue browning caused by phenolic oxidation frequently affects bamboo explants and may inhibit growth. Addressing these challenges requires careful optimization of protocols, strict aseptic techniques, and continuous monitoring of culture conditions.

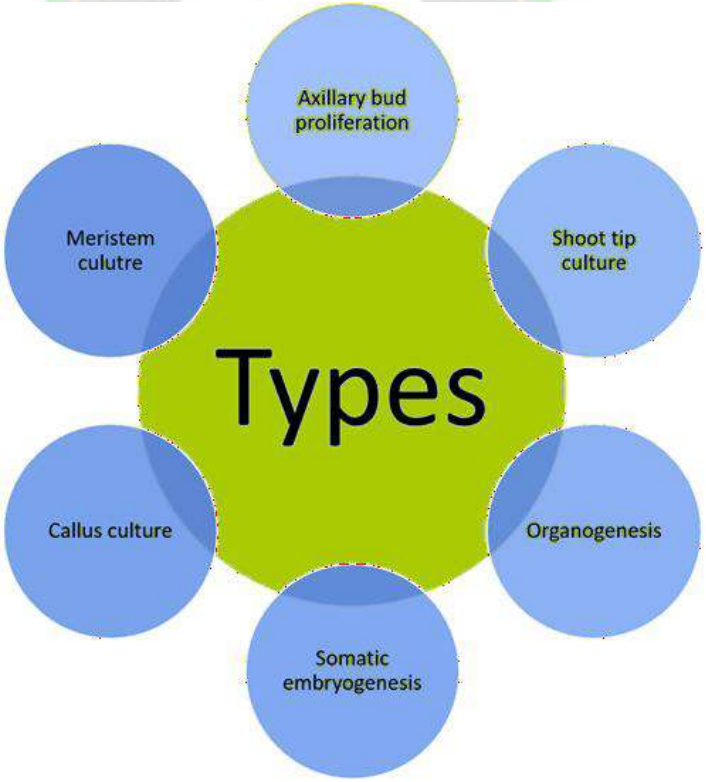
Commercial Scale Production of Bamboo Through Micropropagation

Modern tissue culture laboratories employ large-scale micropropagation systems to meet growing demand for bamboo planting materials. Automated culture rooms, controlled environmental chambers, and specialized growth facilities enable the production of thousands to millions of plantlets annually. Commercial micropropagation supports afforestation programs, industrial plantations, agroforestry initiatives, and environmental restoration projects. By

providing uniform, disease-free planting materials, tissue culture contributes significantly to the expansion of bamboo cultivation worldwide.

Types of Micropropagation Used in Bamboo

Conventional methods of propagation such as seeds, rhizomes, offsets, and culm cuttings often fail to meet this demand because they are slow, labour-intensive, season-dependent, and produce limited numbers of plants. Furthermore, many bamboo species exhibit irregular flowering patterns, making seed availability unpredictable. The technology is based on the principle of totipotency, which enables plant cells to regenerate into complete plants when supplied with appropriate nutrients and growth regulators. The choice of a suitable micropropagation method depends on various factors including bamboo species, laboratory facilities, intended purpose, and desired multiplication rate. Certain methods are preferred for commercial propagation because they maintain genetic stability, while others are valuable for research, conservation, and genetic improvement programs.



Merits of Bamboo Micropropagation

Micropropagation offers numerous advantages over conventional propagation methods. One of the most important advantages is rapid multiplication. Thousands of plants can be

produced from a small amount of starting material within a relatively short period. This capability is particularly valuable for bamboo because traditional propagation methods often produce limited numbers of plants. Another major benefit is genetic uniformity. Since micropropagation typically involves clonal multiplication, the regenerated plants maintain the desirable characteristics of the parent plant. Micropropagation also facilitates year-round production independent of seasonal constraints. The production of disease-free plants is another significant advantage. Through careful explant selection and sterile culture techniques, healthy planting materials can be generated and distributed to growers.

Demerits of Bamboo Micropropagation

Despite its many advantages, micropropagation has certain limitations that must be considered. One major disadvantage is the high initial cost associated with establishing tissue culture laboratories. Specialized equipment, infrastructure, skilled personnel, and consumable materials require substantial investment. Contamination remains a persistent challenge. Even minor microbial contamination can spread rapidly and destroy entire batches of cultures. Another limitation is the occurrence of somaclonal variation, particularly when regeneration involves prolonged callus phases. Such variations may alter plant characteristics and reduce genetic uniformity. The acclimatization stage can also be problematic because plantlets grown under laboratory conditions often experience stress when transferred to natural environments. Poor hardening procedures may result in reduced survival rates.

Challenges and Constraints in Bamboo Micropropagation

Several challenges continue to affect the large-scale application of bamboo micropropagation. Phenolic exudation is one of the most common problems encountered during culture initiation. Bamboo tissues frequently release phenolic compounds that oxidize and cause tissue browning, inhibiting growth and regeneration. Contamination from bacteria and fungi remains another major obstacle. Maintaining sterile conditions throughout the propagation process requires constant vigilance and strict laboratory practices. Species-specific responses also present challenges. Consequently, reducing production costs remains an important objective for commercial laboratories. Transportation and acclimatization of tissue culture-derived plantlets also require careful management to ensure successful field establishment.

Commercial Production and Entrepreneurship Opportunities

The increasing global demand for bamboo has created numerous opportunities for commercial production and entrepreneurship. Tissue culture laboratories can generate substantial revenue by producing and supplying high-quality bamboo planting materials. Entrepreneurs can also establish bamboo nurseries specializing in acclimatized tissue culture plants. Such nurseries serve as important intermediaries between tissue culture laboratories and end users. The processing and marketing of bamboo-based products provide additional business opportunities. Bamboo furniture, handicrafts, flooring materials, construction products, textiles, and bioenergy products represent rapidly growing markets.

Government programs promoting afforestation, sustainable agriculture, and climate change mitigation further enhance the economic potential of bamboo cultivation. The combination of biotechnology and entrepreneurship can contribute significantly to rural development, employment generation, and economic growth.

Future Prospects of Bamboo Micropropagation and Biotechnology

The future of bamboo micropropagation is highly promising due to ongoing advances in biotechnology, artificial intelligence, automation, and molecular biology. Improvements in culture media, growth regulator formulations, and environmental control systems are expected to enhance propagation efficiency. The application of genomics, molecular markers, genetic transformation, and genome editing technologies may facilitate the development of superior bamboo varieties with improved growth, stress tolerance, disease resistance, and industrial properties. Artificial intelligence and automation are likely to revolutionize tissue culture laboratories by enabling real-time monitoring, predictive analytics, and intelligent decision-making systems. As a result, bamboo biotechnology will continue to play a vital role in supporting industrial development, environmental conservation, and global sustainability goals. With continued innovation and investment, bamboo micropropagation and biotechnology are expected to play increasingly important roles in addressing future economic, environmental, and industrial challenges while promoting a greener and more sustainable world.

Conclusion

However, conventional propagation methods are limited by poor seed availability, low multiplication rates, seasonal dependence, and disease susceptibility. Micropropagation has emerged as an effective biotechnology tool for the rapid production of healthy, disease-free, and

genetically uniform planting materials. Advances in molecular biology, genetic transformation, cryopreservation, and synthetic seed technology have further improved bamboo propagation and breeding. Emerging technologies such as artificial intelligence and automation are expected to enhance propagation efficiency and reduce production costs. Despite challenges including contamination, phenolic browning, acclimatization, and high production costs, continuous research is improving tissue culture protocols. Overall, bamboo micropropagation is a promising approach for sustainable forestry, environmental conservation, and industrial development, supporting the increasing global demand for renewable resources.

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SILENCING THE ENEMY: RNA INTERFERENCE (RNAI) - A NOVEL FRONTIER IN SUSTAINABLE PEST MANAGEMENT

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Introduction

Agriculture has entered an era where increasing crop productivity must go hand in hand with environmental stewardship. For more than half a century, synthetic insecticides have played a pivotal role in safeguarding crop yields. However, their extensive and often indiscriminate use has resulted in pesticide resistance, resurgence of secondary pests, destruction of natural enemies and pollinators, contamination of ecosystems, and growing public concerns regarding pesticide residues in food. Consequently, modern crop protection is shifting toward innovative technologies that are both effective and environmentally responsible.

Among these, RNA interference (RNAi) has emerged as one of the most promising breakthroughs in molecular pest management. Rather than poisoning insects, RNAi suppresses the expression of specific genes essential for their survival, offering an unprecedented level of precision. This gene-specific approach has the potential to revolutionize pest management while minimizing adverse impacts on non-target organisms and the environment.

What is RNA Interference?

RNA interference (RNAi) is a naturally occurring biological process through which cells regulate gene expression by degrading specific messenger RNA (mRNA) molecules. Discovered by Andrew Fire and Craig Mello in 1998, this phenomenon earned them the 2006 Nobel Prize in Physiology or Medicine.

In simple terms, every gene in an organism contains instructions for producing proteins that perform essential biological functions. RNAi interrupts this process by destroying the

messenger RNA carrying these instructions, thereby preventing the synthesis of the corresponding protein. When an essential protein is not produced, the insect loses critical physiological functions necessary for survival, growth, feeding, or reproduction.

Thus, RNAi can be viewed as a "genetic switch-off mechanism" that selectively silences harmful genes without affecting unrelated organisms.

How Does RNAi Work?

The RNAi pathway involves a series of precisely coordinated molecular events:

1. Scientists identify an essential gene involved in insect growth, metabolism, digestion, reproduction or nervous system function.
2. A complementary double-stranded RNA (dsRNA) molecule is synthesized.
3. The target insect ingests or absorbs the dsRNA.
4. Inside the insect cell, an enzyme called Dicer cleaves the dsRNA into short fragments known as small interfering RNAs (siRNAs).
5. These siRNAs are incorporated into the RNA-Induced Silencing Complex (RISC).
6. Guided by sequence complementarity, RISC recognizes and degrades the target messenger RNA (mRNA).
7. As the protein can no longer be synthesized, essential biological processes fail, ultimately resulting in reduced feeding, impaired development, sterility, or death.

Unlike chemical insecticides, RNAi does not kill insects through toxicity but by silencing the genes required for their normal functioning.

Why RNAi Represents a Paradigm Shift

The greatest strength of RNAi lies in its remarkable specificity. Conventional insecticides often affect beneficial insects such as honey bees, parasitoids, and predators. In contrast, dsRNA molecules can be designed to target genes unique to a particular pest species.

Consequently, RNAi offers several advantages:

- Highly species-specific pest control
- Minimal impact on beneficial insects and pollinators
- Reduced environmental contamination
- Lower pesticide residues in food
- Compatibility with biological control agents
- Reduced likelihood of cross-resistance with conventional insecticides

- Excellent compatibility with Integrated Pest Management (IPM)

This precision makes RNAi one of the safest and most environmentally friendly pest management tools currently under development.

Applications in Agricultural Pest Management

RNAi has shown encouraging results against numerous economically important insect pests. Successful laboratory and field studies have demonstrated effective gene silencing in:

Common name	Scientific name
Colorado potato beetle	*Leptinotarsa decemlineata*
Western corn rootworm	*Diabrotica virgifera virgifera*
Cotton bollworm	*Helicoverpa armigera*
Pink bollworm	*Pectinophora gossypiella*
Fall armyworm	*Spodoptera frugiperda*
Diamondback moth	*Plutella xylostella*
Whitefly	*Bemisia tabaci*
Brown planthopper	*Nilaparvata lugens*
Cotton aphid	*Aphis gossypii*
Green peach aphid	*Myzus persicae*

In these pests, RNAi has successfully disrupted genes involved in digestion, detoxification, reproduction, moulting, immunity, and nervous system function, leading to reduced survival and crop damage.

Methods of Delivering RNAi

Several delivery strategies have been developed to introduce dsRNA into target insects.

- **Spray-Induced Gene Silencing (SIGS):** Double-stranded RNA is formulated as a foliar spray. Feeding insects ingest the dsRNA, leading to gene silencing without altering the plant's genome.
- **Host-Induced Gene Silencing (HIGS):** Plants are genetically engineered to produce dsRNA targeting specific insect genes. When insects feed on these plants, they consume the RNA molecules and experience gene silencing.
- **Artificial Diet Feeding:** Primarily used in laboratory studies, dsRNA is incorporated into artificial diets to evaluate gene function and RNAi efficiency.

- **Nanotechnology-Based Delivery:** Nanoparticles such as layered double hydroxides, liposomes, and chitosan-based carriers protect dsRNA from degradation by sunlight, rain, and digestive enzymes while enhancing cellular uptake.

Advantages Over Conventional Insecticides

RNAi addresses several shortcomings associated with chemical pesticides.

- High target specificity
- Safe for beneficial insects and pollinators
- Eco-friendly and biodegradable
- Reduced pesticide residues
- Suitable for resistance management
- Compatible with biological control and IPM
- Potential to reduce repeated pesticide applications

These characteristics make RNAi particularly attractive for sustainable agriculture and precision crop protection.

Challenges Ahead

Despite its tremendous promise, RNAi technology still faces practical limitations.

Major challenges include:

- Rapid degradation of dsRNA under field conditions
- Variable RNAi efficiency among insect orders
- High cost of large-scale dsRNA production
- Efficient delivery into insect tissues
- Possible evolution of RNAi resistance
- Regulatory approval and biosafety assessment
- Public perception regarding RNA-based technologies

Researchers worldwide are actively developing cost-effective production systems, improved formulations, and advanced delivery platforms to overcome these barriers.

Future Perspectives

The future of RNAi-based pest management is exceptionally promising. Advances in synthetic biology, genomics, artificial intelligence, and nanotechnology are accelerating the development of next-generation RNA-based pesticides.

Future innovations are expected to include:

- Sprayable RNA biopesticides
- Smart nanoparticle formulations
- Multi-gene silencing strategies
- Precision RNAi tailored to local pest populations
- Integration with CRISPR-based functional genomics
- AI-assisted identification of novel gene targets
- Large-scale commercial RNA formulations

As production costs continue to decline and delivery technologies improve, RNAi is expected to become a cornerstone of sustainable crop protection.

Conclusion

RNA interference represents one of the most exciting advances in modern agricultural biotechnology. By harnessing the natural process of gene silencing, RNAi enables highly selective suppression of insect pests while preserving beneficial organisms and reducing environmental impacts. Although challenges related to delivery, stability, and commercialization remain, ongoing scientific innovations are steadily bringing RNAi closer to widespread agricultural adoption.

The future of pest management lies not merely in developing stronger insecticides but in designing smarter, safer and more sustainable solutions. RNAi exemplifies this transformation by shifting crop protection from broad-spectrum chemical control to precision molecular intervention. As agriculture embraces this silent yet powerful technology, RNAi is poised to become a key pillar of next-generation Integrated Pest Management.

"The future of crop protection may not be determined by how effectively we kill pests, but by how precisely we can silence the genes that make them harmful."

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NATURE-BASED INTENSIFICATION STRATEGIES: LEVERAGING ARTHROPOD ECOSYSTEM SERVICES FOR SUSTAINABLE CROP YIELDS

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Abstract

Global food demand is rising, yet conventional agricultural intensification increasingly threatens biodiversity and ecosystem integrity. Sustainable crop production requires strategies that enhance productivity while conserving biological diversity. Beneficial arthropods — including pollinators, natural enemies of pests, decomposers, and soil engineers — provide key ecosystem services that can be harnessed within nature-based intensification frameworks. This article reviews mechanisms by which arthropod biodiversity supports sustainable yields and outlines evidence-based nature-based intensification strategies to optimize these services.

Introduction

Agricultural intensification traditionally relies on high external inputs (fertilizers, pesticides, monocultures) to maximize yield. However, such practices often reduce landscape heterogeneity and diminish beneficial arthropod populations, undermining their contributions to **ecosystem services such as biological pest control and pollination**.

Nature-based intensification seeks to increase crop yields by enhancing ecological processes and biodiversity rather than relying solely on synthetic inputs. Arthropods — the most speciose animal group on Earth — play central roles in supporting food production and agroecosystem resilience. Their contributions include pollination, predation and parasitism of pests, nutrient cycling, and soil structuring.

Arthropod Ecosystem Services in Agroecosystems

Pollination

Wild bees, butterflies, and other pollinating insects are responsible for the reproduction of a significant proportion of crops globally. Their activity directly influences fruit set, quality, and yield. Declines in pollinator abundance due to habitat loss and intensive management can limit crop performance.

Biological Pest Control

Predators (e.g., carabid beetles, spiders), parasitoids (e.g., braconid wasps), and omnivorous arthropods suppress pest populations by reducing herbivore density and damage. Landscape diversification can increase the abundance and functional diversity of these natural enemies, thereby lowering pest pressure.

Decomposition and Soil Functioning

Soil arthropods such as collembolans and mites accelerate litter decomposition and nutrient cycling, increasing soil fertility and supporting plant growth. Arthropod activities also affect soil structure and water infiltration.

Nature-Based Intensification Strategies

Intercropping and Diversification

Intercropping — growing multiple crops together — consistently enhances beneficial arthropod abundance and species richness compared to monocultures, while suppressing pest populations. A systematic review and meta-analysis showed intercropping increased beneficial arthropod abundance by 36% and reduced pest abundance by ~38% relative to monoculture.

Mechanism: Increased plant diversity enhances resource availability (flowers, prey, shelter) and habitat complexity, benefitting pollinators and natural enemies.

Agroforestry and Perennial Systems

Integrating trees with crops (agroforestry) increases structural heterogeneity and provides semi-natural habitats for arthropods. Perennial crops often support greater natural enemy and pollinator richness due to stable microhabitats.

Habitat Management and Semi-Natural Areas

Creating or maintaining semi-natural habitats (e.g., field margins, hedgerows, flower strips) increases overall landscape complexity, offering refugia and food resources for arthropods. These features can buffer populations against disturbance and improve arthropod ecosystem service provisioning.

Reduced Pesticide Usage

Minimizing broad-spectrum pesticides lessens non-target effects on beneficial arthropods, allowing their populations to contribute more effectively to biological pest control. Integrated pest management (IPM) frameworks balance pest suppression with conservation of functional arthropod groups.

Ecological and Agricultural Outcomes

Evidence indicates that nature-based management can improve arthropod biodiversity without compromising—and in some cases enhancing—crop productivity. For example, recent research on nature-inclusive farming systems found higher arthropod abundance and similar potato yields compared to conventional systems.

However, trade-offs and context-specific responses occur. Spatial scale, crop type, landscape composition, and management history can influence the strength of arthropod services and their effects on yield. Further research on multi-service delivery and economic viability at larger scales is needed.

Policy and Management Implications

To operationalize nature-based intensification:

- **Diversification incentives:** Subsidies and extension services should support intercropping, agroforestry, and habitat restoration.
- **Landscape planning:** Conservation of semi-natural habitats at farm and regional scales helps maintain arthropod metacommunities.
- **Farmer engagement:** Participatory research and knowledge sharing help align ecological strategies with farmer priorities.
- **Monitoring:** Standardized biodiversity and ecosystem service indicators are necessary to assess progress toward sustainable intensification goals.

Conclusion

Nature-based intensification harnesses the ecological functions of arthropods to sustainably support crop yields. By enhancing plant diversity, conserving habitats, and reducing harmful inputs, agricultural systems can achieve environmentally sound productivity. Continued research, adaptive management, and supportive policies will be critical to mainstreaming arthropod-focused intensification strategies.

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FARMER'S GUIDE TO OVERCOME LANDSLIDES DURING EL NINO IN THE NILGIRIS

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Introduction

El Niño years don't just mean "less rain overall" for the Nilgiris they mean erratic, concentrated bursts of rainfall on already-saturated slopes. The Nilgiris Biosphere Reserve, with its steep terrain, shallow topsoil, and extensive conversion of forest and grassland to tea, vegetable, and potato cultivation, is particularly vulnerable. A landslide doesn't need a cyclone to happen a few hours of intense rain on a destabilised slope is often enough. For a small or tribal farmer, losing even a quarter-acre terrace to slippage can mean losing an entire season's income.

The good news: most landslide risk on farmland is manageable without heavy machinery or large budgets. It comes down to how the soil is held together, where water is allowed to flow, and how deep the plant roots go.

1. What Farmers Can Do at the Field Level — Low-Cost, High-Impact Measures

These are techniques any farmer can adopt with local materials, labour, and minimal cash outlay.

a) Contour and Bund-Based Water Management

- Contour bunding with locally available stone, turf, or vetiver grass slows water down instead of letting it rush downhill and cut channels.
- Vetiver (Khus) grass hedgerows planted along contours are one of the cheapest and most effective landslide-prevention tools available. Vetiver roots grow 2–3 metres deep, bind soil like a net, and the grass itself has no invasive root spread, so it doesn't compete with crops. A single planting can last over a decade.
- Silt traps and small check-dams made from stone-packed gunny bags or bamboo at natural drainage points reduce the velocity of runoff before it reaches vulnerable slopes.

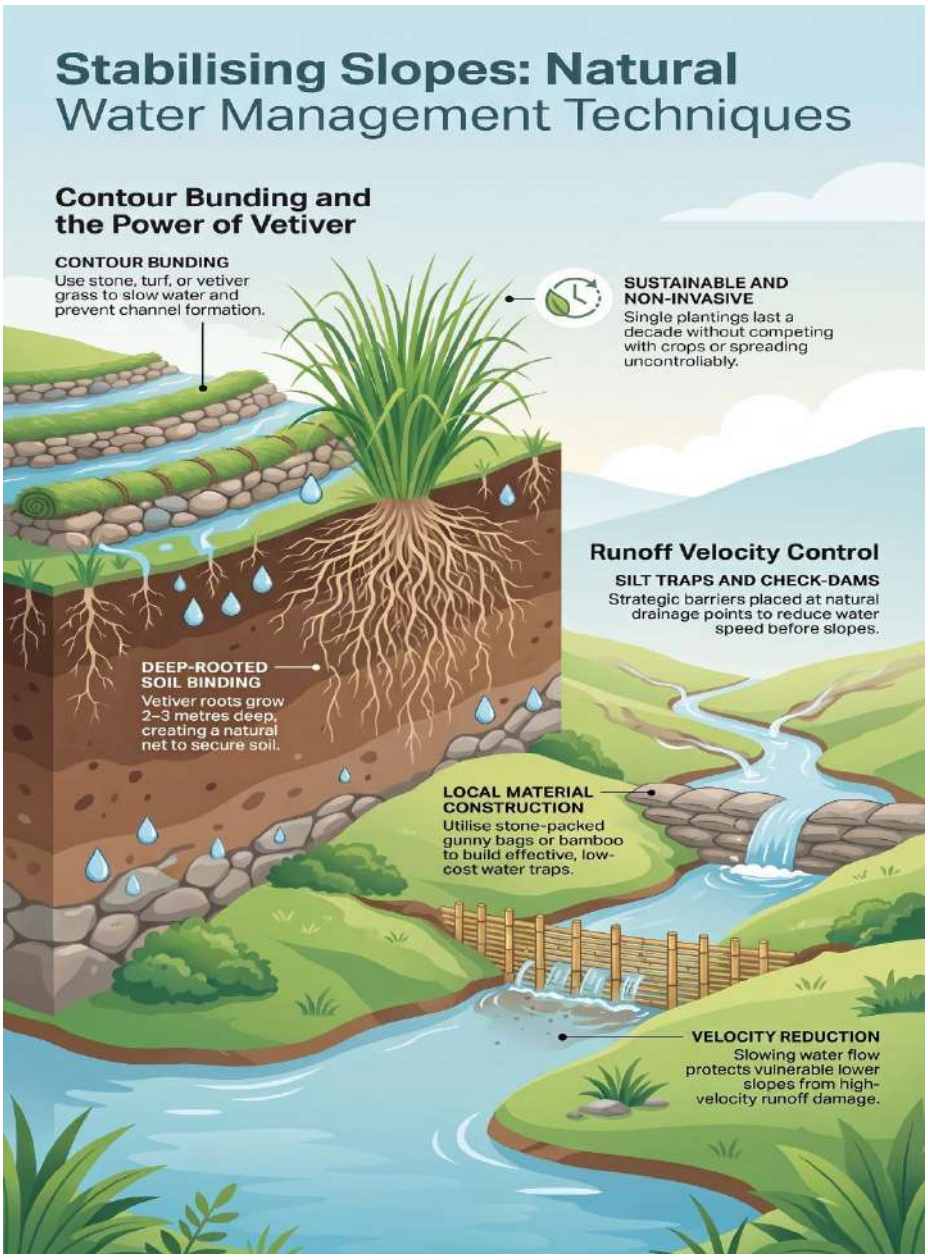


Image 1: Natural water management techniques for stabilizing slopes

b) Living Root Systems as Slope Anchors

- Interplanting deep-rooted perennials (lemongrass, vetiver, napier grass, agroforestry species like silver oak or erythrina) along terrace edges and field boundaries anchors soil far more effectively than any wall.
- Avoid leaving any slope bare during the monsoon transition a cover crop (cowpea, horse gram, or even a green manure crop) between main crop cycles protects topsoil from being washed away and adds organic matter.

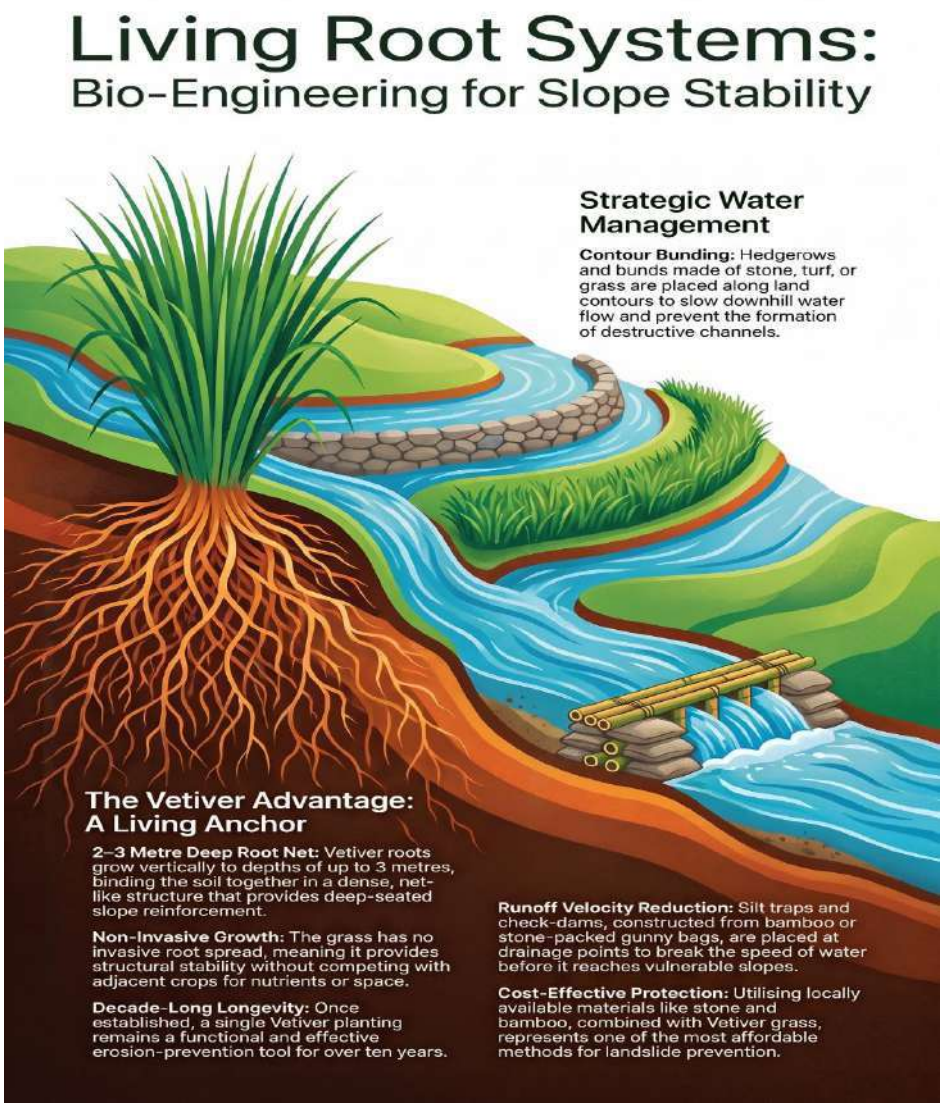


Image 2: Bio-engineering for slope stability

c) Terracing Done the Farmer's Way

- Where terracing already exists (tea, vegetables), maintain the outer bund height and the inward-sloping platform a technique many older Nilgiris farmers already know but have relaxed. A terrace with a slight backward tilt directs water into the hillside drainage system rather than over the edge.
- New terraces don't need concrete retaining walls a well-packed stone pitching (locally sourced rubble, laid dry, no cement) works nearly as well at a fraction of the cost, and it flexes with soil movement instead of cracking.

d) Drainage Discipline

- The single most common cause of field-level landslides in the Nilgiris is blocked or absent field drains. Keep the drains along field boundaries and access paths clear before the monsoon peaks this is a zero-cost task that prevents water from pooling and saturating slopes.
- Divert water away from steep, recently disturbed, or newly planted slopes using simple mud or stone channels.



Image 3: Low-cost landslide prevention methods

e) Avoid these Common Mistakes

- Don't cultivate right up to the edge of a steep slope leave a buffer strip of grass or shrub.
- Don't remove existing shola or grassland vegetation at the top of a slope, even for "just one more row" of vegetables this vegetation is doing free slope-stabilisation work.
- Don't over-till slope soil just before heavy rain is forecast; loosened soil with no root cover is the most landslide-prone condition there is.

2. The Landslide–Chemical Input Connection

This is a connection farmers often don't realise until it's explained plainly, and it is central to why KVK Nilgiris keeps returning to this point.

Healthy soil holds together. Chemically degraded soil doesn't.

- Loss of soil structure: Continuous heavy use of chemical fertilizers (especially urea and single-nutrient NPK blends without organic matter) breaks down soil aggregates over time. Soil aggregation the way particles clump into crumbs is what gives soil its "glue." Without organic matter to bind these crumbs, soil becomes loose, powdery, and far easier for water to detach and carry downhill.
- Dead soil biology: Excess pesticide and fungicide use suppresses soil microorganisms and earthworm populations. These organisms are the ones building the very pore structure and organic "glue" (glomalin, humus) that gives slope soil its cohesion and infiltration capacity. Fewer earthworms and microbes means water runs off the surface instead of soaking in evenly a direct driver of surface erosion that precedes landslides.
- Reduced root diversity: Chemical-intensive monocropping (a single vegetable or potato crop, heavily fertilized, season after season) discourages the mixed, deep-and-shallow root systems that a diversified or organic system naturally supports. Monoculture roots are often shallow and uniform exactly the wrong root architecture for slope stability.



Image 4: Chemical intensive farming – A risk to Nilgiris

- Compaction from repeated chemical-intensive tillage: Fields under constant chemical input regimes are often tilled more aggressively and more frequently to manage nutrient and pest cycles, compacting subsoil layers. Compacted layers block water infiltration, so

water builds up above them and creates a lubricated slip-plane a classic trigger for shallow landslides on agricultural slopes.

In short: chemical-intensive farming trades long-term soil cohesion for short-term yield, and on the steep, high-rainfall terrain of the Nilgiris, that trade shows up as landslide risk within a few seasons.

3. Why KVK Nilgiris Is Insisting on Organic Farming, PMFBY, and KCC Registration

Organic Farming

KVK Nilgiris' push for organic and bio-intensive practices isn't only about food safety or premium markets in this terrain, it is a slope stabilisation strategy:

- Organic matter (FYM, vermicompost, green manure) rebuilds soil aggregation and water-holding capacity.
- Biofertilizers and biopesticides preserve the soil microbial life that maintains porous, well-structured soil.
- Organic systems typically retain more crop residue and cover on the soil surface, reducing raindrop impact and surface runoff the first stage of most landslide sequences.
- It is also the lowest-cost input pathway available to marginal and tribal farmers who cannot absorb repeated chemical input costs, which makes it doubly relevant during an El Niño year when yields are already under climate stress.

PMFBY (Pradhan Mantri Fasal Bima Yojana)

Registering for crop insurance under PMFBY before the season means that if a landslide, cloudburst, or prolonged excess rainfall destroys standing crops, the farmer has a financial safety net rather than facing total loss. In El Niño years, when the risk of sudden, damaging rainfall events is elevated, this registration is not optional paperwork it is the difference between recovering for the next season and falling into debt.

KCC (Kisan Credit Card)

KCC registration ensures farmers have access to timely, low-interest credit for input costs, repair of damaged terraces/bunds, and re-cultivation after a climate shock rather than being forced to borrow from informal, high-interest sources after a landslide event. It also formally links the farmer into the institutional credit and subsidy system that KVK and the Department of Agriculture use to route post-disaster support.

KVK Nilgiris treats organic adoption + PMFBY + KCC as three legs of the same resilience strategy: reduce the risk at the source (organic soil health), and insure against the risk that remains (PMFBY, KCC).



Image 5: KVK's Three legs of Resilience Strategies

4. Where Agricultural Engineering Comes In

Farmer-level, low-cost measures handle most day-to-day slope risk, but agricultural and soil-conservation engineering has a specific, complementary role:

- Slope and drainage surveys: Engineers assess which slopes are structurally critical (steep gradient, poor natural drainage, history of slippage) and need intervention beyond what a farmer can do alone.
- Design of larger conservation structures: Where community-scale work is needed check dams, gully plugs, larger contour trenches, or gabion (wire-mesh stone) structures engineering input ensures these are placed and sized correctly so they don't fail or redirect water onto a neighbouring field.
- Watershed-level planning: Individual field measures work best when coordinated across a micro-watershed. Agricultural engineers map water flow across multiple farms so that

upstream diversions don't overload downstream farms a coordination role individual farmers can't perform alone.

- Technical validation of low-cost methods: Engineering assessment confirms where vetiver hedgerows, stone pitching, or bunding will actually hold under expected rainfall intensity, and where they won't be enough preventing farmers from investing labour in a measure that is undersized for the risk.
- Integration with early-warning and monitoring systems: Where available, engineers help set up simple rain-gauge networks or slope-monitoring markers at the village level, feeding into KVK's advisory alerts.

The role of engineering, in other words, is planning, scale, and technical validation not replacing the farmer's own low-cost, field-level work, but making sure it's applied in the right place and reinforced where the terrain genuinely needs more than bunds and grass.

5. Who to Contact First in an Emergency

In the event of an active landslide, ground cracking, or sudden slope movement:

1. Local Revenue/Village Administrative Officer (VAO) and Village Panchayat first point of contact for immediate evacuation support and official disaster reporting.
2. Nilgiris District Disaster Management Authority / District Collectorate control room for landslide-specific emergency response and rescue coordination.
3. Tamil Nadu State Disaster Management helpline and National Disaster Response Force (NDRF) channels, where the event is severe or involves risk to life.
4. KVK Nilgiris / nearest Agriculture Department office for crop damage documentation (needed for PMFBY claims), post-event advisory, and coordination of relief input support.
5. Police (100) / Fire and Rescue (101) / Ambulance (108) for any immediate life-threatening situation.

Farmers are advised to save these numbers before the monsoon season begins, not after an event occurs, and to know the evacuation route from their own field and homestead in advance.

Summary: A Farmer's Pre-Monsoon Checklist

Action	Cost	Timing
Clear field drains	Free (labour only)	Before monsoon onset

Plant vetiver/lemongrass along contours	Low	Pre-monsoon, dry season
Maintain terrace bund height and inward slope	Low	Ongoing
Reduce chemical fertilizer/pesticide use; add organic matter	Low-moderate saving	Every season
Register for PMFBY	Low premium subsidised	Before crop season notification closes
Apply for/activate KCC	No cost to apply	Anytime, ideally before season
Report any slope cracking or unusual seepage to KVK/VAO immediately	Free	Ongoing vigilance

This advisory is prepared by KVK Nilgiris as part of ongoing El Niño 2026 preparedness outreach to farming communities across the Nilgiris Biosphere Reserve, including tribal and marginal farming households in Bokkapuram, Masinagudi, and Kinnakorai.

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PLAN OF ACTION BEHIND TRAP CROPPING

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Abstract

Trap cropping is a method of intercropping, where group of crops are grown in a planned sequential manner with the main crop. It is a strategy so as the crop of interest is protected and the pests are diverted relay on the main crop. In this article let us unfold the biology behind trap cropping, its types, cost of economics and its reliability among farmers.

Introduction

Have ever wondered about insect's preference for host for its food and breeding? Its where the idea of trap cropping begin.

Imagine a maize field infested with corn ear worm (*Helicoverpa armigera*), which bores its head into the ear of maize and causes huge economic damage. The primary infestation is due to the preferable condition for the pest to continue its life cycle like egg, larva, pupa, adult. But what happens if the worm find a better source of food or attractant crop than maize. It will absolutely be translocated to other crop. This behavior of insects is called **Host preference mechanism**.

How it works?

This method of intercropping is done to distract polyphagous pests which causes infestation in more than one crop.

Before writing this article I am confused with " If trap crops were planted with main crop would the insect eat both the crops ?". Then I came to know that insects shows strong preference and behavioural patterns. So a trap crop should be selected in such a way that it is superior than main crop in flower colour , insect's preference for oviposition and release od VOC's (Volatile Organic Compounds).

Lets unbreak the different behavioural patterns:

1.Preference hierarchy:

Pest prefers one plant over other based on

- Odor
- Leaf texture
- Nutritional quality
- Growth stage

So selection of trap crop should meet all the following criteria.

2. Oviposition behavior:

Trap crops release more attractive VOC's which include Terpenoids, Phenolics and green leaf volatiles which makes believe insects that it would be the better place for oviposition.

Eg: Marigold (thiopenes) , Castor (terpenoids), Mustard (Isothiocyanates) and sunflower (sesquiterpenes).

3. Increase in natural enemies:

When a pest attacks a plant , the plant releases chemical signaling compounds called Herbivore induced plant volatiles (HIPVs) which attracts predators and parasitoids. As a result the population of natural enemies is increased.

Eg: *Helicoverpa armigera* feeds on maize leaves

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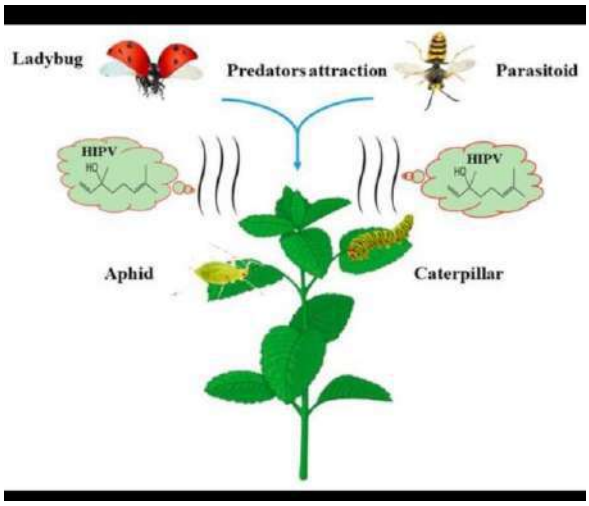
Maize releases specific HIPVs like Indole, Terpenoids

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Parasitoid (*Cotesia* sp) wasp detects these volatiles

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Wasp lays eggs inside caterpillar and the caterpillar dies

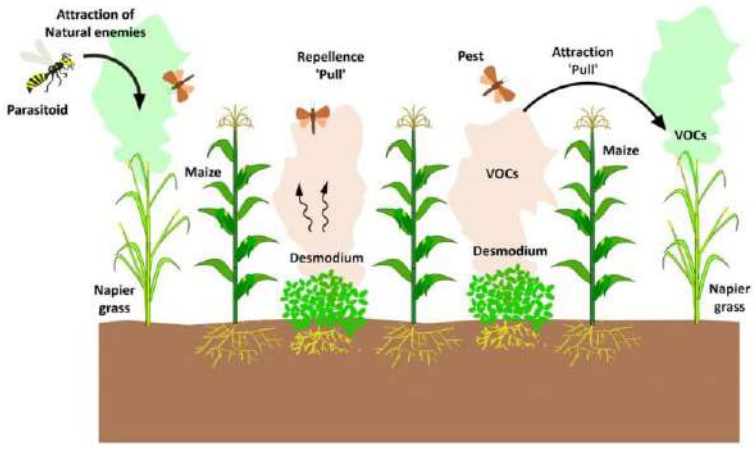


In addition, crops like coriander, sunflower and marigold attracts parasitoid wasps, Hover flies and lacewings due to its bright flower colour.

Types of trap cropping:

Based on the deployment of trap crops , there are 5 types of trap cropping.

- Border trap cropping
- Strip trap cropping
- Multiple trap cropping
- Sequential trap cropping
- Push pull strategy



In push pull strategy, both an intercrop and trap crop is used. Intercrops releases repellent chemicals which drives pest away from the main crop, which is called **push mechanism**. And a trap crop pulls the pest towards it which is called **pull mechanism**.

Eg: Maize (main crop)- Desmodium (intercrop) - Napier grass (trap crop)

Cost of economics:

- Lets analyse cost of economics for the cultivation of maize in 1 ha with red gram as trap cropping.
- Area = 1 ha ; Spacing for maize = 60cm*30cm ; plant population = 83,333 plants/ ha
- If 10% of trap crop is used, the population of trap crops will be 8,333 plants/ha.
- The remaining population of main crop is ~ 75,000.

(Note : Trap crop should be planted before the sowing of main crop to avoid main crop damage)

Maize	Red gram
Seeds - rs.3000	Seeds – rs.800
Fertilizers – rs.8000	Sowing labour – rs.1200
Labour – rs. 10000	Minimal inputs - rs.1000
Irrigation – rs.4000	
Plant protection – rs.5000	
Total : rs. 30,000	Total : rs. 3000

Returns:

- ✓ Maize yield:
  - With trap crop : 50 q /ha
  - Without trap crop : 55q /ha
  - Income : 55*100*50 = rs. 1,65,000
- ✓ Redgram yield:

Yield from 10% area can be used for household purpose.

Opportunity cost :

- 10% of land is utilized for sowing redgram instead of maize.
- In addition main crop is protected from pest.

Reliability among farmers:

Although going to trap crop plantation system provides a reliable method for sustainable agricultural practices, it is not suitable for the small and medium farmers. Since , there is a extra cost spent for purchase of seeds, fertilizers and maintenance it is most suitable for bigland lords and foreign countries.

But some big farmers in India find useful in implementing trap cropping. (https://earth.org/a-forgotten-farming-technique-is-making-a-big-comeback-heres-why/)

Conclusion

This practice also builds more resilient soil ecosystems by enhancing beneficial microbe diversity, creating lasting protection against multiple pest. Trap cropping can be better if it a component of integrated pest management. But complete relaying of trap crops will not be promisary for pest management.

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SOLAR ENERGY APPLICATIONS IN AQUACULTURE: OPPORTUNITIES, TECHNOLOGIES, ENVIRONMENTAL BENEFITS AND FUTURE PERSPECTIVES

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Abstract

Aquaculture is a rapidly expanding food production sector with increasing energy demands for aeration, water pumping, feeding, and environmental monitoring. Conventional energy sources, particularly fossil fuels, increase operational costs and contribute to greenhouse gas emissions. Solar energy has emerged as a clean, renewable, and cost-effective alternative for powering aquaculture operations. Solar photovoltaic (PV) systems are increasingly used for aeration, water circulation, automatic feeding, water quality monitoring, and recirculating aquaculture systems (RAS), improving energy efficiency while reducing carbon emissions. The integration of solar energy supports sustainable aquaculture by lowering dependence on fossil fuels, decreasing production costs, and promoting climate-resilient farming practices. Despite challenges such as high initial investment and dependence on weather conditions, technological advancements in energy storage, smart monitoring, and floating photovoltaic systems are enhancing the feasibility of solar-powered aquaculture. This review highlights the applications, benefits, challenges, and future prospects of solar energy as a key driver of environmentally sustainable aquaculture development.

Keywords: Solar energy, Aquaculture, Renewable energy, Photovoltaic systems, Sustainable aquaculture, Carbon footprint, Green technology.

1. Introduction

Aquaculture has become one of the world's fastest-growing food production sectors and currently supplies more than half of the aquatic food consumed by humans. The rapid expansion of aquaculture has increased demand for energy, particularly in intensive and semi-intensive farming systems where electricity is essential for aeration, pumping, filtration, water circulation, and environmental control. Energy consumption can account for a substantial share of operational costs, making efficient energy management critical for farm profitability.

Traditionally, aquaculture operations have relied on electricity from national grids and fossil fuels such as diesel. Although effective, these energy sources contribute significantly to greenhouse gas emissions, environmental pollution, and increasing production costs. Growing concerns about climate change and the depletion of fossil fuel resources have encouraged the search for renewable energy alternatives that are both economically viable and environmentally sustainable.

Among renewable energy sources, solar energy is considered one of the most abundant, clean, and sustainable options. Advances in photovoltaic technology, battery storage, and power electronics have enabled solar energy to be integrated into aquaculture operations ranging from small rural fish farms to sophisticated recirculating aquaculture systems (RAS). Solar-powered systems can provide reliable electricity for aerators, pumps, feeders, monitoring devices, hatcheries, and aquaponics while reducing dependence on conventional energy sources.

The integration of solar energy into aquaculture not only lowers operational costs but also reduces carbon emissions, improves energy security, and supports the transition toward climate-smart aquaculture. Recent innovations such as floating photovoltaic systems, Internet of Things (IoT)-based monitoring, artificial intelligence (AI), and hybrid renewable energy systems have further enhanced the efficiency and reliability of solar-powered aquaculture. Consequently, solar energy is expected to play a central role in achieving sustainable aquaculture development while contributing to global climate mitigation goals.

Energy Requirements in Aquaculture

Aquaculture production depends heavily on a continuous and reliable energy supply to maintain optimal environmental conditions and ensure healthy growth of aquatic organisms.

Electricity is required to operate aerators, water pumps, filtration units, feeding systems, lighting, and monitoring equipment. In intensive aquaculture systems, particularly shrimp farming and recirculating aquaculture systems (RAS), aeration and water circulation account for the largest share of energy consumption because they operate continuously to maintain dissolved oxygen levels and water quality. Energy is also essential for hatchery operations, temperature regulation, and post-harvest handling, including refrigeration and cold storage. Rising electricity tariffs and dependence on diesel generators increase production costs and carbon emissions, highlighting the need for renewable energy alternatives. Improving energy efficiency through the adoption of solar-powered technologies can significantly reduce operational expenses while enhancing environmental sustainability.

Solar Energy Technologies Used in Aquaculture

Solar energy technologies have become increasingly popular in aquaculture due to their ability to provide clean and sustainable electricity. The most widely used technology is the solar photovoltaic (PV) system, which converts sunlight directly into electricity using semiconductor solar cells. These systems can operate independently (off-grid) or be connected to the electrical grid (grid-tied), depending on farm requirements. Solar thermal systems utilize solar radiation to heat water, making them suitable for hatcheries and species requiring controlled temperatures. Floating photovoltaic (FPV) systems, installed on the surface of ponds or reservoirs, maximize land utilization while reducing water evaporation and improving panel efficiency through natural cooling. Hybrid renewable energy systems combine solar power with wind turbines or battery storage to ensure uninterrupted energy supply during periods of low solar radiation. Recent advances in battery technology, smart inverters, and energy management systems have further improved the efficiency and reliability of solar-powered aquaculture operations.

Major Applications of Solar Energy in Aquaculture

Solar-Powered Aeration

Aeration is one of the most energy-intensive operations in aquaculture, as it maintains dissolved oxygen concentrations necessary for the survival, growth, and health of cultured species. Solar-powered aerators use electricity generated by photovoltaic panels to operate paddle wheels, diffused air systems, or air blowers. These systems reduce dependence on grid electricity and diesel generators while ensuring continuous oxygen supply during daylight hours. Improved aeration enhances feed utilization, reduces stress, minimizes disease outbreaks, and

increases production efficiency. In shrimp farming, where aerators often operate for extended periods, solar-powered systems can significantly lower operational costs and greenhouse gas emissions.

Solar Water Pumping

Water pumping is essential for filling ponds, water exchange, maintaining water levels, and supplying hatcheries. Solar-powered water pumps use photovoltaic panels to operate surface or submersible pumps without relying on conventional electricity. These systems are particularly valuable in remote coastal and rural areas where grid electricity is unreliable or unavailable. Solar pumping systems reduce fuel consumption, lower maintenance costs, and provide a sustainable solution for water management. By ensuring a reliable water supply, they contribute to maintaining optimal water quality and improving aquaculture productivity.

Solar-Powered Automatic Feeders

Efficient feeding is essential for maximizing growth and minimizing feed waste in aquaculture. Solar-powered automatic feeders use photovoltaic energy to distribute feed at predetermined intervals, ensuring accurate and consistent feeding schedules. Automated feeding reduces labor requirements, improves feed conversion efficiency, and minimizes nutrient losses to the environment. Precision feeding also decreases water pollution caused by uneaten feed, thereby improving water quality and reducing production costs. The integration of sensors and programmable controllers further enhances feeding efficiency by adjusting feed delivery according to biomass and environmental conditions.

Solar Energy in Recirculating Aquaculture Systems (RAS)

Recirculating Aquaculture Systems (RAS) require continuous operation of pumps, biofilters, aerators, ultraviolet sterilizers, and monitoring equipment to maintain water quality. Consequently, RAS have relatively high electricity demands compared to traditional pond culture. Solar photovoltaic systems can supply a substantial portion of this energy requirement, reducing dependence on conventional electricity and lowering operating costs. Coupled with battery storage or hybrid renewable energy systems, solar-powered RAS can maintain uninterrupted operation while significantly reducing carbon emissions and improving the environmental sustainability of intensive aquaculture production.

Solar Energy in Aquaponics

Aquaponics combines aquaculture with hydroponic crop production in a closed-loop

system where fish waste provides nutrients for plant growth. Solar energy is widely used to power water pumps, aerators, lighting systems, and nutrient circulation, reducing electricity consumption and operational costs. Solar-powered aquaponics enhances resource efficiency by simultaneously producing fish and vegetables with minimal water use and environmental impact. This integrated system supports sustainable food production, particularly in urban and water-scarce regions, while contributing to renewable energy adoption.

Floating Solar Photovoltaic Systems

Floating photovoltaic (FPV) systems involve installing solar panels on floating structures over aquaculture ponds, reservoirs, or lakes. This innovative technology enables dual utilization of water bodies for both aquaculture production and renewable energy generation without requiring additional land. Floating panels reduce water evaporation, suppress algal growth by limiting sunlight penetration, and improve solar panel efficiency through the cooling effect of water. FPV systems generate clean electricity while minimizing land-use conflicts, making them an attractive option for large-scale aquaculture enterprises seeking sustainable energy solutions.

Environmental Benefits of Solar Energy in Aquaculture

The adoption of solar energy in aquaculture provides substantial environmental benefits by reducing greenhouse gas emissions associated with fossil fuel-based electricity generation. Solar-powered systems decrease carbon dioxide emissions, improve air quality, and reduce dependence on non-renewable energy sources. Replacing diesel-powered equipment with solar technologies minimizes fuel spills, noise pollution, and operational emissions. Furthermore, solar-powered precision feeding, water pumping, and aeration improve resource-use efficiency, reducing nutrient discharge and enhancing water quality. Collectively, these benefits contribute to climate change mitigation, environmental conservation, and the long-term sustainability of aquaculture production.

Economic Benefits

The use of solar energy significantly reduces long-term operational costs by decreasing electricity and fuel expenses. Although the initial installation cost of solar photovoltaic systems is relatively high, the long service life of solar panels (typically 20–25 years) and low maintenance requirements provide substantial economic returns over time. Government incentives, subsidies, and net-metering policies further improve the financial viability of solar energy investments. Reduced energy costs enhance farm profitability, improve production

efficiency, and increase resilience against fluctuations in electricity prices, making solar technology an economically attractive option for aquaculture enterprises.

Challenges and Limitations

Despite its numerous advantages, the adoption of solar energy in aquaculture faces several challenges. High initial capital investment remains a significant barrier, particularly for small-scale farmers. The intermittent nature of solar radiation limits electricity generation during cloudy weather and nighttime, necessitating battery storage or hybrid energy systems. Battery replacement and maintenance add to overall system costs. Additionally, technical expertise is required for installation, operation, and maintenance of photovoltaic systems. Limited awareness, inadequate financial support, and lack of infrastructure also hinder the widespread adoption of solar technologies in developing regions.

Recent Innovations

Technological advancements have significantly improved the performance and applicability of solar energy in aquaculture. Innovations such as high-efficiency photovoltaic panels, lithium-ion battery storage, floating solar systems, Internet of Things (IoT)-based monitoring, artificial intelligence (AI)-driven energy management, and automated control systems have enhanced energy utilization and farm productivity. Smart sensors can optimize aeration, feeding, and water quality management based on real-time environmental data, reducing energy consumption while improving production efficiency. These innovations are accelerating the transition toward precision and climate-smart aquaculture.

Future Perspectives

Future aquaculture development is expected to increasingly integrate renewable energy technologies with digital farming practices. Solar-powered smart aquaculture systems incorporating IoT, AI, robotics, and automated monitoring will improve resource efficiency, reduce environmental impacts, and optimize production. Expansion of floating photovoltaic systems, hybrid renewable energy networks, and carbon-neutral aquaculture farms will support sustainable seafood production while contributing to national and global climate goals. Continued technological innovation, supportive government policies, and increased investment in renewable energy infrastructure will play a crucial role in accelerating the adoption of solar energy in aquaculture worldwide.

Conclusion

Solar energy represents one of the most promising renewable energy solutions for modern aquaculture. By supplying clean electricity for aeration, pumping, feeding, monitoring, and recirculating systems, solar technology reduces operational costs, minimizes greenhouse gas emissions, and enhances environmental sustainability. Although challenges such as high initial investment and intermittent solar availability remain, advances in photovoltaic efficiency, energy storage, and digital technologies are making solar-powered aquaculture increasingly practical. The integration of solar energy with IoT, AI, and floating photovoltaic systems has the potential to transform aquaculture into a climate-smart and low-carbon industry. Continued investment, supportive policies, and technological innovation will be essential for expanding the adoption of solar energy and achieving sustainable aquaculture development worldwide.

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METHANE ICE: THE FROZEN FUEL HIDDEN BENEATH THE OCEAN

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Abstract

The deep ocean represents one of the least explored environments on Earth and contains unique geological resources with significant scientific and environmental importance. Among these resources, methane hydrates, commonly known as *"burning ice,"* are ice-like crystalline compounds in which methane molecules are trapped within water molecule structures under high-pressure and low-temperature conditions. These deposits are primarily found beneath marine sediments along continental margins and in Arctic permafrost regions. Methane hydrates have gained global attention due to their vast energy potential and their possible role as a future natural gas resource. Beyond their energy value, they are important components of the global carbon cycle and influence interactions between geological processes, marine ecosystems, and climate systems. Changes in ocean conditions may affect hydrate stability, raising concerns regarding methane release and environmental impacts. Advances in deep-sea exploration technologies, including seismic surveys, drilling methods, and underwater vehicles, have enhanced understanding of methane hydrate distribution and behaviour. Although methane hydrates provide promising opportunities for future energy development, sustainable utilization requires careful evaluation of ecological risks, greenhouse gas emissions, and deep-sea ecosystem protection.

Keywords: Methane hydrates; Gas hydrates; Deep ocean; Marine sediments; Climate change; Blue economy; Carbon cycle; Ocean sustainability.

Introduction

The Earth's oceans cover more than 70% of the planet's surface, yet the vast majority of the deep ocean remains unexplored. While scientific discoveries over the past century have revealed remarkable ecosystems, unique geological formations, and diverse marine organisms, the deep seafloor continues to conceal valuable natural resources that could influence the future of global energy security and environmental sustainability. Among these hidden resources, **methane hydrates**, popularly known as **methane ice** or **burning ice**, have emerged as one of the most intriguing discoveries in marine science. Methane hydrates are naturally occurring crystalline compounds in which methane molecules are enclosed within a cage-like framework of water molecules. Unlike conventional ice, methane hydrates contain enormous quantities of methane gas, a hydrocarbon that serves as an important source of energy worldwide. When removed from the high-pressure, low-temperature environment of the deep ocean, methane hydrates dissociate, releasing methane gas that can be ignited. This unique property has earned them the popular name "burning ice."

The scientific significance of methane hydrates extends far beyond their unusual physical characteristics. Geological surveys indicate that methane hydrates may contain more organic carbon than all known reserves of coal, crude oil, and natural gas combined. This has generated considerable interest among researchers, governments, and energy industries seeking alternative energy resources to meet the growing global demand. At the same time, methane hydrates play an important role in regulating the Earth's carbon cycle and maintaining the stability of marine sediments. Since methane is a potent greenhouse gas, changes in hydrate stability caused by ocean warming may have important implications for climate change. The study of methane hydrates is therefore inherently interdisciplinary, integrating marine geology, oceanography, microbiology, environmental science, geochemistry, petroleum engineering, and climate science. As technological advancements enable scientists to explore greater depths of the ocean, methane hydrates have become an increasingly important subject in discussions surrounding sustainable energy, marine resource management, and environmental conservation.

What Are Methane Hydrates?

Methane hydrates are crystalline solids belonging to a class of compounds known as **gas hydrates** or **clathrate hydrates**. In these compounds, water molecules form three-dimensional cage-like structures through hydrogen bonding. These cages physically trap methane molecules without forming chemical bonds, resulting in a stable solid under specific environmental conditions. The stability of methane hydrates depends primarily on two environmental factors:

- **High hydrostatic pressure**
- **Low temperature**

Such conditions occur naturally beneath deep ocean sediments and in permanently frozen Arctic permafrost regions. In marine environments, methane hydrates are generally stable beneath water depths exceeding 500 metres, although the exact depth varies depending on local temperature, salinity, and geothermal conditions. Unlike conventional natural gas reservoirs, where methane occupies pore spaces within rocks, methane hydrates store methane in a highly compact form. A single cubic metre of methane hydrate can release approximately **160–180 cubic metres of methane gas** at standard temperature and pressure. This exceptionally high storage capacity makes methane hydrates one of the most concentrated natural gas resources known. Methane itself is the simplest hydrocarbon, consisting of one carbon atom bonded to four hydrogen atoms (CH_4). It is colourless, odourless, highly combustible, and the principal component of natural gas. Within methane hydrates, methane molecules remain physically trapped inside the crystalline lattice until environmental conditions change. A reduction in pressure or an increase in temperature causes the hydrate structure to break down, releasing methane gas and liquid water.The formation of methane hydrates represents a remarkable example of nature's ability to store energy under extreme environmental conditions.

Formation of Methane Hydrates

The formation of methane hydrates is closely associated with the long-term cycling of carbon in marine environments. This process begins with the continuous deposition of organic matter onto the ocean floor. Marine phytoplankton, zooplankton, algae, bacteria, and other microscopic organisms constitute the primary source of organic carbon in marine sediments. Upon death, these organisms sink through the water column and gradually accumulate on the seabed. Over thousands to millions of years, thick layers of sediment bury this organic material beneath the ocean floor. Within these oxygen-deficient sediments, microorganisms decompose

organic matter through a series of biochemical reactions. During the final stage of decomposition, specialized microorganisms known as **methanogenic archaea** convert organic compounds into methane gas through a process called **methanogenesis**. In addition to microbial production, methane may also originate from deeper geological formations where high temperatures and pressures convert buried organic matter into hydrocarbons. This thermogenic methane migrates upward through fractures and porous sediments, where it may combine with methane produced by microorganisms.

As methane moves through water-saturated sediments, it eventually enters zones characterized by sufficiently low temperatures and high pressures. Under these conditions, water molecules spontaneously arrange themselves into cage-like crystalline frameworks that encapsulate methane molecules, producing methane hydrate. The region within marine sediments where pressure and temperature conditions favour hydrate formation is known as the **Gas Hydrate Stability Zone (GHSZ)**. The thickness of this zone varies depending on several environmental factors, including Water depth, Bottom-water temperature, Geothermal gradient, Sediment composition, Salinity and Methane availability. In some continental margins, the Gas Hydrate Stability Zone may extend several hundred metres below the seafloor.

Occurrence of Methane Hydrates in Marine Environments

Methane hydrates are not uniformly distributed throughout the world's oceans. Instead, they occur in specific geological settings where favourable physical and chemical conditions exist. The majority of marine methane hydrates are found along **continental margins**, which represent the transition between continental shelves and deep ocean basins. These regions receive large quantities of sediments transported by rivers and ocean currents, providing abundant organic matter necessary for methane generation.

Hydrate deposits are commonly associated with:

- Continental slopes
- Continental rises
- Deep marine sedimentary basins
- Submarine canyons
- Cold seep ecosystems
- Mud volcanoes
- Accretionary wedges

- Passive continental margins

Cold seeps deserve particular attention because they represent areas where methane-rich fluids naturally migrate upward through sediments and escape into the overlying seawater. These methane-rich environments support unique ecosystems based on **chemosynthesis**, in which microorganisms derive energy from methane and hydrogen sulfide instead of sunlight. Such ecosystems host a remarkable diversity of organisms, including giant tube worms, mussels, clams, crabs, shrimp, and numerous microbial communities specially adapted to extreme environments. Marine methane hydrates are generally buried beneath several metres to hundreds of metres of sediment rather than occurring directly on the seafloor. Their presence is often inferred through geophysical techniques such as seismic reflection surveys, which identify a characteristic feature known as the **Bottom Simulating Reflector (BSR)**. The BSR marks the lower boundary of the Gas Hydrate Stability Zone and serves as one of the most important indicators of hydrate-bearing sediments.

Global Distribution of Methane Hydrates

Methane hydrates have been identified in marine environments across almost every major ocean basin. Since the first confirmed discoveries during the latter half of the twentieth century, numerous scientific expeditions have expanded our understanding of their global occurrence. Significant hydrate-bearing provinces are distributed globally, including the Gulf of Mexico, Blake Ridge (Atlantic Ocean), Cascadia Margin (Pacific Ocean), Nankai Trough (Japan), South China Sea, Sea of Okhotsk, Black Sea, Arctic Ocean, Norwegian Continental Margin, and Eastern Siberian Arctic Shelf.

Among these regions, the **Nankai Trough of Japan** has become one of the most extensively investigated hydrate provinces due to its potential for commercial methane production. Japan has conducted several successful offshore production tests and continues to lead global research on methane hydrate extraction technologies. China has also made substantial progress in hydrate exploration within the South China Sea, while the United States and Canada have undertaken extensive investigations in Alaska, the Gulf of Mexico, and the Cascadia Margin. The widespread occurrence of methane hydrates suggests that they represent a globally significant component of the Earth's carbon reservoir. However, estimates of total methane hydrate resources vary considerably because much of the deep ocean remains unexplored.

Advances in marine geophysics, deep-sea drilling, and remote sensing continue to improve estimates of hydrate distribution and abundance.

India's Methane Hydrate Resources

India possesses one of the largest Exclusive Economic Zones (EEZs) in the Indian Ocean, encompassing vast continental margins with favourable conditions for methane hydrate formation. Recognizing the strategic importance of these resources, the Government of India initiated the **National Gas Hydrate Program (NGHP)** to investigate the occurrence, distribution, and commercial potential of methane hydrates in Indian waters. Scientific drilling expeditions conducted under NGHP have confirmed hydrate-bearing sediments in several offshore basins, including the **Krishna–Godavari Basin**, **Mahanadi Basin**, **Kerala–Konkan Basin**, and the **Andaman offshore region**. These investigations employed advanced drilling technologies, geophysical surveys, sediment coring, and downhole logging to characterize hydrate-bearing formations.

Among these regions, the Krishna–Godavari Basin has attracted particular attention because of its extensive hydrate accumulations and favourable geological conditions. Studies indicate that these deposits could represent a significant indigenous energy resource if economically and environmentally viable extraction technologies become available. Despite these promising discoveries, India continues to prioritize scientific research over commercial exploitation. Ongoing investigations aim to improve understanding of hydrate stability, reservoir behaviour, environmental impacts, and extraction technologies before considering large-scale development. This balanced approach reflects the recognition that methane hydrates represent both an opportunity for energy security and a responsibility for protecting marine ecosystems.

Methane Hydrates as a Potential Energy Resource

The increasing global demand for energy, combined with concerns regarding the depletion of conventional fossil fuel reserves, has encouraged researchers to explore alternative sources of natural gas. Among the various unconventional energy resources being investigated, methane hydrates have gained considerable attention due to their extensive distribution and exceptionally high methane storage capacity. Methane hydrates are considered one of the largest potential reservoirs of natural gas on Earth. Although precise estimates remain uncertain due to the difficulty of mapping deep-sea deposits, scientific assessments suggest that the amount of methane stored within hydrate deposits may exceed the total amount of carbon contained in

conventional fossil fuel reserves, including coal, petroleum, and natural gas. The energy potential of methane hydrates is primarily attributed to the large quantity of methane trapped within their crystalline structure. When extracted and converted into usable energy, methane produces fewer carbon emissions compared with coal and oil. Natural gas combustion releases approximately 50–60% less carbon dioxide than coal for the same amount of energy produced, making methane a relatively cleaner fossil fuel option. For countries with limited conventional fossil fuel resources, methane hydrates represent a possible pathway toward improving energy security. Nations such as Japan, India, China, the United States, and South Korea have invested significantly in hydrate research programs to evaluate their feasibility as future energy resources. However, the transition from laboratory research and experimental production to commercial-scale methane hydrate extraction remains challenging. Unlike conventional gas reservoirs, methane hydrates are dispersed within marine sediments under extreme pressure and temperature conditions. Efficient extraction requires advanced technologies capable of recovering methane while maintaining geological stability and minimizing environmental impacts.

Methane Hydrates and Climate Change

Methane is a powerful greenhouse gas that contributes significantly to global warming. Although carbon dioxide is present in much larger quantities in the atmosphere, methane has a much greater heat-trapping capacity over shorter time periods.

Because methane hydrates contain enormous quantities of methane, scientists have investigated whether changes in ocean temperature could destabilize these deposits and increase methane release. Climate warming can influence methane hydrates in several ways:

1. Ocean Warming: The deep ocean is gradually absorbing excess heat associated with global climate change. Increased bottom-water temperatures may reduce the stability of methane hydrates, causing them to dissociate.

2. Methane Release: When methane hydrates break down, methane gas may be released into surrounding sediments and seawater. Some methane is consumed by microorganisms before reaching the atmosphere, but large-scale releases could potentially influence climate processes.

3. Feedback Mechanism: A potential concern is a positive climate feedback:

Ocean warming → Methane hydrate destabilization → Methane release → Increased greenhouse effect → Further warming

Methane Hydrates and Deep-Sea Ecosystems

Methane hydrate regions are closely associated with unique deep-sea ecosystems known as **cold seep communities**. Unlike surface ecosystems that depend on sunlight-driven photosynthesis, cold seep organisms rely on **chemosynthesis**. Microorganisms convert chemical energy from methane and hydrogen sulfide into organic matter, forming the foundation of these ecosystems. Cold seep communities include:

- Methane-oxidizing bacteria
- Giant tube worms
- Clams
- Mussels
- Shrimp
- Crabs
- Other specialized deep-sea organisms

These ecosystems provide valuable insights into:

- Adaptation of life under extreme conditions
- Carbon cycling in the deep ocean
- Evolution of early life on Earth

Disturbance of methane hydrate deposits through drilling, mining, or other activities could potentially affect these fragile ecosystems.

Potential Risks of Methane Hydrate Exploitation

While methane hydrates offer significant energy potential, their extraction must consider several environmental and engineering challenges.

1. Seafloor Instability: Methane hydrates can contribute to sediment stability by acting as a binding material. Rapid hydrate dissociation may weaken sediments and increase the possibility of submarine landslides. Such events have occurred naturally throughout geological history and can generate large underwater disturbances.

2. Methane Leakage: During extraction, uncontrolled methane release could reduce the climate benefits of methane hydrate utilization. Preventing leakage during drilling and production is therefore a major technological priority.

Conclusion

Methane hydrates, hidden beneath the ocean floor, represent one of Earth's most extraordinary natural resources. These deposits hold immense energy potential while also playing an important role in marine carbon cycling and climate regulation. The discovery and study of methane hydrates demonstrate the complexity of the deep ocean, where geological processes, biological communities, and climate systems are closely interconnected. Although methane hydrates may contribute to future energy solutions, responsible management and environmental protection must remain central to their exploration. As humanity continues to explore the deep ocean, methane ice serves as a reminder that the ocean floor is not merely a source of resources but a delicate environment that requires scientific understanding and careful stewardship.

Volume: 06 Issue No: 07

NURSERY ACCREDITATION: A QUALITY ASSURANCE SYSTEM FOR FARMERS TO OBTAIN QUALITY PLANTING MATERIAL

Article ID: AG-V06-I07-97

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Introduction

The National Horticulture Board (NHB) was established by the Government of India in 1984 as an autonomous organization under the administrative control of the Ministry of Agriculture & Farmers Welfare. Registered under the Societies Registration Act, NHB has its headquarters at Gurugram, Haryana, and presently operates through 29 field offices across the country. The organization is currently headed by Sh. Kapil Meena, IAS, Managing Director, National Horticulture Board.



Sh. Kapil Meena, IAS, MD, NHB

NHB plays a pivotal role in the development of India's horticulture sector by promoting high-tech commercial horticulture, strengthening post-harvest management, developing cold

chain infrastructure, encouraging modern cultivation technologies and ensuring the availability of quality planting material for farmers.

Among its various initiatives, the Nursery Accreditation Programme stands out as an important quality assurance system designed to ensure that farmers receive genuine, healthy, and scientifically produced planting material.

Why Quality Planting Material Matters

The success of any horticultural enterprise begins with the quality of planting material. Healthy, true-to-type and disease-free plants form the foundation of productive orchards, plantations, and protected cultivation.

Poor-quality planting material often results in low productivity, poor fruit quality, spread of pests and diseases, reduced orchard life and significant financial losses to farmers

Recognizing this, NHB has introduced a voluntary Nursery Accreditation System to promote scientific nursery management and ensure the availability of quality planting material across the country.

What is Nursery Accreditation?

Nursery Accreditation is a voluntary quality certification granted by the National Horticulture Board to nurseries that comply with prescribed technical standards relating to infrastructure, production practices, mother plant maintenance, propagation techniques, record keeping, and overall nursery management.





The accreditation serves as a mark of quality and reliability, enabling farmers to identify nurseries that consistently produce genuine planting material.



Objectives of the Nursery Accreditation Programme

The programme has been designed to achieve the following objectives:

- Promote production of quality horticultural planting material.
- Standardize nursery management practices.
- Ensure genetic purity and varietal authenticity.
- Encourage scientific propagation techniques.
- Improve traceability through proper documentation.
- Enhance farmers' confidence while purchasing nursery plants.
- Promote healthy, disease-free planting material throughout the country.

Why Nursery Accreditation is Important

A nursery is the starting point of every horticultural crop. The quality of plants supplied determines the future productivity and profitability of the orchard.

Accredited nurseries assure farmers of:

- True-to-type planting material
- Healthy and disease-free plants
- Quality-assured propagation material
- Scientific nursery management
- Reliable planting stock
- Proper varietal identification

This quality assurance system benefits both nursery owners and farmers by creating greater confidence in the marketplace.

Eligibility for Accreditation

Nurseries engaged in scientific production of horticultural planting material may apply for accreditation, provided they possess the required infrastructure and comply with NHB standards.

The nursery should have:

- Adequate land and infrastructure
- Reliable irrigation facilities
- Healthy and authenticated mother plants
- Suitable propagation structures
- Qualified technical personnel
- Proper production and sales records
- Pest and disease management systems
- Labelling and traceability mechanisms





The prescribed standards must be maintained throughout the validity period of accreditation.

Importance of Mother Plants

The quality of planting material is directly dependent upon the quality of the mother plants maintained in the nursery.

Mother plants should be:

- True-to-type
- Disease-free
- Properly identified and labelled variety-wise
- Scientifically maintained



- Regularly inspected and monitored

Propagation material should always be collected only from approved and healthy mother plants to preserve varietal purity and genetic integrity.

Inspection and Evaluation Process

Upon receipt of an application, NHB arranges a comprehensive inspection by an authorized inspection team comprising

1. NHB-appointed Nursery Consultant (Team Leader)
2. Scientist/Assistant Professor from ICAR or State Agricultural/Horticultural University
3. Representative from the State Department of Horticulture/Agriculture
4. Official from the concerned NHB State Office

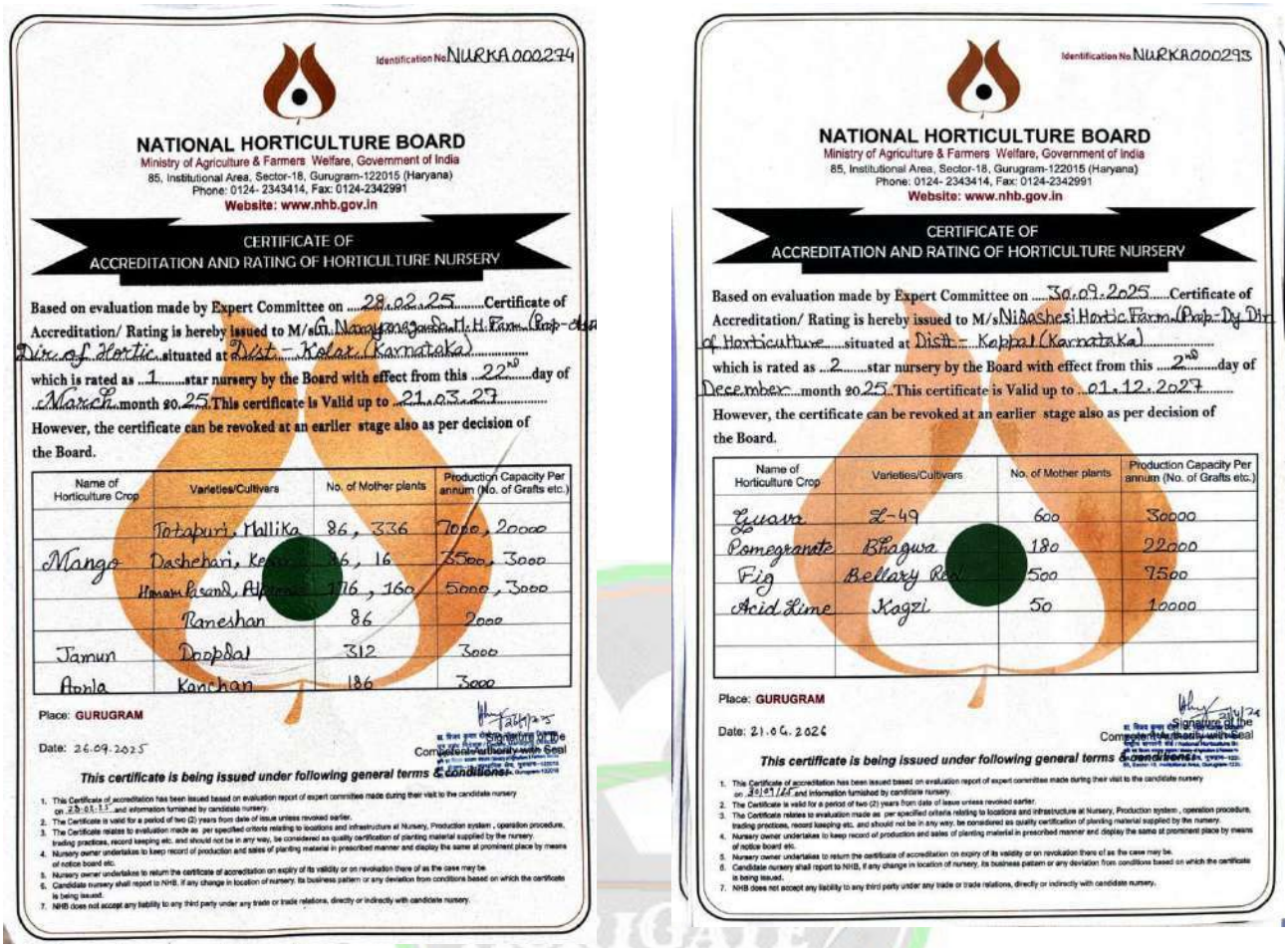
During the inspection, the team evaluates:

- Nursery infrastructure
- Mother block maintenance
- Propagation facilities
- Plant health
- Irrigation systems
- Shade-net and polyhouse facilities
- Record keeping
- Production practices
- Overall quality management

Star Rating System

Marks are awarded as per NHB guidelines based on the observations made during the inspection.

Marks Obtained	Star Rating	Grade
Below 40	Not Eligible	Unsatisfactory
41–60	★	Good
61–80	★★	Very Good
81 and above	★★★	Excellent



NATIONAL HORTICULTURE BOARD
Ministry of Agriculture & Farmers Welfare, Government of India
85, Institutional Area, Sector-18, Gurugram-122015 (Haryana)
Phone: 0124- 2343414, Fax: 0124-2342991
Website: www.nhb.gov.in

CERTIFICATE OF
ACCREDITATION AND RATING OF HORTICULTURE NURSERY

Identification No. NURKA000234

Based on evaluation made by Expert Committee on 28.02.25 Certificate of Accreditation/ Rating is hereby issued to M/s G. Narayanagouda H. H. Farm (Prop- Dy Dir of Hortic. situated at Dist – Kolar (Karnataka) which is rated as 1 star nursery by the Board with effect from this 22nd day of March month 20 25 This certificate is Valid up to 21.03.27

However, the certificate can be revoked at an earlier stage also as per decision of the Board.

Name of Horticulture Crop	Varieties/Cultivars	No. of Mother plants	Production Capacity Per annum (No. of Grafts etc.)
	Totapuri, Mallika	86, 336	7000, 20000
Manga	Dashehari, Ke	86, 16	3500, 3000
	Himsagar, Alpho	116, 160	5000, 3000
	Raneshan	86	2000
Jamun	Doppdal	312	3000
Aonla	Kanchan	186	3000

Place: GURUGRAM
Date: 26.09.2025
Signature of the Competent Authority with Seal

This certificate is being issued under following general terms & conditions.

1. This Certificate of accreditation has been issued based on evaluation report of expert committee made during their visit to the candidate nursery on 25.02.25 and information furnished by candidate nursery.
2. The Certificate is valid for a period of two (2) years from date of issue unless revoked earlier.
3. The Certificate relates to evaluation made as per specified criteria relating to locations and infrastructure at Nursery, Production system , operation procedure, trading practices, record keeping etc. and should not be in any way, be considered as quality certification of planting material supplied by the nursery.
4. Nursery owner undertakes to keep record of production and sales of planting material in prescribed manner and display the same at prominent place by means of notice board etc.
5. Nursery owner undertakes to return the certificate of accreditation on expiry of its validity or on revokation there of as the case may be.
6. Candidate nursery shall report to NHB, if any change in location of nursery, its business pattern or any deviation from conditions based on which the certificate is being issued.
7. NHB does not accept any liability to any third party under any trade or trade relations, directly or indirectly with candidate nursery.

NATIONAL HORTICULTURE BOARD
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Website: www.nhb.gov.in

CERTIFICATE OF
ACCREDITATION AND RATING OF HORTICULTURE NURSERY

Identification No. NURKA000293

Based on evaluation made by Expert Committee on 30.09.2025 Certificate of Accreditation/ Rating is hereby issued to M/s Nidoshesi Hortic Farm (Prop- Dy Dir of Horticulture situated at Dist – Koppal (Karnataka) which is rated as 2 star nursery by the Board with effect from this 2nd day of December month 20 25 This certificate is Valid up to 01.12.2027

However, the certificate can be revoked at an earlier stage also as per decision of the Board.

Name of Horticulture Crop	Varieties/Cultivars	No. of Mother plants	Production Capacity Per annum (No. of Grafts etc.)
Guava	L-49	600	30000
Pomegranate	Bhagwa	180	22000
Fig	Bellary Red	500	7500
Acid Lime	Kagzi	50	10000

Place: GURUGRAM
Date: 21.04.2026
Signature of the Competent Authority with Seal

This certificate is being issued under following general terms & conditions.

1. This Certificate of accreditation has been issued based on evaluation report of expert committee made during their visit to the candidate nursery on 30/09/25 and information furnished by candidate nursery.
2. The Certificate is valid for a period of two (2) years from date of issue unless revoked earlier.
3. The Certificate relates to evaluation made as per specified criteria relating to locations and infrastructure at Nursery, Production system , operation procedure, trading practices, record keeping etc. and should not be in any way, be considered as quality certification of planting material supplied by the nursery.
4. Nursery owner undertakes to keep record of production and sales of planting material in prescribed manner and display the same at prominent place by means of notice board etc.
5. Nursery owner undertakes to return the certificate of accreditation on expiry of its validity or on revokation there of as the case may be.
6. Candidate nursery shall report to NHB, if any change in location of nursery, its business pattern or any deviation from conditions based on which the certificate is being issued.
7. NHB does not accept any liability to any third party under any trade or trade relations, directly or indirectly with candidate nursery.

Higher star ratings reflect superior nursery management practices and higher standards of quality assurance.

Validity of Accreditation

The Nursery Accreditation Certificate is valid for two years.

Nurseries intending to continue their accredited status must apply for renewal before the expiry of the validity period.

Benefits of Nursery Accreditation

Accreditation offers several advantages to nursery owners and farmers alike.

For Nursery Owners

- Recognition as a quality nursery
- Enhanced credibility
- Better market reputation
- Increased customer confidence

- Improved business opportunities
- Scientific nursery management
- Standardized production systems
- Better traceability of planting material
- Higher demand for accredited plants

For Farmers

- Access to genuine planting material
- Healthy and disease-free plants
- Better crop establishment
- Higher productivity
- Improved produce quality
- Better economic returns
- Reduced risk of crop failure

Renewal of Accreditation

Before the expiry of accreditation, nurseries may apply for renewal. NHB reassesses whether the nursery continues to comply with the prescribed standards before extending the accreditation.

Processing Fee

The prescribed application fee is new Accreditation: Rs 5,000 and renewal: Rs 3,000

Contribution to Sustainable Horticulture

The NHB Nursery Accreditation Programme is a significant initiative aimed at strengthening the quality ecosystem of Indian horticulture.

By encouraging scientific nursery practices and ensuring the availability of genuine planting material, the programme contributes to:

- Sustainable horticultural development
- Improved productivity
- Better quality produce
- Enhanced farmer income
- Greater consumer confidence
- Modernization of the nursery sector

The programme also promotes accountability, traceability, and quality assurance throughout the horticultural value chain.

Conclusion

Quality planting material is the cornerstone of successful horticulture. The National Horticulture Board's Nursery Accreditation Programme provides farmers with a reliable mechanism to identify nurseries producing healthy, true-to-type and disease-free plants.Farmers are therefore encouraged to procure planting material only from NHB-accredited nurseries to ensure better crop performance, higher productivity and improved profitability.For nursery owners, accreditation represents a mark of excellence that enhances credibility, expands business opportunities, and encourages continuous improvement through scientific nursery management.

As India moves towards sustainable and technology-driven horticulture, the NHB Nursery Accreditation Programme will continue to play a vital role in improving the quality of planting material and strengthening the country's horticultural sector.

For Further Information

State Office	**Head Office**
The Deputy Director National Horticulture Board Ministry of Agriculture & Farmers Welfare Government of India No. 14/43, 2nd Floor, 1st & 2nd Stage Industrial Suburb Tumkur Road, Yeshwanthpur Bengaluru – 560022, **Telephone:** 080-23371935, 080-23374149, **E-mail:** blrnhb@gmail.com	**The Managing Director** National Horticulture Board Ministry of Agriculture & Farmers Welfare Government of India Plot No. 85, Sector-18, Institutional Area Gurugram – 122015, Haryana, **Telephone:** 0124-2342992 **E-mail:** md@nhb.gov.in dmd.nhb@gov.in

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OCCURRENCE OF PROTOZOAN (FLAGELLATES) PARASITIC DISEASES OF FISH

Article ID: AG-VO6-I07-98

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Introduction

Ichthyobodo necatrix or *Coastia necator*, a flagellated protozoan from the genus *Ichthyobodo*, cause Ichthyobodosis or Costiasis. This organism lacks host specificity and infects a wide variety of warm and cold-water fish species and amphibians worldwide. Although primarily in freshwater, there have been reports of marine or euryhaline strains/species. *Ichthyobodo* sp. has been reported from smooth-backed blowfish *(Lagocephalus inermis*) from Kerala (Prasad and Radhakrishnan, 2010). In China, *Ichthyobodo* was reported from hosts such as Common carp (*Cyprinus carpio*) and Grass carp (*Ctenopharyngodon idella*) in 2020, where high mortality was observed in fry and fingerlings. Symptoms include the characteristic "blue slime," where copious skin mucus gives a steel/blue-gray film, often accompanied by loss of pigment and epithelial sloughing. Infected fish show abnormal behavior such as flashing/scraping, lethargy, inappetence, and respiratory distress when gills are involved. On wet mount, the parasite appears as a small pear- to kidney-shaped flagellate showing a distinct "flickering flame" motility (Rogers , 1971)

Control and treatment strategies include temperature leverage, as infections are suppressed at ~25–30 °C. UV disinfection is effective for system management. Chemical treatments include formaldehyde (formalin), with 80 mg/L for 2 h (static bath) nearly eliminating *I. necator* on rainbow trout fry (Mohammad *et al*., 2013). Peracetic acid (PAA) is an effective alternative to formalin, where 0.3 mg/L for 2 h (static bath) showed comparable efficacy, and lower doses (0.1–0.2 mg/L) reduced burdens (Mohammad *et al*., 2013). Sodium percarbonate

(SPC), a promising oxidizer, at 120 mg/L for 2 h (static bath) was highly effective on rainbow trout, with its slower H_2O_2 release being gentler than direct hydrogen peroxide (Mohammad *et al*., 2013). Hydrogen peroxide (H_2O_2) at 30 mg/L for 2 h significantly reduced parasite numbers but caused adverse reactions in trout fry (Mohammad *et al*., 2013). Copper sulfate ($CuSO_4$) and potassium permanganate ($KMnO_4$) were effective in channel catfish, where $CuSO_4$ at ~2.1 mg/L once daily for 3 days (flow-through) significantly improved survival and reduced *Ichthyobodo* burden (Mohammad *et al*., 2013). Salt (NaCl) at 2% (20 g/L) for 20 minutes was also found effective against I. necator in trout (Balta *et al*., 2008).

Amyloodinium

Amyloodinium, is the causative agent of velvet disease, rust disease, or gold dust disease usually found in warm waters and is a significant problem in tropical aquaria. It is transmitted by contaminated water, fomites, or carrier fish, and its prevalence is influenced by factors like temperature (16–30°C), salinity (10–60‰), and high stocking densities, leading to severe morbidity and mortality in affected fish species. In India, there are reports of high mortality due to *Amyloodinium* infestation in silver pompano (*Trachinotus blochii*) percula clownfish (*Amphiprion percula*) and *Monodactylus argenteus* (Kumar *et al*., 2015; Dhayanithi *et al*., 2022; Thomas *et al*., 2020). Symptoms include a fine, dust-like "velvet" or golden/brown sheen on the skin. Severe and early gill involvement leads to rapid or labored breathing, "piping" at the surface, and congregation where oxygen levels are highest (Francis-Floyd and Floyd, 2011). Heavy gill mucus, hyperplasia, and lamellar fusion are observed on histology. The disease shows swift morbidity and mortality compared with *Cryptocaryon* (Luana *et al*., 2023).

Control and treatment measures include quarantine and biosecurity, as free-swimming dinospores are susceptible to chemicals and UV, while tomonts on tank and pond bottoms are tougher to manage. UV-C disinfection and system hygiene can inactivate tomonts and dinospores under controlled conditions, and regular removal of detritus with drying/disinfection between cohorts is beneficial (Sousa *et al*., 2024). Copper ($CuSO_4$ or chelated copper) is widely used for treatment (Yanong, 2010). Hydrogen peroxide baths at ~75 mg/L reduced and cleared infestations in both laboratory and farm trials; these are often repeated after about six days to target newly emerged dinospores (Montgomery-Brock *et al*., 2001).

Coccidians

Coccidia are microscopic, single-celled, obligate intracellular parasites causing coccidiosis, a disease characterized by intestinal damage and other systemic effects. A bibliographic survey in Azerbaijan, identified 173 coccidian parasites including *Haemococcidia, Dactylosoma, Haemogregarine, Babesiosoma, Hepatozoon, Cryptosporidium, Eimeria, Goussia, Isospora,* and *Crystallospora* in fishes such as Common carp, Goldfish, European perch, Bullhead, North African catfish, and Peacock cichlid (Mamedova and Karanis, 2025). Coccidia infect various organs, including the intestines, liver, kidney, spleen, and gonads. They are often transmitted through water, with waterborne outbreaks being a significant public health concern in some cases. Ultrastructural and molecular identification of *Babesiosoma* spp. was reported from Egyptian freshwater fishes such as Common carp and African catfish (Ali *et al*., 2024). Symptoms include infections, especially from genera such as *Eimeria* and *Goussia*, which commonly target the gut, leading to inflammation, enteritis, mucosal necrosis, and tissue destruction (Dyková and Lom, 1981). In wild fish such as bluegill, heavy coccidian infections have been linked with increased susceptibility to bacterial bloodstream infections (bacteremia) (Dyková and Lom, 1981).

Control and treatment include environmental and management practices, where maintaining optimal water quality and reducing fish stress are crucial for preventing coccidia outbreaks. Chemotherapeutic treatments such as amprolium chloride, commonly administered at feed rates of 5 g per kg of fish every two days for three doses, have shown good efficacy. Sulfonamides and amprolium are known to inhibit coccidian reproduction and support recovery in affected species (Lamps, 2008).

Cephaline Gregarines

Cephaline gregarines are protozoan parasites frequently associated with mud crabs. In India, research on mud crab diseases noted that cephaline gregarines of the genus *Nematopsis* utilize mollusks (bivalves) as intermediate hosts and may infect pond-reared mud crabs (Jithendran *et al*., 2010). The cephaline gregarines generally are not noted for being highly detrimental to their hosts, the best-known effect being damage done to the epithelial cells to which the young trophozoites are attached in the intestine of the host. Trophozoites or the motile stage of the parasite can be seen attached to the villi or gliding about in the intestine. Transmission of the parasite to new host usually takes place by oral ingestion of oocysts in both

aquatic and terrestrial environments. Transmission along with egg laying is also known. In Malaysia, a preliminary morphological study and food uptake experiment demonstrated transmission of gregarine infection from infected bivalves such as the ark shellfish (Anadara cornea) to the mud crab genus *Scylla*, confirming their role as intermediate hosts (Zakariah *et al*., 2020). Symptoms include a yellow or brownish midgut visible through the cuticle, sometimes with a distended and "packed" intestine. Wet mounts reveal abundant trophozoites and gametocysts, as observed in ("Gregarine Disease of Penaeid Shrimp" 2017). At heavy intensities, impaired gut function and tissue disruption occur. Gamete syzygy and gametocysts in the posterior gut or rectum are typical for shrimp and decapod gregarines, aiding in diagnosis (Chakraborti and Bandyopadhyay, 2010).

Control and treatment measures emphasize sourcing clean seed and treating or conditioning intake water, along with maintaining strict pond and facility hygiene. Controling co-culture and feeds is important, and the use of raw bivalves or material from areas with known Nematopsis prevalence should be avoided, as these serve as common reservoirs. (Chakraborti and Bandyopadhyay, 2010).

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ARTIFICIAL INTELLIGENCE IN WATER QUALITY MONITORING AND ENVIRONMENTAL DECISION-MAKING

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Introduction

Climate change has emerged as one of the greatest challenges of the twenty-first century, driven largely by increasing greenhouse gas emissions from industries, transportation, and other human activities. The resulting impacts including rising temperatures, extreme weather events, sea-level rise, and biodiversity loss have highlighted the urgent need for effective climate action. Traditionally, the environmental costs of carbon emissions were not borne by the polluters, allowing industries to use the atmosphere as a free disposal site. To address this imbalance, governments introduced the concept of carbon pricing, assigning a financial value to carbon emissions and encouraging businesses to reduce their environmental footprint. This approach, together with carbon trading, aims to combine economic incentives with environmental responsibility, promoting cleaner technologies and sustainable development. Today, these market-based mechanisms are increasingly recognized as important tools in the global effort to combat climate change. But can pollution really be bought and sold? Understanding carbon pricing, carbon trading, and carbon credits provides the answer to this intriguing question.

Why Has Carbon Become the Centre of Climate Discussions?

Carbon is a fundamental element that supports life on Earth and naturally circulates

through the atmosphere, oceans, plants, and soils in a process known as the carbon cycle. Under normal conditions, this cycle maintains a balance between the carbon released into the atmosphere and the carbon absorbed by natural ecosystems. However, since the Industrial Revolution, human activities such as burning fossil fuels, industrialization, and deforestation have disrupted this balance, leading to a significant increase in atmospheric carbon dioxide (CO_2).

The accumulation of CO_2 has intensified the greenhouse effect, trapping more heat in the atmosphere and contributing to global warming. As a result, the world is experiencing rising temperatures, changing rainfall patterns, melting glaciers, sea-level rise, and an increase in the frequency of extreme weather events. Countries like India are particularly vulnerable, with agriculture, fisheries, and coastal communities facing growing risks from climate change.

Beyond its environmental consequences, excessive carbon emissions also impose substantial economic and social costs, including damage to infrastructure, biodiversity loss, health impacts, and disaster recovery expenses. These costs are often borne by society rather than the polluters themselves. This has led to the adoption of the "Polluter Pays Principle," which emphasizes that those responsible for emissions should bear the financial responsibility for the environmental damage they cause. Carbon pricing is based on this principle, encouraging industries to reduce emissions while supporting climate mitigation and sustainable development.

What Is Carbon Pricing?

Carbon pricing is an environmental policy that assigns a monetary value to greenhouse gas emissions, particularly carbon dioxide (CO_2), ensuring that emitting carbon is no longer free. By placing a cost on emissions, it encourages industries and businesses to adopt cleaner technologies, improve energy efficiency, and reduce their carbon footprint.

There are two main approaches to carbon pricing. The first is a carbon tax, where governments impose a fixed price on each tonne of CO_2 emitted. The second is carbon trading or an Emissions Trading System (ETS), where governments set a limit on total emissions and allow companies to buy and sell emission allowances, with the market determining the carbon price.

Although these mechanisms differ in their implementation, both aim to reduce greenhouse gas emissions while promoting innovation and sustainable economic growth. By making environmentally responsible practices financially beneficial, carbon pricing encourages investment in renewable energy and low-carbon technologies. Ultimately, it helps integrate

environmental costs into economic decision-making, supporting the global transition toward a low-carbon and climate-resilient future.

Carbon Trading: How Does It Work?

Carbon trading, also known as an Emissions Trading System (ETS) or cap-and-trade system, is a market-based approach that helps reduce greenhouse gas emissions by placing a limit on the amount of carbon industries can emit. Rather than trading pollution itself, companies trade emission allowances, which represent the right to emit a certain amount of carbon dioxide.

Under this system, the government sets an overall emissions cap and distributes allowances to industries. Companies that emit less than their allocated limit can sell their unused allowances to companies that exceed their limits. This creates a financial incentive for businesses to reduce emissions, adopt cleaner technologies, and improve energy efficiency. Over time, governments gradually lower the emissions cap, making allowances scarcer and encouraging continuous reductions in greenhouse gas emissions.

One of the best-known examples is the European Union Emissions Trading System (EU ETS), the world's largest carbon market, with similar systems also operating in countries such as China, New Zealand, South Korea, Canada, and the United States. By combining environmental goals with economic incentives, carbon trading promotes innovation while helping countries achieve their climate targets.

Carbon Credits: What Exactly Are They?

The terms carbon credit, carbon trading, and carbon offset are often used interchangeably, but they represent different concepts.

A carbon credit is a certificate representing the reduction, removal, or avoidance of one metric tonne of carbon dioxide (CO_2) or its equivalent from the atmosphere.

Think of carbon credits as environmental certificates. Whenever a verified project successfully prevents or removes greenhouse gas emissions, it generates carbon credits. These credits can then be purchased by governments, businesses, or organizations wishing to compensate for part of their own emissions.

Carbon credits are created through a wide variety of climate-friendly activities, including:

- Large-scale afforestation and reforestation projects
- Protection of existing forests from deforestation
- Restoration of mangroves and coastal wetlands

- Renewable energy projects such as wind and solar farms
- Biogas production
- Methane capture from landfills
- Energy-efficient industrial technologies
- Sustainable agricultural practices
- Improved waste management systems

For example, consider a coastal village that restores hundreds of hectares of degraded mangrove forests. As these mangroves grow, they absorb and store significant amounts of carbon dioxide from the atmosphere. Independent experts calculate the amount of carbon stored, verify the results, and certify the project. Based on the verified carbon removal, carbon credits are issued.

Companies seeking to offset part of their emissions may purchase these credits, thereby providing financial support for ecosystem restoration while compensating for emissions that cannot yet be eliminated.

This system transforms environmental conservation into an economic opportunity.

Carbon Credits vs. Carbon Offsets

Although closely related, carbon credits and carbon offsets are not identical.

A carbon credit is the measurable unit itself the certificate representing one tonne of carbon dioxide reduced or removed.

A carbon offset refers to the act of using those credits to compensate for one's own emissions.

For example, suppose an airline emits one million tonnes of carbon dioxide annually. Despite improving fuel efficiency, eliminating every emission immediately may not be technically possible. The airline may therefore purchase verified carbon credits generated through renewable energy or mangrove restoration projects.

In doing so, the airline offsets part of its emissions while continuing efforts to reduce its own carbon footprint.

However, scientists emphasize that offsetting should never become an excuse for continued pollution. The primary objective should always be direct emission reduction, with offsets used only for unavoidable emissions.

Compliance and Voluntary Carbon Markets

Not all carbon markets operate in the same way. Broadly, they are classified into compliance

markets and voluntary markets.

Compliance Carbon Markets

Compliance markets are created through government regulations.

Industries covered under national or regional climate policies are legally required to limit their greenhouse gas emissions. Companies exceeding their permitted emission levels must either reduce pollution or purchase additional allowances from other participants.

Examples include:

- European Union Emissions Trading System
- China National Carbon Market
- California Cap-and-Trade Program
- South Korea Emissions Trading Scheme

Participation in these markets is mandatory for eligible industries.

Voluntary Carbon Markets

Voluntary carbon markets operate differently.

Here, companies, organizations, universities, airlines, event organizers, and even individuals voluntarily purchase carbon credits to reduce their environmental footprint, even when no law requires them to do so.

Many multinational companies now voluntarily invest in:

- Forest restoration
- Mangrove conservation
- Renewable energy
- Community-based climate projects
- Sustainable agriculture

These investments not only improve environmental performance but also strengthen corporate sustainability commitments and public trust.

The voluntary carbon market has grown rapidly over the past decade as businesses increasingly adopt Environmental, Social, and Governance (ESG) goals and net-zero commitments.

Why Does Carbon Trading Matter?

Carbon trading is an important economic tool for addressing climate change by encouraging cost-effective reductions in greenhouse gas emissions. Instead of requiring all industries to reduce emissions equally, it allows companies that can cut emissions at lower costs

to do so and trade their surplus allowances with others. This flexibility helps achieve climate goals while minimizing economic impacts.

In addition to reducing emissions, carbon trading promotes investment in cleaner technologies, renewable energy, energy efficiency, and environmental conservation projects such as forest restoration and wetland protection. It also encourages innovation by rewarding companies that adopt sustainable practices and reduce their carbon footprint.

However, the effectiveness of carbon markets depends on strong regulations, transparent monitoring, and reliable governance. When implemented properly, carbon trading not only helps reduce greenhouse gas emissions but also supports sustainable economic growth and the transition to a low-carbon future.

The Rise of Blue Carbon: The Ocean's Hidden Climate Solution

While forests are widely recognized for their role in carbon sequestration, coastal ecosystems such as mangrove forests, seagrass meadows, and salt marshes are among the world's most effective natural carbon sinks. Collectively known as blue carbon ecosystems, they capture and store large amounts of carbon dioxide in their vegetation and sediments for centuries, helping to mitigate climate change.

In addition to storing carbon, blue carbon ecosystems provide numerous ecological benefits, including shoreline protection, improved water quality, biodiversity conservation, and nursery habitats for fish and shellfish. Their restoration and conservation are increasingly being recognized as climate investments, with many blue carbon projects generating carbon credits that support ecosystem restoration and benefit coastal communities.

India has significant blue carbon resources, including the mangroves of the Sundarbans and Gujarat, and seagrass meadows in the Gulf of Mannar and Palk Bay. Protecting these ecosystems not only contributes to climate mitigation but also strengthens fisheries, supports the blue economy, and promotes sustainable coastal development. As carbon markets continue to expand, blue carbon is expected to play an increasingly important role in linking marine conservation with climate action.

India's Journey Towards Carbon Markets

As one of the world's fastest-growing economies, India faces the challenge of balancing economic growth with environmental sustainability. To address rising greenhouse gas emissions while meeting its climate commitments, India has pledged to achieve Net Zero emissions by

2070 and has introduced the Carbon Credit Trading Scheme (CCTS) under the Energy Conservation framework.

The CCTS promotes market-based emission reductions by rewarding industries that lower their greenhouse gas emissions with carbon credit certificates, while encouraging high-emitting industries to improve efficiency or purchase credits. The scheme aims to support cleaner production and sustainable economic growth. The success of India's carbon market will depend on effective regulations, accurate monitoring, and active participation from industries. In addition to industrial sectors, agriculture, forestry, fisheries, and coastal ecosystem conservation including mangrove and wetland restoration can play a significant role in reducing emissions and supporting the country's transition to a sustainable, low-carbon economy.

Challenges and Criticisms of Carbon Trading

Despite its potential, carbon trading faces several challenges. One major concern is that some companies may rely on purchasing carbon credits instead of making genuine efforts to reduce their own emissions. Additionally, the credibility of carbon credits depends on accurate measurement, transparent monitoring, and independent verification to ensure that emission reductions are real and measurable.

Other challenges include ensuring fairness for developing countries, which must balance economic growth with climate commitments, and managing fluctuations in carbon prices that can affect long-term investments in clean technologies. Therefore, effective governance, robust regulations, and continuous policy improvements are essential to ensure that carbon markets deliver meaningful environmental benefits and contribute effectively to global climate goals.

The Future of Carbon Pricing

Carbon pricing is expected to play an increasingly important role in the global transition to a low-carbon economy. As more countries adopt carbon pricing mechanisms, advancements in technologies such as artificial intelligence, satellite monitoring, blockchain, and remote sensing will improve the accuracy, transparency, and reliability of carbon markets.

At the same time, increased investment in renewable energy, sustainable agriculture, ecosystem restoration, electric mobility, and blue carbon initiatives will support emission reductions while creating new economic opportunities. Researchers, environmental professionals, and policymakers will be instrumental in developing innovative solutions and ensuring that carbon pricing contributes to a more sustainable and climate-resilient future.

Conclusion

Carbon pricing and carbon trading are innovative approaches that assign a financial value to carbon emissions, encouraging industries to reduce pollution, adopt cleaner technologies, and support sustainable development. Rather than allowing unlimited pollution, carbon markets create economic incentives for emission reductions while promoting innovation, renewable energy, and ecosystem restoration, including the conservation of blue carbon ecosystems.

For countries like India, these mechanisms offer significant opportunities to balance economic growth with environmental sustainability. However, their success depends on transparent policies, effective governance, and collective efforts from governments, industries, researchers, and society. As the world strives to combat climate change, carbon pricing has the potential to drive a cleaner, more resilient, and sustainable future by transforming environmental responsibility into economic opportunity.

"The greatest investment we can make is not in carbon itself, but in the future of the planet that sustains us."

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SHEEP FATTENING: A PROFITABLE ENTERPRISE FOR ENHANCING RURAL LIVELIHOODS AND MEAT PRODUCTION

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Introduction

Sheep fattening has emerged as one of the most profitable livestock production systems because it provides higher economic returns within a relatively short period. Unlike breeding enterprises, which require long-term investment and continuous management of breeding animals, fattening programmes focus on raising healthy young lambs for a limited duration, generally between 90 and 120 days, before marketing them for meat. This short production cycle enables farmers to recover their investment quickly while generating regular income throughout the year.The increasing demand for quality mutton has made sheep fattening an attractive enterprise for rural entrepreneurs, unemployed youth, women self-help groups, and progressive farmers. Mutton is considered a premium meat in India and commands a consistently higher market price than most other livestock products.

During festivals, family functions, religious celebrations, and wedding seasons, the demand for well-finished sheep increases considerably, often resulting in premium prices for heavier animals with superior body condition.Scientific sheep fattening significantly improves feed utilization and growth performance. When lambs receive balanced concentrate feed along with quality green fodder, dry roughages, clean drinking water, and mineral supplementation, they convert feed into body weight much more efficiently than under traditional grazing systems. This results in faster weight gain, better muscle development, improved dressing percentage, and enhanced carcass quality. Farmers are therefore able to market heavier animals within a shorter period, thereby increasing overall profitability.

Another important advantage of sheep fattening is the efficient utilization of locally available feed resources. Crop residues, fodder grasses, tree leaves, agricultural by-products, and agro-industrial wastes can all be incorporated into feeding programmes, reducing feed costs considerably. Scientific feeding practices also minimize wastage and improve feed conversion efficiency, making the enterprise economically viable even for small and marginal farmers.Sheep fattening fits well into integrated farming systems and contributes significantly to sustainable agriculture. Sheep manure produced during the fattening period is an excellent source of organic nutrients for crop production, helping to improve soil fertility while reducing dependence on chemical fertilizers. In addition, the enterprise creates employment opportunities for rural youth and women, strengthens household income, and contributes to nutritional security by increasing the availability of quality animal protein. With scientific management, sheep fattening has the potential to become a reliable and sustainable agribusiness for rural communities.

Selection of Lambs for Fattening

The success of a sheep fattening enterprise depends primarily on selecting healthy, fast-growing, and genetically superior lambs. Even the best feeding programme cannot compensate for poor-quality animals. Therefore, careful selection at the beginning of the fattening programme plays a decisive role in determining final body weight, feed efficiency, carcass quality, and profitability.Young male lambs between three and six months of age are generally considered ideal for fattening because they possess excellent growth potential and convert feed into body weight more efficiently than older animals. Lambs weighing approximately 15–20 kg at the start of the programme respond exceptionally well to intensive feeding and can achieve substantial weight gain within three to four months.

Male lambs are usually preferred over females because they grow faster, develop better musculature, and fetch higher market prices in meat markets.Healthy lambs should appear active, alert, and free from any signs of disease. Their eyes should be bright and clear, nostrils clean without discharge, and the hair coat should be smooth and glossy. Animals should have a broad chest, straight back, strong legs, and well-developed muscles, indicating good growth potential. The skin should be free from wounds, abscesses, ticks, lice, mites, and other ectoparasites. Likewise, the feet should be healthy without signs of foot rot, overgrown hooves, or lameness, which could reduce feed intake and growth.Farmers should avoid purchasing lambs that appear weak, emaciated, dehydrated, or suffering from diarrhoea, coughing, nasal discharge, or

respiratory distress. Such animals often require expensive treatment, exhibit poor growth performance, and may introduce infectious diseases into the flock. Purchasing animals solely because they are cheaper frequently results in economic losses rather than savings.Whenever possible, lambs should be procured from reliable breeders, organized sheep farms, government livestock breeding stations, or recognized livestock markets where veterinary inspection is available.

Before introducing newly purchased animals into the main flock, they should be quarantined separately for approximately two weeks. During this period, the animals should be observed carefully for signs of illness and should undergo deworming, vaccination, ectoparasite control, and general health examination. Quarantine serves as an effective biosecurity measure and greatly reduces the risk of disease transmission to the existing flock.Proper identification of individual animals through ear tags or other suitable methods is also recommended. Maintaining records of body weight, feed intake, deworming, vaccination, and growth performance enables farmers to monitor progress effectively and identify superior animals for future fattening programmes.

Suitable Sheep Breeds for Fattening

Breed selection is another important factor influencing the success of sheep fattening. Different breeds possess varying capacities for growth, feed conversion, adaptability, disease resistance, and carcass quality. Therefore, farmers should always select breeds that are well adapted to local climatic conditions and have proven meat-producing ability.Tamil Nadu possesses several excellent indigenous sheep breeds that perform remarkably well under semi-intensive and intensive fattening systems. Among them, Mecheri sheep are widely recognized as one of the finest meat breeds in India. They are highly valued for their rapid growth rate, excellent feed conversion efficiency, lean meat production, and superior dressing percentage. Their adaptability to the dry climatic conditions of western Tamil Nadu further enhances their suitability for commercial fattening enterprises.Madras Red sheep are another important indigenous breed extensively reared in northern districts of Tamil Nadu.

These animals exhibit good adaptability, efficient grazing ability, and satisfactory growth under improved feeding conditions. Their attractive reddish coat colour and good meat quality make them popular among farmers and consumers alike.Kilakarsal sheep, commonly found in the southern districts of Tamil Nadu, are hardy animals capable of thriving under harsh

environmental conditions. They tolerate drought well and respond positively to concentrate supplementation during fattening programmes. Similarly, Vembur sheep, native to the Thoothukudi region, are known for their tall stature, strong legs, and excellent growth performance. They perform particularly well under semi-intensive systems combining grazing with concentrate feeding.Besides Tamil Nadu breeds, several other indigenous meat breeds are suitable for commercial fattening in different parts of India. Nellore sheep from Andhra Pradesh are among the largest indigenous breeds and exhibit rapid growth with high mature body weights. Mandya sheep of Karnataka are famous for their tender meat and excellent feed conversion efficiency, while Deccani sheep of Maharashtra and Telangana are hardy animals capable of utilizing poor-quality grazing resources efficiently.

The choice of breed should always be based on local adaptability, market preference, availability of breeding stock, and production objectives. Indigenous breeds generally require less management, show better resistance to diseases, and utilize locally available feed resources more efficiently than exotic breeds. They are also better adapted to tropical climatic conditions and therefore perform consistently under village farming systems.In recent years, crossbred meat sheep developed through scientific breeding programmes have also shown encouraging performance under intensive fattening systems. However, farmers should adopt crossbred animals only when adequate feeding, housing, veterinary care, and management facilities are available. For most smallholder farmers in Tamil Nadu, indigenous breeds such as Mecheri, Madras Red, Kilakarsal, and Vembur continue to remain the most reliable and profitable choices for scientific sheep fattening.

Housing Management – Creating the Right Environment for Faster Growth

Proper housing is one of the fundamental requirements for successful sheep fattening. Although sheep are generally hardy animals capable of tolerating a wide range of climatic conditions, they perform much better when provided with a clean, dry, and comfortable shelter. A well-designed sheep shed protects animals from excessive heat, heavy rain, cold winds, and predators while minimizing stress and disease incidence. Since the objective of sheep fattening is to achieve maximum weight gain within a short period, providing a suitable housing environment plays a significant role in improving feed intake, growth rate, and overall productivity.The location of the sheep shed should preferably be on elevated ground with good drainage facilities to prevent water stagnation during rainy seasons. Damp floors increase the risk

of parasitic infestations, foot rot, pneumonia, and other infectious diseases that can reduce growth performance. The shed should be constructed in an east-west direction to minimize direct sunlight exposure during the hottest hours of the day. Adequate ventilation is equally important because proper air circulation removes excess moisture, harmful gases such as ammonia, and airborne pathogens while maintaining a comfortable environment for the animals.

The floor of the shed should remain dry, clean, and non-slippery. Earthen floors with adequate bedding, brick flooring, or concrete floors covered with dry litter materials such as paddy straw, wood shavings, or groundnut husk are commonly used. The bedding should be replaced regularly to maintain hygiene and reduce disease transmission. Wet litter should never be allowed to accumulate because it encourages bacterial growth and increases ammonia concentration, which may adversely affect respiratory health.Each growing sheep should be provided with approximately 1.0 to 1.2 square metres of covered floor space and about 2 to 3 square metres of open exercise area. Overcrowding should always be avoided because it increases competition for feed and water, reduces feed intake, facilitates disease transmission, and ultimately lowers weight gain. Separate feeding and watering areas help minimize feed wastage and maintain cleanliness within the shed.

Feed troughs and water troughs should be designed to allow all animals to eat comfortably without excessive competition. The height of the feeding trough should be appropriate for growing lambs to prevent feed spillage. Drinking water containers should be cleaned every day to prevent microbial contamination.Farmers with limited investment can construct economical sheep sheds using locally available materials such as bamboo, wooden poles, coconut leaves, GI sheets, or thatched roofing. These low-cost structures provide adequate protection while significantly reducing construction expenses. Regardless of the type of housing adopted, maintaining cleanliness and good sanitation remains the most important management practice.

Feeding Management – The Key to Rapid Weight Gain

Among all management practices, nutrition exerts the greatest influence on the success of sheep fattening. Approximately 65 to 70 percent of the total production cost in sheep farming is spent on feed. Therefore, scientific feeding not only improves growth but also determines the profitability of the enterprise.The objective of fattening is to maximize lean muscle deposition rather than excessive fat accumulation. This can only be achieved by supplying balanced

nutrition containing adequate energy, protein, minerals, vitamins, and clean drinking water. Sheep maintained solely on grazing often fail to achieve their genetic growth potential because grazing lands are becoming increasingly degraded and deficient in nutrients. Supplementary feeding with concentrate mixtures and quality fodders therefore becomes essential.Young growing lambs require diets rich in digestible protein and energy to support rapid muscle development. Balanced feeding enhances feed conversion efficiency, strengthens immunity, improves digestive function, and shortens the fattening period. Farmers should avoid sudden dietary changes, as abrupt alterations may disturb rumen microorganisms and reduce feed intake. Instead, concentrate feeding should be introduced gradually over one to two weeks.A typical feeding programme for sheep fattening includes good-quality green fodder, dry roughage, concentrate mixture, mineral mixture, common salt, and unlimited access to clean drinking water. Feeding should be carried out at fixed timings every day to establish regular feeding behaviour and improve nutrient utilization.

Green Fodder – The Foundation of Healthy Growth

Green fodder supplies essential vitamins, minerals, digestible fibre, and moisture necessary for proper rumen function. Feeding adequate quantities of green fodder improves appetite, enhances digestion, and promotes efficient nutrient utilization. Good-quality green fodder also reduces dependence on expensive concentrate feeds, thereby lowering production costs.Farmers can cultivate high-yielding fodder crops such as CO-4, COFS-29, Cumbu Napier Hybrid, Hedge Lucerne, Fodder Sorghum, Maize, Cowpea, Desmanthus, Stylo, and Guinea grass depending on local climatic conditions. Tree fodders like Subabul (Leucaena), Agathi (Sesbania grandiflora), Gliricidia, and Moringa leaves can also be incorporated into feeding programmes after proper adaptation.Fresh fodder should be harvested at the optimum stage of maturity to ensure high digestibility and nutrient availability. Extremely mature fodders contain excessive fibre, reducing feed intake and nutrient utilization. Wilted or mouldy fodder should never be offered because it may cause digestive disturbances or toxin-related health problems.

Dry Fodder – Supporting Proper Digestion

Dry roughages are equally important because they stimulate chewing activity, saliva production, and healthy rumen fermentation. Paddy straw, sorghum stover, maize stover, groundnut haulms, black gram straw, and horse gram haulms are commonly used roughages in sheep fattening systems.Although dry fodders contain relatively lower protein than green

fodders, they provide effective fibre required for maintaining normal digestive function. Chopping roughages before feeding reduces wastage and improves consumption. Farmers should ensure that dry fodders are free from fungal contamination, dust, and foreign materials.

Concentrate Feeding – The Engine of Rapid Growth

Concentrate feed provides the additional energy and protein required for accelerated weight gain. During the fattening period, concentrate supplementation plays a decisive role in improving growth performance and shortening the finishing period.A balanced concentrate mixture may include ingredients such as crushed maize, broken maize, pearl millet, sorghum, wheat bran, rice bran, groundnut cake, soybean meal, cottonseed cake, mineral mixture, and common salt. The exact formulation may vary depending on ingredient availability and local market prices.Growing lambs are generally offered concentrate feed equivalent to approximately 1.5 to 2.0 percent of their body weight per day, divided into morning and evening feedings. Feed quantity should be adjusted periodically according to body weight gain. Regular weighing of animals helps farmers determine whether nutritional management is adequate.The concentrate should always be fresh, free from fungal contamination, and stored in a cool, dry place. Mouldy feed may contain mycotoxins that adversely affect liver function, immunity, and growth performance.

Mineral and Vitamin Supplementation

Although required in relatively small quantities, minerals and vitamins are essential for proper growth, bone development, enzyme activity, reproductive health, and immune function. Deficiency of calcium, phosphorus, copper, zinc, cobalt, selenium, or vitamins may reduce feed intake, slow growth, weaken immunity, and predispose animals to various metabolic disorders.Commercial mineral mixtures formulated specifically for sheep should be incorporated into concentrate feed according to the manufacturer's recommendation. Common salt should also be supplied regularly, either mixed with feed or provided separately as salt licks.Vitamin supplementation becomes particularly beneficial during transportation, disease outbreaks, vaccination, deworming, or periods of environmental stress. Multivitamin preparations containing vitamins A, D, and E support growth, immunity, and overall health.

Water Management – The Most Neglected Nutrient

Water is often described as the forgotten nutrient, yet it is the most important component of the animal's body. More than 60 percent of the body weight of growing lambs consists of

water, making adequate hydration essential for digestion, metabolism, nutrient transport, and temperature regulation.Sheep should have unrestricted access to clean, cool drinking water throughout the day. During hot summer months, water intake may increase substantially, particularly when concentrate feeding levels are high. Insufficient water intake reduces feed consumption, slows growth, and increases susceptibility to urinary calculi and dehydration.Water troughs should be cleaned daily to prevent bacterial growth and contamination with faeces. Water should never be stagnant or contaminated with chemicals, fertilizers, or industrial pollutants



Feed Additives for Better Performance

Several nutritional supplements have been shown to improve growth performance during sheep fattening. Probiotics help maintain healthy rumen microorganisms and improve feed digestion. Prebiotics stimulate beneficial microbial populations, enhancing nutrient absorption

and immune response. Yeast culture supplementation has also been reported to improve fibre digestion and feed efficiency.Natural feed resources such as Azolla, Moringa leaves, hydroponically grown maize fodder, tree leaves, herbal growth promoters, and bypass protein supplements have gained popularity in recent years because they improve growth while reducing feed costs. Incorporating these locally available feed resources can substantially enhance profitability, especially for smallholder farmers.However, farmers should avoid indiscriminate use of synthetic growth promoters or antibiotics solely for growth enhancement, as such practices may contribute to antimicrobial resistance and food safety concerns. Scientific feeding based on balanced nutrition remains the safest and most sustainable approach to achieving optimum growth.

Health Care Management – Healthy Sheep Grow Faster

Health management is one of the most important components of a successful sheep fattening programme. Even the best feeding practices cannot produce satisfactory weight gain if animals suffer from diseases, parasitic infestations, or environmental stress. Disease not only reduces feed intake but also lowers feed conversion efficiency, delays growth, increases treatment costs, and ultimately decreases profitability. Therefore, preventive health care should always receive greater priority than treatment.A healthy sheep is active, alert, and consumes feed eagerly. It has bright eyes, a smooth and glossy coat, normal body temperature, regular rumination, and firm pellet-shaped dung. Farmers should observe their animals every day for any changes in appetite, behaviour, posture, breathing pattern, or movement. Early detection of illness allows timely intervention and prevents disease spread within the flock.=Daily cleaning of the sheep shed, proper disposal of manure, adequate ventilation, and regular disinfection of feeding and watering equipment are simple but effective measures to reduce disease occurrence. Farmers should also avoid overcrowding, since excessive stocking density increases stress and facilitates the transmission of infectious diseases.

Vaccination – Prevention is Better than Cure

Vaccination is one of the most economical methods of protecting sheep against major infectious diseases. Many diseases affecting sheep cannot be treated successfully once clinical signs appear. However, timely vaccination stimulates immunity and provides long-lasting protection.

The vaccination programme should always be planned according to the disease prevalence in the locality and the recommendations of the local veterinary department. Vaccines should be purchased only from authorized sources and transported under proper cold-chain conditions. Vaccination should preferably be carried out during the cooler hours of the day, and animals should be healthy at the time of vaccination.

A commonly recommended vaccination schedule for sheep is shown below.

Disease	**Recommended Age/Time**	**Booster/Frequency**
Enterotoxaemia	3 months of age	Once every year
Sheep Pox	3 months of age	Annual vaccination
PPR (Peste des Petits Ruminants)	Above 3 months	Once in 3 years (as per vaccine recommendation)
Foot and Mouth Disease (where recommended)	Above 4 months	Every 6 months
Anthrax (endemic areas only)	As advised by veterinarian	Annual vaccination

Regular vaccination considerably reduces mortality, improves flock health, and enhances the overall profitability of sheep fattening.

Deworming and Parasite Control

Internal and external parasites are among the most common constraints affecting sheep production. Worm infestation causes poor appetite, anaemia, diarrhoea, reduced weight gain, rough hair coat, and poor feed conversion. Young lambs are particularly susceptible because their immune system is still developing.Strategic deworming should be carried out before starting the fattening programme and repeated every two to three months depending on the grazing system and parasite burden. Deworming should preferably be done based on veterinary advice or faecal examination whenever possible. Rotating different classes of anthelmintics helps reduce the development of drug resistance.External parasites such as ticks, lice, and mites also reduce productivity by causing irritation, blood loss, skin damage, and transmission of diseases. Regular inspection of animals, maintenance of clean housing, and use of approved ectoparasiticides help control these infestations effectively.

Common Diseases Affecting Fattening Sheep

Several diseases can adversely affect growth during the fattening period if preventive measures are neglected. Enterotoxaemia commonly affects rapidly growing sheep receiving high concentrate diets and often causes sudden death. Proper vaccination and gradual dietary changes significantly reduce this risk.Peste des Petits Ruminants (PPR) is a highly contagious viral disease characterized by fever, nasal discharge, mouth lesions, diarrhoea, and pneumonia. Timely vaccination remains the most effective preventive measure.Sheep pox causes fever and skin lesions that reduce feed intake and body condition. Foot rot, particularly during the rainy season, results in severe lameness and reduced grazing activity. Pneumonia may develop when sheep are exposed to cold weather, poor ventilation, or overcrowded housing. Good management practices and prompt veterinary attention are essential to minimize production losses.



Biosecurity – Keeping Diseases Away

Biosecurity refers to all measures adopted to prevent the introduction and spread of diseases within a farm. Effective biosecurity is often inexpensive but provides enormous

economic benefits.Newly purchased sheep should always be quarantined separately for at least 14 days before being introduced into the existing flock. During this period, animals should be examined for signs of illness, dewormed, vaccinated, and treated for external parasites.Visitors should have limited access to the sheep shed, and unnecessary movement of vehicles and equipment should be avoided. Footbaths containing suitable disinfectants can be placed at the entrance of the shed. Dead animals should never be disposed of in open fields; instead, they should be buried deeply or disposed of according to veterinary recommendations.Maintaining strict biosecurity greatly reduces disease outbreaks and minimizes economic losses.

Growth Monitoring and Record Keeping

Successful sheep fattening requires continuous monitoring of animal performance. Farmers should weigh animals at the beginning of the fattening programme and thereafter at intervals of two to four weeks. Regular weighing helps determine whether the feeding programme is achieving the desired weight gain.Simple farm records should include animal identification number, purchase date, purchase weight, vaccination details, deworming schedule, feed consumption, health treatments, monthly body weight, and date of sale. Such records help farmers evaluate profitability and improve future management decisions.Under proper feeding and management, lambs can achieve an average daily weight gain of 120–180 grams and attain an additional live weight of approximately 10–18 kg during a 90–120 day fattening period.

Economics of Sheep Fattening (Example: 20 Lamb Unit)

Scientific sheep fattening is economically attractive because of its relatively short production cycle and high market demand. A farmer purchasing 20 healthy lambs and rearing them under intensive management for approximately 100 days can obtain substantial financial returns. The major expenditure includes the purchase of lambs, concentrate feed, green fodder, mineral mixture, veterinary care, labour, and miscellaneous expenses.With scientific feeding and proper health care, each lamb may gain approximately 12–15 kg during the fattening period. Depending on prevailing market prices, the sale of finished sheep often provides an attractive profit margin. In addition to meat production, farmers also obtain income through the sale of manure, which serves as a valuable organic fertilizer.Although production costs vary depending on feed prices and local market conditions, scientific sheep fattening generally offers a favourable benefit-cost ratio when good management practices are followed.

Marketing Strategies for Higher Profit

Marketing is an important determinant of profitability in sheep fattening. Farmers should identify market demand before purchasing lambs and plan the fattening period accordingly. Selling sheep during major religious festivals, wedding seasons, and holidays generally fetches higher prices because consumer demand increases significantly.Animals should be marketed only after achieving optimum body condition. Over-fattening unnecessarily increases feeding costs without proportionate improvement in selling price. Maintaining healthy, well-finished sheep with good body conformation and attractive appearance helps secure premium prices.Collective marketing through Farmer Producer Organizations (FPOs), livestock cooperatives, and farmer groups can improve bargaining power and reduce transportation costs.

Common Mistakes to Avoid

Many farmers experience reduced profits because of avoidable management errors. Purchasing unhealthy or underweight lambs, changing diets abruptly, feeding poor-quality fodder, neglecting mineral supplementation, delaying vaccination, failing to control parasites, overcrowding animals, and providing inadequate drinking water all reduce growth performance.Ignoring market trends is another common mistake. Farmers who fail to synchronize fattening with peak demand periods often receive lower prices. Scientific planning, proper record keeping, and regular veterinary consultation help avoid these problems.

Conclusion

Sheep fattening has emerged as one of the most promising livestock enterprises for improving rural livelihoods and meeting the growing demand for quality mutton. By combining healthy lamb selection, balanced nutrition, comfortable housing, preventive healthcare, strategic marketing, and efficient management, farmers can substantially improve growth performance and profitability within a relatively short period.Scientific sheep fattening is particularly suitable for small and marginal farmers because it requires moderate investment, offers quick financial returns, and integrates well with existing farming systems. Utilization of locally available feed resources, adoption of improved management practices, and timely veterinary care further enhance the sustainability of the enterprise.As consumer demand for hygienically produced, high-quality mutton continues to increase, scientific sheep fattening will play an increasingly important role in strengthening the livestock sector, creating rural employment, and improving

farm income. With proper planning, dedication, and technical guidance, sheep fattening can become a profitable and sustainable agribusiness for the farming community.

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ETHNOBOTANICAL USES OF PURPLE NUTSEDGE (*Cyperus rotundus* L.)

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Introduction

Cyperus rotundus is a perennial herb, commonly known as 'purple nut sedge' due to its characteristic reddish-brown-purple spikelet. The other names are Coco grass, Ground almond, Java grass, Nut sedge, Nut grass, Purple nutgrass, Red nut sedge. It is designated as "world's worst weed" as it infests at least 52 different crops worldwide. The plant is classified as 'Least Concern' in the IUCN Red List of Threatened Species (2018). The troublesome weed causes 20 – 90 per cent yield loss in various crops across the world due to its allelochemicals and vigorous competition. Rhizomes and tubers of nutgrass interfere with harvesting for root crops and increase post-harvest processing costs. However, *Cyperus rotundus*, one of the oldest known medicinal plants, widely used to treat various ailments. The 25th chapter of sutrasthana of *Charaka Samhita* mentioned *Cyperus rotundus* as the best among all herbs in causing astringent effect.

Taxonomical classification of *Cyperus rotundus*

Kingdom	:	Plantae
Phylum		Streptophyta
Class	:	Equisetopsida
Subclass	:	Magnoliidae
Order	:	Poales
Family	:	Cyperaceae
Genus	:	*Cyperus*
Species	:	*rotundus*



Distribution of *Cyperus rotundus*

India is considered as the centre of origin of purple nutsedge and widely distributed in more than 92 countries in the tropical and subtropical regions worldwide. Perennial nature, genetic diversity, ability to tolerate adverse climatic conditions, high rate of reproduction, ease-of-dispersion, strong competitive abilities, and allelopathic potential assist this weed to thrive in a wide range of agro-climatic regions.

Growth, development and morphology of *Cyperus rotundus*

Cyperus rotundus L is a colonial, noxious perennial herb with fibrous root system and grow up to 40 cm height. Culms of unequal length, usually erect, unbranched, dark green, smooth and trigonous with a much-branched terminal inflorescence. Leaves are dark green, shiny, narrow with an upper surface having grooves and no ligules or auricles, and generally shorter than the culm. There are up to 22 leaves per plant, emerging in three vertical rows near ground level.

Inflorescence is simple to compound corymb, loose and variable in size, consisting of 3-9 rays of different length. Spikes densely to sub-loosely bearing 3-12 spikelets with glabrous rachis. Spikelet is spicately arranged, suberect to spreading, compressed, linear and 10-14 flowered. The reddish-brown bisexual flowers are with three stamens and a pistil bearing three stigmas. They produce flowers abundantly but rarely produce viable seeds.

Rhizomes and tubers are produced extensively and most tubers are found growing in 15 to 20 cm of soil, a few penetrate more than 40 below the soil. Rhizomes may grow in any direction in the soil. Rhizomes are white and fleshy with scale leaves during their production and as they mature, become ligneous or wiry. Later the rhizomes grow upwards and reach the surface, swell to form a basal bulb, or corm that grows into a new plant producing shoots, roots and rhizomes. The rhizomes that are growing downwards or horizontally form individual tubers or chains of tubers, each of which may separate from the parent plant and lie dormant for years before growing into a new plant.

Mature individual tubers are dark reddish-brown, sub-globose shaped with specific fragrance, about 12 mm thick and vary from 10 to 35 mm long. A single tuber could produce 99 tubers in 90 days under favourable conditions. Tuber has 16 months half-life and 42 months predicted longevity. The nuts are trigonous, oblong-obovoid and brownish. Nutlets are rarely produced. Tubers and basal bulbs help in vegetative propagation. *Cyperus rotundus* is prolific in

disturbed soil due to their tuber production which can remain as dormant for several months. During active growing periods, 2-3 million tubers/ha/week can be produced yielding 30-40 million tubers/ha. Annually, it produces up to 40 t/ha of subterranean plant material.

Soil and climatic requirements of *Cyperus rotundus*

Cyperus rotundus is widespread from the warm temperate zone to the tropics, where it is found at elevations up to 800 metres. It shows abundant growth in low-lying areas where water accumulates. It prefers a mean annual rainfall of 500 - 3,000 mm, but tolerates 300 - 4,200 mm. The plant prefers moderate to high fertility soils, and moderate moisture levels. Prefers a moist sandy loam with a pH in the range 5.5 - 7, tolerating 3.5 – 8. However, it can tolerate almost every soil type, moisture level and soil pH.

Cyperus rotundus is a C_4 plant, which has an adaptation to assimilating CO_2 at higher temperatures and higher light intensities. It grows best in areas where annual daytime temperatures are within the range 24 - 32° C, but can tolerate 10 - 45° C. It can be killed by temperatures of -5°c or lower. Plant growth is slow and tuber sprouting is inhibited below 20°C. Flowering may occur in 3-6 weeks after emergence, which is commonly during summer. Plant growth can be restricted by shade, low temperature and saline soil. It is susceptible to extended dry condition. The tubers will not survive when their water content reaches 15 per cent. Plant growth rate is high in hot weather, high light and high temperature. Tubers can remain dormant during drought or flooding and viable for future regrowth once conditions suit.

Chemical constituents of *Cyperus rotundus*

Tannins, alkaloids, cyperol, essential oils (α-longipinane, *β*-selinene, cyperene, and caryophyllene oxide), flavonoids (anthocyanidins, catechins, flavans, flavones, flavanonols, and isoflavane), fatty oils, furochromones, glycerol, linolenic acid, myristic acid, nootkatone, starch, saponins, sesquiterpenes, sitosterol, stearic acid, terpenoids, polyphenol, and valencene are the active ingredients present in the tubers and rhizomes of *Cyperus rotundus* responsible for the biological and therapeutic properties of *Cyperus rotundus.*

Medicinal uses of *Cyperus rotundus*

Cyperus rotundus (Ayurvedic name: Nagarmotha) is considered to have originated in India 2000 years ago and regarded as one of the best Ayurvedic herb. The plant can be used as an analgesic, anti-arthritic, antibacterial, anticancer, anti-candida, anti-convulsant, anti-diabetic,

anti-emetic, anti-histaminic, anti-inflammatory, anti-malarial, anti-obesity, anti-pyretic, anti-spastic, gastroprotective, hypotensive, sedative, and tranquilizing agent.

Rhizomes and tubers of *Cyperus rotundus* have been used as a traditional folk medicine since ancient time to treat bowel and stomach disorders and inflammatory diseases in several countries including China, India, Iran, and Japan. Rhizomes and tubers of *C. rotundus* possess antidiarrheal, antioxidant, anti-inflammatory, antimutagenic, antiperiodic, anticonvulsant, anti-saturative, antipyretic, antifungal, antidiabetic, antimalarial, antilipidemic, antibacterial, antiviral, anti-tumoral, cardioprotective, and wound-healing properties. It is also considered as an appetizer; diuretic; digestant; nervine tonic; and thirst-relieving, lactodepurant, and Ayurvedic or selective drug for the treatment of amenorrhea, bronchitis, blood disorders, leprosy, spasms, diarrhea, dysentery, stomach disorder, menstrual irregularities, and inflammatory diseases.

The leaves and seeds of *C. rotundus* are rich sources of volatile oils with efficient bactericidal and fungicidal compounds that improve the digestive system, stimulate appetite, and relieve irritation.

Table 1. Ethnomedicinal applications of *Cyperus rotundus*

Parts used	Medicinal use	Medicinal formulations
Flower	Blood dysentery	Juice of the macerated flowers of *Cyperus rotundus* with honey
Leaves	Gonorrhoea, Syphilis	Dried powdered leaves of *Cyperus rotundus*
	Headache, Hyperacidity	Dried leaves of *Cyperus rotundus*
	Hypoglycemia	A mix of tseeds of Jamun and bitter gourd, and dried powder of *Cyperus rotundus* and white rose leaves
Rhizome	Bronchitis	Fruits of *Pergularia daemia* with rhizomes of *Cyperus rotundus* and leaves of *Tinospora cordifolia*
	Cholera	Boiled rhizomes of *Cyperus rotundus* and spear mint
	Dermatitis	Rhizome of *Cyperus rotundus*, stem bark of neem and leaves of snake gourd in the form of paste
	Eczema	Henna and neem leaves are macerated with *Cyperus rotundus* for topical application
	Gynaecological disorder	Dried powder of rhizome of *Cyperus rotundus* and juice of pummelo fruit
	Kidney stone	Rhizome of *Cyperus rotundus*, roots of touch me

Parts used	Medicinal use	Medicinal formulations
		not plant and flintstone for oral use
	Malaria	Decoction of *Cyperus rotundus* rhizomes and neem bark
	Snake bite	Paste of rhizome of *Cyperus rotundus* leaf and root bark of *Albizia amara* and root bark of *wild jasmine* heated with neem oil for topical application
	Stomach ache	Sun dried rhizomes of *Cyperus rotundus*, stem bark of *Holarrhena antidysenterica* and ginger for oral administration, along with buttermilk
	Tonsillitis	Paste of *Cyperus rotundus* rhizome with turmeric powder is rubbed inwards of the tongue
	Amenorrhoea, Cervical cancer, Diarrhoea, Deficient lactation, Dyspepsia, Dysmenorrhoea, Fever, Flatulence, Food poisoning, Indigestion, Infertility, Intestinal parasite, Loss of memory, Nausea, Renal and vesical calculi, Urinary tenesmus, Vomiting, Wounds	Dried rhizome of *Cyperus rotundus*
Rhizome and root	Rheumatic pain Bile problems Body ache	A mix of the rhizomes and roots of *Cyperus rotundus*, the stem bark of *Gmelina arborea*, root of *Asparagus racemosus*, leaves of *Adhatoda zeylanica*, *Aerva lanata*, honey and *Piper longum*
Root	Intermittent fever	Decoction prepared from *Cyperus rotundus* roots and fresh ginger
	Jaundice	A paste of fresh roots of *Cyperus rotundus* and fruits of Amla
	Pimples	Roots of *Cyperus rotundus* along with turmeric and curd are made into a paste
	Reduced lactation	Paste of the roots of *Cyperus rotundus*
	Skin eruptions	Decoction of the ash of *Ammannia baccifera* leaves and *Cyperus rotundus* roots and fresh ginger in sesame oil

Parts used	Medicinal use	Medicinal formulations
Tuber	Constipation	Juice obtained from macerated tubers of *Cyperus rotundus*
	Cough	Tubers of *Cyperus rotundus*
	Diabetes	Dried powdered tuber of *Cyperus rotundus*
	Leukorrhea	*Cyperus rotundus* tubers with *Abutilon indicum* leaves and Cumin seeds for oral use
	Vaginal discharge	Tubers of *Cyperus rotundus* crushed with *Abutilon indicum* leaves and *Cumin* seeds
Whole plant	Bone fracture	Dried powder of *Cyperus rotundus*, *Cissus quadrangularis*, *Evolvulus nummularius* and ginger
	Epilepsy	Decoction of *Cyperus rotundus* with honey
	Loss of libido in men	Leaves of guava, leaves of pomegranate, and whole plants of *Cyperus rotundus*
	Puerperal fever	Juice of *Cyperus rotundus* whole plant mixed with guava and pomegranate leaves
	Urinary trouble, Stone removal	Decoction of the whole plant

Edible uses of *Cyperus rotundus*

In Asia, the leaves of *Cyperus rotundus* were used as a food flavouring agent, while the rhizomes and tubers were widely used in curries, pickles and bakery products. The rhizomes and tubers were also used to purify water, and as a thirst quencher. It is a staple carbohydrate in tropical regions especially during the famine seasons. It can be eaten raw or processed in the form roasting, drying, baking and extract with milk.

Phytoremediation potential of *Cyperus rotundus*

Cyperus rotundus is a hyper tolerant plant with high ability to take up heavy metals *viz*., cadmium, chromium, copper, lead and nickel from soil, accumulate it in its underground tissues. Hence, it could be used in natural treatment of polluted soil and in the rehabilitation programmes as a safe tool.

Other uses of *Cyperus rotundus*

The leaves are used in basketry and for weaving hats, matting etc. The aromatic tubers contain an essential oil and are used for perfumery in India. When dried and ground into a fine powder it is used like talcum powder. The tuber is also used as an insect repellent and to scent clothes in the cupboard. An extract of the tubers is used as an ingredient in commercial cosmetic preparations as a skin conditioner.

Conclusion

Though *Cyperus rotundus* has an unfavourable effect on natural ecosystems, it is the oldest herbs being used by mankind. Recently, ethno-botanical and traditional uses of natural compounds, especially of plant origin, received much attention as they are generally safe for human use. Being a noxious weed widely distributed globally, *Cyperus rotundus* can be collected in huge quantity, efforts should be directed to develop the value added herbal products from the weed by the skilful application of modern science and technology tools.

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DRIVING INDIA'S AGRI-EXPORTS: THE RISING ROLE OF OILSEEDS

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Abstract

Agriculture plays a crucial role in India's external trade and economic development, contributing significantly to export earnings, employment generation, and rural income. Among agricultural commodities, oilseeds occupy a prominent position due to their growing domestic and international demand. The present study examines the production and export performance of major oilseeds in India, with a special focus on Gujarat, a leading oilseed-producing state. The findings reveal that India's oilseed sector has experienced steady growth, with production increasing at a compound annual growth rate of about 6 per cent over the last decade. The export structure is highly concentrated, with groundnut and sesame seeds accounting for more than 90 per cent of total exports. Gujarat plays a dominant role, particularly in groundnut and castor production. However, fluctuations in export performance indicate vulnerability to global price volatility, quality standards, and trade disruptions. The study suggests the need for diversification, value addition, and improved quality compliance to enhance India's competitiveness in the global oilseed market.

Keywords

Oilseeds, Export performance, Groundnut, Castor, Sesamum

1. Introduction

Agriculture is a vital component of India's economy and a key contributor to its external trade. India accounts for nearly 2.5 per cent of global agricultural exports and contributes about 12 per cent to the country's total export earnings. The sector plays a significant role in foreign exchange generation, employment creation, and rural development. In recent years, the diversification and value addition of agricultural commodities have strengthened India's global trade position. Within this framework, oilseeds have emerged as an important export commodity group. India has also witnessed regional specialization in export-oriented crops, with Gujarat emerging as a leading contributor.

Gujarat has developed a strong comparative advantage in oilseed production, particularly in groundnut, castor, and sesamum. Favorable agro-climatic conditions, strong processing infrastructure, and efficient port facilities have enabled the state to dominate both domestic production and export markets. Gujarat is the largest producer and exporter of groundnut and castor oil in India, supplying to major international markets such as China, the USA, and Southeast Asia. Given the increasing importance of oilseeds in agricultural exports, this study aims to analyse their production and export performance to understand economic significance and evolving trade dynamics.

2. Data and Methodology

The study is based on secondary data collected from various sources, including the Directorate of Economics and Statistics, Government of Gujarat, APEDA, and DGCIS reports. Time-series data on production and exports were analyzed to examine trends and growth patterns. Simple statistical tools such as percentage analysis and compound annual growth rate (CAGR) were used to assess growth and distribution patterns. The study also employs descriptive analysis to examine commodity-wise export performance.

3. Results and Discussion

3.1 Status of Oilseeds in India

India is one of the leading producers of oilseeds, accounting for about 20.8 per cent of the global oilseed area and nearly 10 per cent of total production. Oilseeds occupy around 14.3 per cent of the country's gross cropped area and contribute significantly to dietary energy and agricultural exports. Oilseed production in India has shown a steady increase, rising from 25.3 million tonnes in FY16 to 42.6 million tonnes in FY25, registering a CAGR of about 6 per cent.

Despite some year-to-year fluctuations, the overall trend reflects sustained growth.

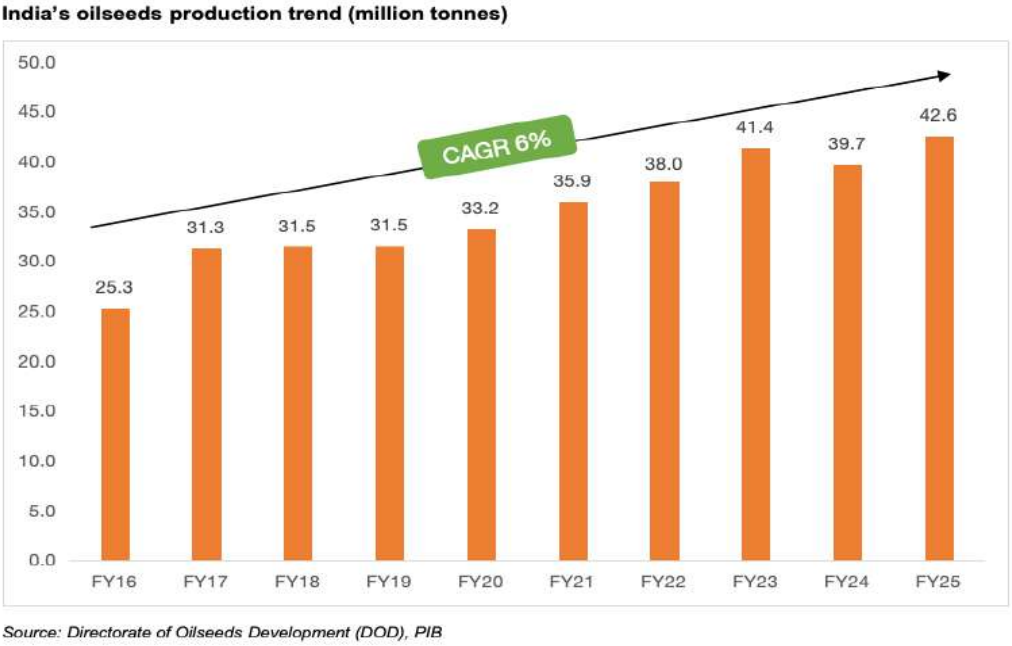


Figure 3.1: Total oilseeds production in India (FY-2016 to FY-2025) (million tonnes)

The production structure is highly concentrated among three major crops—rapeseed and mustard (33.42 per cent), soybean (32.93 per cent), and groundnut (25.66 per cent). Together, they contribute more than 90 per cent of total oilseed production. Other oilseeds such as castor and sesamum contribute relatively smaller shares.

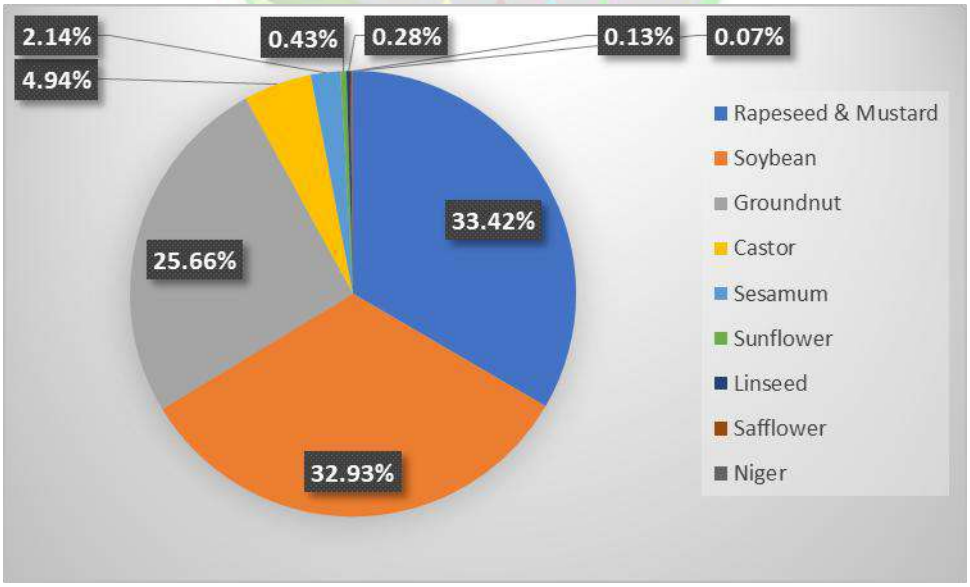


Figure 3.2: Commodity -wise share of major oilseed production in India (2023-24)

3.2 Oilseed Economy in Gujarat

Gujarat is a major oilseed-producing state, with oilseeds covering 31.36 lakh hectares, accounting for 27.05 per cent of the total cropped area. Groundnut is the dominant crop, occupying 54.05 per cent of the oilseed area and contributing 62.78 per cent of production. Castor ranks second, followed by rapeseed and mustard, soybean, and sesamum. The concentration of production in groundnut and castor highlights Gujarat's specialization in these crops. These commodities also form the backbone of the state's agro-processing and export industries.

Table 3.1: Area and Production of major oilseeds crop in Gujarat (2023-24)

Crop	Area ('00 ha)	Per cent share in total area	Production ('00 MT)	Per cent share in total production
Groundnut	16953.4	54.05	46458.08	62.78
Castor seed	7247.68	23.11	15954.77	21.56
Rapeseed & Mustard	2773.81	8.84	5260.53	7.11
Soybean	2657.37	8.47	4882.97	6.6
Sesamum	1732.44	5.52	1439.98	1.95
Total oilseeds	**31364.70**	**100.00**	**73996.33**	**100.00**

Source: https://dag.gujarat.gov.in/

3.3 Export Performance of Oilseeds

India's oilseed exports have shown fluctuations over time. Exports increased from US$ 1,246.90 million in FY16 to US$ 1,436.21 million in FY24, with intermittent declines due to global price volatility, quality standards, and trade disruptions.

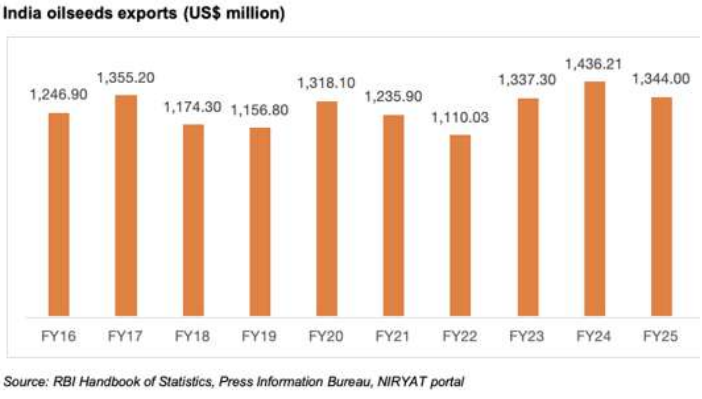


Figure 3.3: Export of total oilseeds from India (US$ million)

The decline during FY18–FY19 can be attributed to stricter international quality standards and increased competition, while the dip in FY22 reflects the impact of the COVID-19 pandemic and high logistics costs. The recovery in FY23 and FY24 indicates improved global demand and domestic production.

3.4 Commodity-wise Export Analysis

The export structure of oilseeds is highly concentrated. During 2025–26, total oilseed exports were 10,69,079.79 MT, valued at US$ 1,355.70 million. Groundnut dominated exports, accounting for 69.81 per cent of total quantity and 58.64 per cent of value. Sesame seeds ranked second, contributing 23.47 per cent of quantity and 36.25 per cent of value. Other oilseeds such as rapeseed, linseed, soybean, and castor seeds had marginal contributions. Overall, groundnut and sesame seeds together accounted for more than 93 per cent of export quantity and about 95 per cent of export value.

Table 3.2: Quantity and value of commodity-wise oilseeds exports from India (2025-26)

Product	Quantity (MT)	% share in the total quantity	Value (million)	% share in total value
Groundnut	7,46,303.13	69.81	794.99	58.64
Sesame seeds	2,50,933.43	23.47	491.39	36.25
Rapeseed and mustard	25,294.89	2.37	20.91	1.54
Lin seed	17,419.19	1.63	20.46	1.51
Soybean	9,030.35	0.84	5.52	0.41
Copra	9,030.35	0.84	5.52	0.41
Niger seed	4,525.89	0.42	7.18	0.53
Castor seeds	2,549.31	0.24	4.74	0.35
Safflower	2,323.75	0.22	1.57	0.12
Sunflower	1,555.48	0.15	2.41	0.18
Cotton seeds	96	0.01	0.96	0.07
Total oilseeds	**10,69,079.79**	**100.00**	**1,355.70**	**100.00**

Source: APEDA

Conclusion

The study highlights that India's oilseed sector has experienced steady growth, supported by increasing demand and improved production performance. Gujarat plays a significant role in this sector, particularly in groundnut and castor production. The export performance of oilseeds is highly concentrated in a few commodities, making it vulnerable to global market fluctuations. Therefore, there is a need to diversify the export basket, promote value addition, and strengthen quality standards. Policy measures should focus on improving productivity, enhancing infrastructure, and expanding market access to sustain export growth and improve farmers' income.

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SMART SEEDS FOR A SUSTAINABLE FUTURE: NEXT GENERATION SEED TREATMENT TECHNOLOGIES FOR CLIMATE RESILIENT AGRICULTURE

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Abstract

Climate change has become a major challenge for modern agriculture by affecting crop productivity through drought, heat stress, salinity and increasing pest and disease pressure. Seed treatment technologies have evolved from conventional chemical protection methods to advanced approaches that enhance seed vigour, nutrient efficiency and stress tolerance.Next-generation seed treatment technologies such as biological seed treatment, nano-based seed enhancement, microbial consortia, seed priming and smart coating systems provide new opportunities for developing climate-resilient crops. These technologies improve germination, strengthen early plant growth, enhance resistance against environmental stresses and reduce dependency on chemical inputs.

Introduction

Climate change is one of the major challenges affecting global agriculture by causing drought, heat stress, irregular rainfall and increased pest and disease pressure. To overcome these challenges, improving crop resilience from the seed stage has become essential. Seed treatment, once mainly used for disease protection, has now evolved into an advanced technology that enhances seed vigour, nutrient efficiency and stress tolerance. Next-generation seed treatment

technologies such as biological treatments, nanotechnology, seed priming and smart coating systems are paving the way for sustainable and climate-resilient agriculture.

Why Next-Generation Seed Treatment?

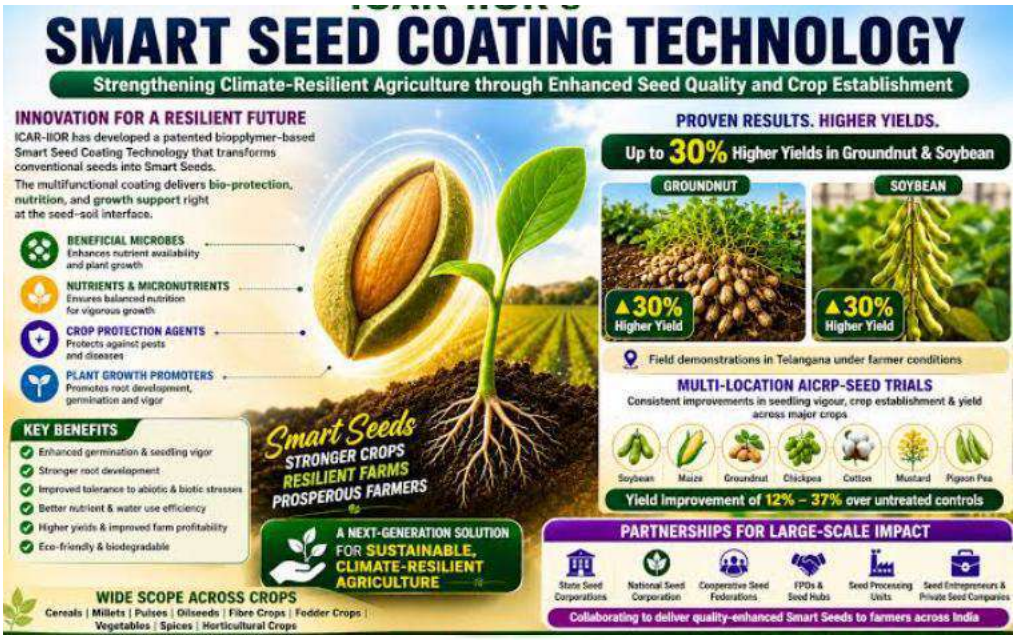
Enhances seed germination and vigour.

Improves drought and heat tolerance.

Promotes healthy root development.

Reduces chemical input dependency

Supports sustainable crop production.



Evolution of Seed Treatment Technologies:

- Seed treatment has evolved significantly over the years. Earlier, farmers mainly used simple methods such as soaking seeds, applying ash or using chemical fungicides to protect seeds from diseases.
- Modern seed treatment technologies focus on improving the overall quality and performance of seeds.

The major stages of development include:

I. Traditional Seed Treatment.

II. Fungicide and insecticide application.

III. Protection against seed-borne diseases.

IV. Improvement of seed health.
V. Advanced Seed Treatment.
VI. Seed priming techniques.
VII. Biofertilizer and microbial treatments.
VIII. Polymer-based seed coating.
IX. Next-Generation Technologies.
X. Nano-enabled seed treatments.
XI. Smart seed coating systems.
XII. Microbial consortia technology.
XIII. Precision-based seed enhancement.

These technologies are transforming seeds from simple planting materials into intelligent biological systems capable of responding better to environmental challenges.

Next-Generation Seed Treatment Technologies

1. Biological Seed Treatment: Harnessing Beneficial Microorganisms

Biological seed treatment is one of the most promising approaches for sustainable agriculture. It involves the application of beneficial microorganisms on seeds to improve plant growth and protection.

Important biological agents include:

- Plant Growth-Promoting Rhizobacteria (PGPR)
- Trichoderma species
- Arbuscular mycorrhizal fungi
- Beneficial bacterial consortia
- These microorganisms colonize the root zone and enhance plant growth through multiple mechanisms.
- Benefits of Biological Seed Treatment
- Improved nutrient availability:Beneficial microbes increase the availability of essential nutrients such as nitrogen and phosphorus.

Disease suppression:

Microbial treatments protect young seedlings by competing with harmful pathogens and producing natural antimicrobial compounds.

Enhanced stress tolerance:

These microorganisms help plants withstand drought, heat and salinity stress by improving root growth and physiological activity.

Biological seed treatments are gaining importance because they are eco-friendly and reduce chemical dependency in crop production.

2. Nano-Based Seed Treatment Technology

- Nanotechnology is creating new opportunities in agriculture by improving the efficiency of nutrients and protective compounds.
- Nano-based seed treatments involve the use of extremely small particles that can interact effectively with plant cells.

Commonly used nano materials include:

- Nano zinc, Nano iron, Nano silica, Nano-based nutrient formulations

Advantages of Nano Seed Treatment

- Faster and uniform seed germination
- Improved seedling growth
- Better nutrient absorption
- Enhanced tolerance against environmental stress
- Reduced requirement of chemical inputs

For example, nano silica applications can improve plant strength and tolerance against drought and heat stress by enhancing water-use efficiency and strengthening plant tissues.

However, proper research and safe application methods are essential for successful adoption of nano technologies.

3. Seed Priming Technologies: Preparing Seeds for Better Performance

Seed priming is a controlled hydration process that activates important metabolic activities inside seeds before sowing.

Major types of seed priming include:

Hydropriming:

Seeds are soaked in water for a specific period and dried before sowing.

Osmo priming:

Seeds are treated with osmotic solutions to improve germination performance.

Biopriming:

Seeds are treated with beneficial microorganisms along with hydration.

Nano priming:

- Seeds are treated with nanoparticles to improve physiological activity.
- Advantages of Seed Priming
- Faster germination
- Uniform crop establishment
- Better seedling vigour
- Improved tolerance under stressful environments
- Seed priming is a simple and affordable technology that can provide significant benefits to farmers.

4. Microbial Consortia-Based Seed Coating

- Single microbial treatments may provide limited benefits under complex field conditions. Therefore, combining multiple beneficial microorganisms is becoming an advanced approach.
- Microbial consortia may include:
- Nitrogen-fixing bacteria
- Phosphate-solubilizing microorganisms
- Plant growth-promoting fungi
- These combinations provide multiple benefits by improving nutrient cycling, root development and plant defence mechanisms.
- This technology is particularly useful in climate-stressed environments where crops require additional support during early growth stages.

5. Smart Seed Coating Technology

Smart seed coating is an emerging technology that provides controlled delivery of nutrients, microbes and protective compounds.

Advanced polymer coatings are used to cover seeds and regulate the release of useful materials according to environmental conditions.

- Features of Smart Seed Coating
- Controlled nutrient release

- Protection from pathogens
- Improved seed storage ability
- Better seed-soil interaction

This technology supports precision agriculture by ensuring that the right input reaches the plant at the right time.

Role of Next-Generation Seed Treatment in Climate-Resilient Agriculture

Climate change creates several stresses that affect crop establishment and productivity. Advanced seed treatments help crops overcome these challenges.

- Climate Challenge -Role of Advanced Seed Treatment.
- Drought stress-Improves root growth and water absorption.
- Heat stress-Enhances antioxidant activity and plant defence.
- Salinity stress -Improves nutrient balance and osmotic adjustment.
- Disease pressure-Provides early protection against pathogens.
- Poor soil conditions-Improves microbial activity and nutrient availability.
- By strengthening crops from the beginning, seed treatment technologies contribute to stable production even under unpredictable climatic conditions.
- **Comparison of Next-Generation Seed Treatment Technologies.**

Technology	Key Components	Major Benefits	Climate Resilience
Biological Seed Treatment	PGPR, *Trichoderma*, Mycorrhiza	Improves nutrient uptake, suppresses diseases.	Enhances drought, salinity and disease tolerance.
Nano-Based Seed Treatment	Nano zinc, nano silica, nano iron	Better nutrient absorption, faster germination.	Improves heat and drought tolerance.
Seed Priming	Hydropriming, Osmo priming, Biopriming, Nano priming	Uniform germination and vigorous seedlings.	Improves crop establishment under stress.
Microbial Consortia		Enhances root growth and nutrient	Improves crop establishment under

	Nitrogen-fixing and phosphate-solubilizing microbes	availability.	stress.

Future Prospects:

i. The future of seed treatment will be driven by advanced research and digital technologies.
ii. Future developments may include:
iii. AI-based selection of suitable seed treatments
iv. Smart sensors for monitoring seed performance
v. Genome-based stress prediction
vi. Advanced bio-nano formulations
vii. Farmer-friendly low-cost coating technologies
viii. Integration of biotechnology, nanotechnology and precision agriculture will create the next generation of climate-smart seeds.

Conclusion

Seeds are no longer considered only as planting materials; they are becoming carriers of advanced technologies that support sustainable crop production. Next-generation seed treatment technologies provide a promising pathway to improve germination, enhance crop resilience and reduce environmental impacts.In the era of climate change, smart seed treatments will play a crucial role in developing agriculture that is productive, sustainable and capable of meeting future food demands. By combining scientific innovation with farmer-friendly approaches, these technologies can help build a climate-resilient agricultural system for generations to come.

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CLIMATE CHANGE AND EL NINO: BUILDING CLIMATE-RESILIENT CASHEW ORCHARDS

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Introduction

Cashew (*Anacardium occidentale* L.) is one of India's most important plantation crops, cultivated predominantly in the coastal and rainfed regions where it provides livelihood security to millions of farming families. Its ability to grow on marginal and lateritic soils with relatively low management inputs has made it a preferred crop in areas where cultivation of many other crops is constrained by poor soil fertility and limited water availability. Besides generating income through high-value kernels, cashew also supports rural employment and offers opportunities for value addition through products derived from the cashew apple and cashew nut shell.

In recent years, however, changing climatic conditions have emerged as a major challenge to sustainable cashew production. Rising temperatures, erratic rainfall, prolonged dry spells, heat waves, and unseasonal rains are increasingly affecting orchard performance. These weather abnormalities disrupt critical growth stages such as flushing, flowering, fruit set, and nut development, resulting in reduced productivity and increased incidence of insect pests and diseases. Climatic phenomena such as El Nino, which often influence the timing and distribution of the southwest monsoon, further add to the uncertainty of cashew cultivation, particularly in rainfed areas. Although cashew is naturally more resilient than many commercial crops, maintaining stable yields under changing climatic conditions requires climate-smart production practices. Improved varieties, efficient water management, soil moisture conservation, balanced

nutrition, and timely pest and disease management are becoming increasingly important for sustaining orchard productivity. This article highlights the impact of climate change and El Nino on cashew cultivation and outlines practical strategies for developing resilient and sustainable cashew orchards.

Climate Change and El Nino: Challenges for Cashew Cultivation

Climate change has become a major concern for cashew cultivation as increasing temperatures, erratic rainfall, prolonged droughts, and frequent extreme weather events are affecting orchard productivity across many growing regions. These changes are particularly significant in rainfed areas, where cashew production largely depends on the timely receipt and distribution of monsoon rainfall. Unpredictable weather often results in moisture stress, poor vegetative growth, irregular flowering, reduced fruit set, and lower nut yield.

Among the climatic factors influencing Indian weather, El Nino plays an important role by affecting the southwest monsoon. El Nino years are commonly associated with delayed or deficient rainfall, prolonged dry spells, and above-normal temperatures in several parts of the country. Such conditions reduce soil moisture availability and increase evapotranspiration, exposing cashew trees to drought and heat stress during critical growth stages. However, the impact varies depending on the intensity of the event, local weather conditions, and orchard management practices. Besides reducing water availability, changing weather patterns also favour the incidence of insect pests and diseases. Unseasonal rains during flowering increase the risk of diseases such as anthracnose, while warm and humid conditions often encourage the multiplication of tea mosquito bug, one of the most destructive pests of cashew. As climate variability continues to increase, adopting climate-smart orchard management practices has become essential for minimizing production risks and ensuring sustainable cashew cultivation.

Cashew: A Climate-Resilient Plantation Crop

Cashew is widely recognized as a climate-resilient plantation crop because of its remarkable adaptability to diverse agro-climatic conditions. It grows successfully on lateritic, sandy, and other marginal soils with relatively low water and nutrient requirements after establishment. Its deep and extensive root system enables efficient extraction of moisture from deeper soil layers, allowing the crop to withstand moderate drought better than many other plantation crops (**Figure 1**).



Figure 1: General View of a Healthy Cashew Orchard (**Source: ICAR-DCR, Puttur**)

Apart from its adaptability, cashew offers significant economic and environmental benefits. The crop provides a dependable source of income through cashew kernels, while value-added products from the cashew apple and cashew nut shell further enhance its economic potential. As a perennial tree crop, cashew helps conserve soil, reduces erosion, improves soil organic matter through leaf litter, and contributes to carbon sequestration, making it an environmentally sustainable option for rainfed farming systems. However, climate resilience does not imply complete tolerance to adverse weather. Prolonged drought, high temperatures during flowering, and unseasonal rainfall can reduce flowering, fruit set, and nut development, while also increasing the incidence of pests and diseases. Therefore, realizing the full potential of cashew under changing climatic conditions depends on integrating its natural resilience with appropriate climate-smart orchard management practices.

Impact of Climate Change on Cashew Growth and Productivity

Climate change affects almost every stage of cashew growth, from vegetative flushing to nut maturity. The extent of damage depends on the intensity and duration of weather stress, the variety grown, and orchard management practices. Prolonged drought and high temperatures reduce soil moisture, limiting vegetative growth and the emergence of healthy flushing shoots that produce the next season's flowers. Moisture stress also restricts nutrient uptake and photosynthesis, resulting in poor tree vigour and reduced yield potential.

The reproductive stage is particularly vulnerable to climatic stress (**Table 1**). High temperatures during flowering can reduce pollen viability, impair pollination, and increase flower and young fruit drop, leading to poor fruit set (**Figure 2**). If moisture stress continues

during nut development, nut size, kernel weight, and overall yield may decline significantly. Erratic rainfall further aggravates the problem. While dry weather is favourable for flowering, unseasonal rains during the flowering period interfere with pollination and create favourable conditions for diseases such as anthracnose. Similarly, warm and humid weather encourages the multiplication of tea mosquito bug, which damages tender shoots, inflorescences, and developing nuts, causing substantial yield losses (**Figure 3**).



Figure 2: Drying of Cashew flower panicles under adverse weather conditions (Source: ICAR-DCR, Puttur)

The impact of climate change can be minimized through timely orchard management. Maintaining adequate soil moisture, balanced nutrition, proper canopy management, and regular monitoring of pests and diseases improve the resilience of cashew trees and helps sustain productivity even under adverse weather conditions.

Table 1. Major climate stresses, their impact on Cashew and adaptation strategies

Climate stress	**Major impact on cashew**	**Recommended adaptation**
High temperature	Reduced pollen viability, flower drop and poor fruit set	Mulching, protective irrigation during flowering, heat-tolerant varieties
Prolonged drought	Poor flushing, reduced nut development and lower yield	Rainwater harvesting, drip irrigation and soil moisture conservation
Erratic rainfall	Irregular flowering and poor fruit retention	Efficient drainage and timely orchard operations
Unseasonal rains	Increased incidence of anthracnose and tea mosquito bug	Regular monitoring and timely plant protection measures
Water scarcity	Reduced tree vigour and productivity	Micro-irrigation, organic mulching and balanced nutrient management



Figure 3: Cashew flower morphology: A. cashew inflorescence bearing both male and hermaphrodite flowers; B. male flower and C. hermaphrodite flower. Tea mosquito bug (TMB) damage symptoms: a and b necrotic lesions in young shoot; c dried young shoot; d affected inflorescence; e-affected tender nut; f-affected tree (**Source: Babli et al., 2023; Eradasappa et al., 2024**)

Climate-Smart Orchard Management Practices

Adoption of climate-smart orchard management practices is essential for sustaining cashew productivity under changing climatic conditions. An integrated approach that combines improved planting material, efficient resource management, and timely crop protection can substantially reduce the adverse effects of drought, heat, and erratic rainfall.

Selection of suitable varieties: Establish orchards with high-yielding, region-specific varieties using quality grafts from certified nurseries. Planting adapted varieties improves orchard establishment, productivity, and resilience to climatic stresses.

Soil and water management: Conserve soil moisture through mulching with cashew leaf litter, coconut husk, or other organic materials. Rainwater harvesting structures such as farm ponds, contour trenches, and percolation pits help store rainwater and improve groundwater recharge. Where water is available, drip irrigation during flowering and nut development can significantly improve fruit retention and yield.

Balanced nutrient management: Apply fertilizers based on recommended schedules, supplemented with organic manures to improve soil health and nutrient-use efficiency. Balanced nutrition enhances tree vigour, improves stress tolerance, and supports better flowering and nut development.

Canopy management: Regular pruning of dead, diseased, and overcrowded branches improves light penetration and air circulation, promotes healthy flushing, and reduces the incidence of pests and diseases.

Integrated pest and disease management: Regular orchard surveillance, field sanitation, and timely application of recommended plant protection measures are essential for managing tea mosquito bug, stem and root borer, anthracnose, and other major pests and diseases. Weather-based advisories should be used to plan timely interventions.

Integrating these climate-smart practices improves orchard resilience, stabilizes productivity, and enables farmers to better cope with the challenges posed by climate change and increasing weather variability.

Climate-Smart Recommendations for Cashew Growers

Successful adaptation to climate change requires a combination of improved technologies and timely orchard management. Cashew growers should adopt region-specific high-yielding varieties, use healthy grafts from certified nurseries, and conserve soil moisture through mulching and organic matter addition. Rainwater harvesting and drip irrigation, wherever feasible, can minimize the impact of prolonged dry spells, particularly during flowering and nut development. Balanced nutrient management based on soil and leaf analysis helps maintain tree vigour and improve stress tolerance. Regular pruning enhances canopy health and reduces pest and disease incidence, while continuous orchard monitoring enables timely management of tea mosquito bug, anthracnose, and other major problems. Farmers should also make use of weather forecasts and agro-advisories to plan irrigation, nutrient application, and plant protection measures. Adoption of these climate-smart practices will improve orchard resilience, stabilize yields, and ensure sustainable and profitable cashew cultivation under changing climatic conditions.

Future Outlook

Climate change will continue to influence cashew cultivation, making resilience and adaptability key to sustaining productivity. Future efforts should focus on developing climate-resilient varieties with improved tolerance to drought, heat, and major pests and diseases. Advances in plant breeding, precision irrigation, weather-based advisory services, and digital technologies will enable farmers to make timely management decisions and use natural resources more efficiently. At the same time, strengthening extension services and improving access to

quality planting material and climate-smart production technologies will accelerate their adoption at the farm level. By integrating scientific innovations with improved orchard management, cashew cultivation can remain productive, profitable, and sustainable under changing climatic conditions.

Conclusion

Climate change and El Nino are increasing the vulnerability of cashew cultivation by altering temperature and rainfall patterns and increasing the frequency of extreme weather events. Although cashew is naturally resilient and well adapted to rainfed conditions, sustaining high productivity under changing climates requires scientific orchard management and timely adaptation measures. Adoption of climate-smart practices such as improved varieties, soil and water conservation, balanced nutrient management, and integrated pest and disease management can minimize climate-related risks and improve orchard resilience. With continued research, effective extension support, and wider adoption of these technologies, cashew cultivation can remain a sustainable and profitable enterprise for farmers while contributing to climate-resilient horticulture in India.

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TOXICITY AND PERSISTENCE OF MALACHITE GREEN IN AQUATIC ECOSYSTEMS

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Abstract

Aquaculture is a rapidly growing global food-producing sector, but it faces vulnerability to parasitic and fungal diseases. Despite international bans or restrictions due to health concerns, the synthetic dye malachite green (MG) is still used illegally in aquaculture because of its low cost and effectiveness. Once administered, fish rapidly metabolise MG into leucomalachite green (LMG), a highly lipophilic compound that persists in fatty tissues. Both MG and LMG present significant toxicological risks. In fish, exposure causes liver necrosis, anaemia, and reproductive dysfunction. In humans, dietary exposure through contaminated fish poses serious public health risks, including carcinogenicity, mutagenicity, genotoxicity, and disruption of the gut microbiome. Residue accumulation varies by geography and species, with high-fat species like eels exhibiting the highest retention rates. Sensitive analytical methods like UHPLC-MS/MS can detect these residues at ultra-trace levels. The persistent global detection of MG and LMG highlights the critical need for stricter regulatory enforcement, continuous monitoring, and safer alternative treatments.

1. Introduction

Fish is an important part of the human diet worldwide, and demand for fish and fish products has continued to rise over the years (Tidwell and Allan, 2001). With the growing importance of fisheries and aquaculture in providing food, nutrition, and employment, aquaculture has developed into a rapidly expanding global food-producing sector, growing at

about 10% per year (FAO, 2020). The Food and Agriculture Organisation estimates that around 38.2 million people are employed in fisheries (Wamukota and McClanahan, 2017). Fish is also highly valued for its nutritional benefits. It is a low-fat, high-quality protein source and contains important vitamins, including B2 (riboflavin) and D, along with minerals such as phosphorus and calcium. It also provides essential elements including zinc, iron, iodine, potassium, and magnesium, as well as omega-3 fatty acids, which the human body cannot produce (DOH, 2022b; Oliveri Conti et al., 2015). Despite these benefits, fish and aquatic products can also pose health risks due to contamination. Harmful substances such as heavy metals and mycotoxins may accumulate in aquatic organisms and enter the human food chain (Hashempour-Baltork et al., 2023; Mirza Alizadeh et al., 2020, 2021). In addition, aquaculture systems are vulnerable to viral, bacterial, and parasitic diseases that can reduce production and increase mortality. To control these infections, chemicals such as antiparasitics, antimicrobials, and antibiotics, including malachite green, fluoroquinolones, tetracyclines, oxytetracycline, and doxycycline, are commonly used (Mossa et al., 2017; Pipoyan et al., 2020; Tittlemier et al., 2007).

2. Properties and toxicities of Malachite green

Malachite green is a synthetic dye used to treat parasitic, fungal, and protozoan infections in fish. Although its use in food fish is restricted or banned in many countries, illegal application still occurs due to its low cost, easy availability, and effectiveness (Wang et al., 2012). However, its use is considered a serious public health concern because it has been linked to teratogenic, genotoxic, carcinogenic, and immunosuppressive effects.

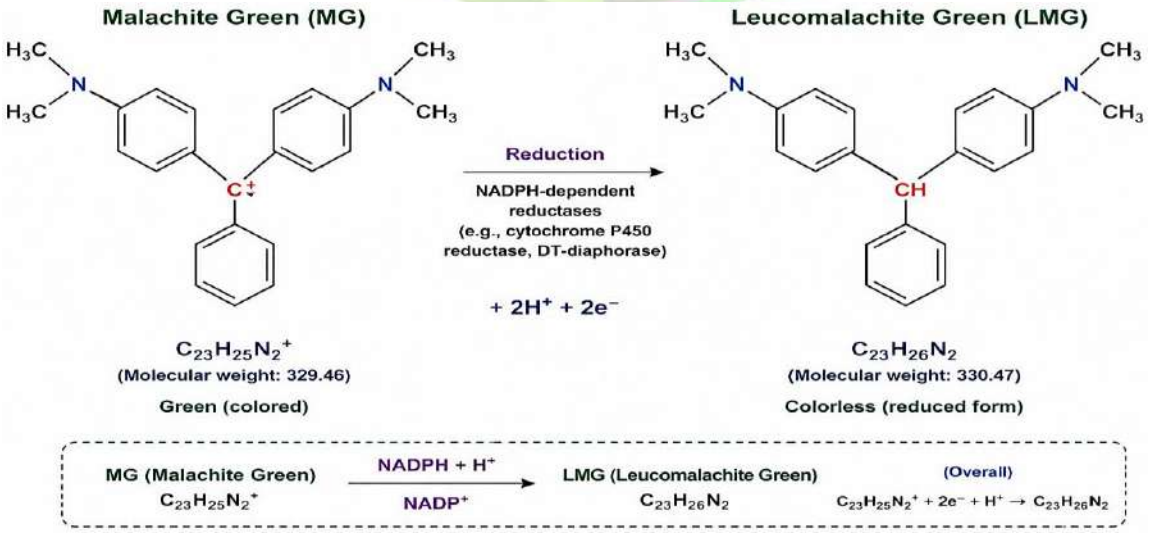


Fig. 1. Structure of malachite green and lucomalachite green

Malachite green belongs to the triphenylmethane dye group and is widely used in the textile industry and aquaculture due to its high water solubility (Gopinathan et al., 2015). It is a cationic dye with the chemical formula C23H25N2Cl and a molecular weight of 364.91 g/mol. Its reduced form is leucomalachite green (LMG; C23H26N2) with a molecular weight of 330.46 g/mol (Chain, 2016).

3. Impact of malachite green

Malachite green (MG) has been used since the 1930s for its antifungal activity and later became a common treatment in aquaculture to control ectoparasites and protozoan infections. By the 1960s, it was regarded as one of the most effective chemicals for managing parasitic diseases in fish. However, its use has raised serious environmental and health concerns due to its toxic effects on aquatic ecosystems, soil, and human consumers, leading many countries to restrict or ban its use in the production of fish for food. After administration, MG is quickly taken up by fish tissues and converted into its reduced, colourless metabolite, leucomalachite green (LMG). This compound is highly fat-soluble, allowing it to accumulate in lipid-rich tissues and persist for long periods. Because of this property, LMG can enter the human food chain and remain in edible tissues for extended durations. Its elimination is slow, particularly in fatty fish species, where the half-life may reach around 40 days (Barani & Tajik, 2017). Both MG and LMG residues have been detected in various fish organs, including muscle, liver, kidney, blood, and reproductive tissues such as roe and eggs. Exposure to MG can cause significant physiological harm, including liver damage characterised by sinusoidal congestion and necrosis, along with mitochondrial impairment and changes in blood parameters. In species such as rainbow trout, it has been linked to anaemia, reduced hematocrit, and reproductive dysfunction (Srivastava et al., 2004; Stammati et al., 2005).

The toxic effects of MG are not limited to fish. It has been associated with mutagenic, genotoxic, and carcinogenic properties that may affect multiple organs, including the liver, kidney, and spleen. It can also weaken immune and reproductive systems, disturb intestinal microbiota, and increase gut permeability. Developmental abnormalities have also been reported in animal studies (Barani & Tajik, 2017; Li et al., 2019; Srivastava et al., 2004). In addition, MG promotes the generation of reactive oxygen species in the liver, which may lead to DNA damage and DNA adduct formation (Pipoyan et al., 2020b). Even at very low concentrations (0.1 mg/L), MG is highly toxic to mammalian cells (Henderson et al., 1997).

The persistence of MG and its metabolite LMG in fish tissues varies with species, body size, dosage, exposure duration, and environmental conditions, including temperature and pH. Residues of MG may remain detectable for up to two months after exposure, while LMG can persist for up to nine months. Overall, LMG tends to remain in tissues longer due to its higher stability and slower elimination rate (Chain, 2016). Although MG has been suggested to have tumour-promoting potential, its carcinogenic mechanism remains incompletely understood. LMG is generally considered less toxic, with some studies reporting minimal effects on cell viability and DNA integrity (Fessard et al., 1999). Nevertheless, other evidence indicates that both MG and its metabolites may still contribute to carcinogenicity, mutagenicity, teratogenicity, and respiratory toxicity, with severity influenced by concentration, exposure time, and temperature. Exposure to 0.1 mg/L MG can be lethal to fish (Atamanalp, 2007; Fang et al., 2016; Heydari et al., 2022).

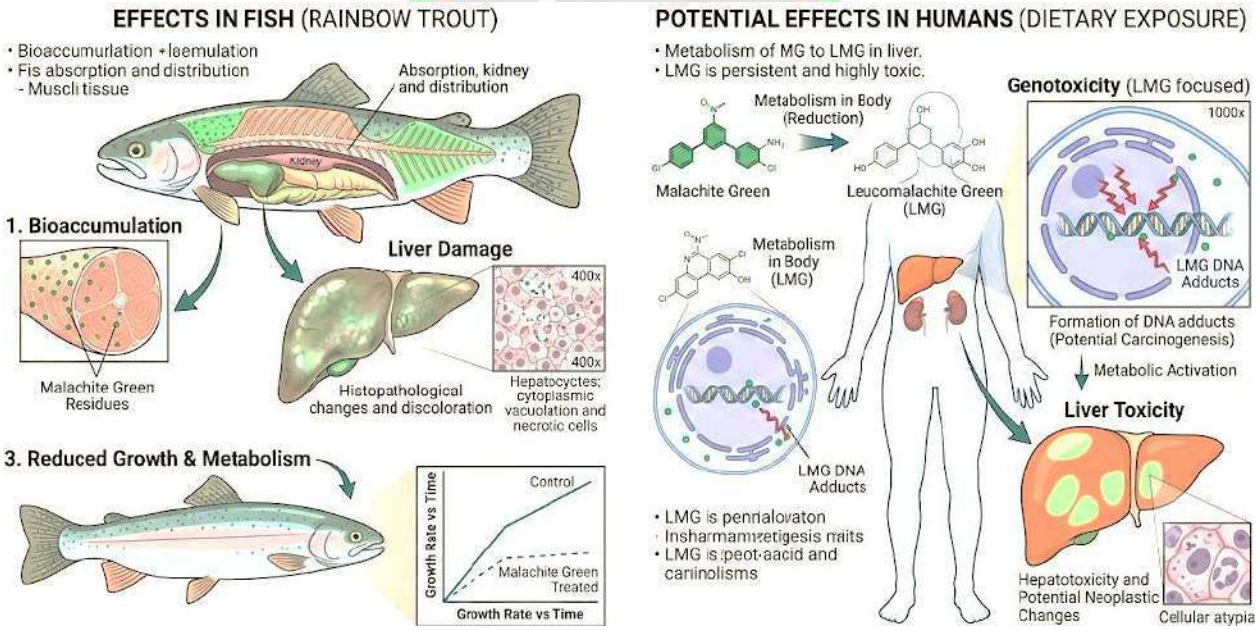


Fig. 2. Effects of Malachite green on fish and humans

Post-harvest processing also affects residue levels. LMG remains relatively stable during storage and cooking, although some conversion back to MG may occur during freezing or prolonged storage (Aziz A. Fallah & Barani, 2014; Stammati et al., 2005). However, heat treatments such as boiling, baking, and microwaving, as well as refrigeration and freezing, can reduce the levels of MG and LMG in fish tissues (Chain, 2016). The human gut microbiome plays a crucial role in maintaining overall health by regulating metabolic and immune functions

(Li et al., 2019). Exposure to MG can disrupt microbial balance, leading to reduced stability of gut bacterial networks and increased intestinal permeability.

3. Malachite green in fish

Malachite green (MG) is a synthetic triphenylmethane dye widely used in aquaculture for the treatment of fungal, protozoan, and parasitic infections. Despite its effectiveness and low cost, its use in food fish is prohibited in many countries because of its carcinogenic, mutagenic, teratogenic, and genotoxic properties. After administration, MG is rapidly metabolised into leucomalachite green (LMG), a more lipophilic and persistent metabolite that accumulates in fish tissues for extended periods. Consequently, the presence of MG and LMG residues in fish represents a significant food safety concern. The meta-analysis conducted by Gharavi-Nakhjavani et al. (2023) revealed considerable species-specific variation in the accumulation of malachite green (MG) and its metabolite leucomalachite green (LMG) in fish. Among the species evaluated, common carp and tilapia exhibited relatively high MG residue levels, with pooled concentrations of 4.10 and 3.31 µg/kg, respectively. In contrast, the highest LMG concentrations were detected in European eel (Anguilla anguilla) (4.46 µg/kg), Asian swamp eel (Monopterus albus) (2.05 µg/kg), and rainbow trout (2.01 µg/kg) (Gharavi-Nakhjavani et al., 2023). According to Belpaire et al. (2015), exceptionally high MG concentrations were reported in eels from Hong Kong, China (30.75 µg/kg), while Adel et al. (2017) documented elevated levels in rainbow trout from northern Iran (15.8 µg/kg).

These findings indicate significant geographical and species-related differences in residue accumulation. Furthermore, Gharavi-Nakhjavani et al. (2023) highlighted that lipid-rich species, particularly eels, exhibit a greater propensity to retain MG and LMG residues. The higher accumulation is largely attributed to the lipophilic nature of LMG, which promotes its persistence in muscle and adipose tissues and slows its elimination. Similarly, Belpaire et al. (2015) reported that MG and LMG preferentially accumulate in adipose tissues, making high-fat species more susceptible to long-term residue retention. European eels, which may contain more than 25% body fat, have a substantial capacity to bioaccumulate these compounds in their tissues. Overall, the evidence suggests that fish species, lipid content, and environmental conditions are key determinants of MG and LMG residue burdens, thereby influencing consumers' potential dietary exposure (Gharavi-Nakhjavani et al., 2023). Analytical methods used for detection included HPLC, LC-MS/MS, ELISA, electrochemical assays,

chemiluminescence immunoassays, and UHPLC-MS/MS. Among these, UHPLC-MS/MS demonstrated the greatest sensitivity, achieving a detection limit of 0.000005 µg/kg.

Conclusion

The available evidence indicates that malachite green (MG) and leucomalachite green (LMG) residues continue to be detected in fish worldwide despite their prohibition in aquaculture in many countries. The few studies identified eels, common carp, tilapia, and rainbow trout as the species most frequently associated with elevated residue levels, reflecting species-specific differences in accumulation and persistence. In particular, the tendency of LMG to accumulate in fatty tissues raises concerns regarding prolonged retention and potential dietary exposure. Furthermore, residue levels exceeding established regulatory limits in countries such as China, Iran, and the Netherlands underscore the continued misuse of MG and the need for stronger regulatory oversight. This underscores the importance of continuous residue monitoring, stricter enforcement of existing regulations, and the adoption of safer alternatives for disease control in aquaculture.

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PROTECTED CULTIVATION (POLYHOUSE / GREEN HOUSE) FOR HIGH-VALUE HORTICULTURAL CROPS

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Introduction

Protected cultivation has been one of the most important technical initiatives in contemporary horticulture. It includes the growing of crops in regulated or semi-controlled climatic conditions utilizing buildings like greenhouses, polyhouses, shade net houses, low tunnels and walk-in tunnels. These structures protect crops from severe climatic conditions and generate a favourable microclimate for better growth, yield and quality. In the last several decades, production of high-value horticultural crops such vegetables, flowers, fruits, herbs and nursery plants is now widely popular in protected horticulture. Increasing demand for high quality horticultural output throughout the year has led to the implementation of shielded growing systems globally. The significance of greenhouse and polyhouse technologies has been hastened by urbanization, decreasing land resources, climatic unpredictability and rising customer desire for pesticide-free and premium grade products.

High value crops such as tomato, cucumber, capsicum, strawberry, gerbera, carnation, rose, lettuce and exotic vegetables are being farmed on large scale beneath protected structures owing to their higher productivity and economic rewards. There are certain benefits of protected horticulture over open field cultivation. It facilitates out-of-season production, protects crops from pests and diseases, increases the efficiency of water and fertilizer usage and improves crop quality. The enclosed structures provide a regulated environment which helps to maintain optimum temperature, humidity, light and ventilation for greater plant development and production. Also, shielded farming lessens the severe impacts of climate change such excessive temperatures, erratic rainfall, hailstorms and strong winds.

Types and Structures of Protected Cultivation

Greenhouse

A greenhouse is a framed structure covered with transparent materials such as glass or polycarbonate sheets that allows sunlight to enter while trapping heat inside. Greenhouses are equipped with advanced systems for temperature regulation, humidity control, ventilation, cooling and irrigation. They provide a highly controlled environment suitable for year-round crop production. Modern greenhouses often include automated fertigation systems, climate sensors, fogging systems and computerized monitoring units. These structures are widely used for cultivating tomato, cucumber, capsicum, lettuce, gerbera, carnation and exotic flowers.

Polyhouse

Polyhouses are structures covered with polyethylene sheets. Compared to glasshouses, polyhouses are more economical and suitable for tropical and subtropical regions. Naturally ventilated polyhouses are widely adopted due to their low construction and maintenance costs. Polyhouses create a favorable microclimate by protecting crops from heavy rainfall, frost, wind and excessive sunlight. They are extensively used for off-season vegetable production and flower cultivation.

Shade Net House

Shade net houses are covered with shade nets that regulate sunlight intensity and temperature. These structures are mainly used for nursery raising, hardening of tissue culture plants and cultivation of shade-loving ornamental plants.

Low Tunnels and Walk-In Tunnels

Low tunnels are temporary structures used for early crop establishment and frost protection. Walk-in tunnels are slightly larger and provide better environmental control. These structures are commonly used for cucurbits, strawberry and leafy vegetables.

Hydroponic and Soilless Systems

Modern protected cultivation increasingly uses hydroponics and soilless media such as cocopeat, perlite and vermiculite. These systems allow precise nutrient management and reduce soil-borne diseases. Hydroponics is highly suitable for leafy vegetables, herbs and high-value crops grown under greenhouse conditions.

Role of Protected Cultivation in High-Value Horticultural Crops

Off-Season Production

One of the greatest advantages of protected cultivation is the ability to produce crops during off-seasons. Environmental control inside greenhouses allows cultivation even when external climatic conditions are unfavorable. Farmers can supply vegetables and flowers during periods of high market demand and obtain premium prices. Tomato, cucumber, capsicum, lettuce and strawberry are among the major crops grown during off-seasons under protected structures.

Higher Yield and Productivity

Protected cultivation significantly increases crop productivity compared to open-field cultivation. Controlled environmental conditions optimize photosynthesis, nutrient uptake and plant growth. Greenhouse-grown tomatoes and cucumbers often produce several times higher yields than open-field crops. High-density planting, vertical training systems and precise irrigation further enhance productivity.

Improved Crop Quality

High-value horticultural crops require superior quality characteristics such as size, color, shape, texture and shelf life. Protected cultivation minimizes physical damage and environmental stress, resulting in uniform and premium-quality produce. Flowers such as gerbera, rose, carnation and orchids grown under greenhouse conditions exhibit better stem length, color intensity and vase life.

Efficient Water and Nutrient Management

Protected cultivation utilizes drip irrigation and fertigation systems for precise application of water and nutrients. This reduces wastage and improves nutrient use efficiency. Water-saving technologies are especially beneficial in water-scarce regions. Fertigation ensures balanced nutrient availability and enhances crop growth.

Reduced Pest and Disease Incidence

Protected structures act as physical barriers against insects, pests and diseases. Insect-proof nets and controlled environments reduce pest infestation and minimize pesticide use. Integrated pest management practices combined with protected cultivation improve crop safety and reduce environmental contamination.

Climate Change Adaptation

Climate variability has become a major challenge for horticultural production. Protected cultivation shields crops from extreme weather conditions such as heatwaves, frost, hailstorms and heavy rainfall.

Major High-Value Horticultural Crops Grown Under Protected Cultivation

Crop	Type of Structure Commonly Used	Major Purpose
Tomato	Polyhouse/Greenhouse	Off-season production
Cucumber	Greenhouse	High yield cultivation
Capsicum	Polyhouse	Premium quality fruits
Strawberry	Low tunnel/Polyhouse	Early fruit production
Lettuce	Hydroponic greenhouse	Leafy vegetable production
Gerbera	Greenhouse	Cut flower production
Rose	Greenhouse	Export-quality flowers
Carnation	Polyhouse	Commercial floriculture
Orchid	Shade net house	Ornamental cultivation
Chrysanthemum	Polyhouse	Flower production
Cherry tomato	Greenhouse	Exotic vegetable production
Zucchini	Polyhouse	High-value vegetable
Broccoli	Net house	Quality vegetable production
Herbs	Hydroponic greenhouse	Medicinal and culinary use
Spinach	Polyhouse	Leafy vegetable cultivation
Basil	Greenhouse	Aromatic herb production
Gherkin	Polyhouse	Processing industry
Blueberry	Greenhouse	Exotic fruit cultivation
Lilium	Greenhouse	Bulb flower production

Challenges and Future Prospects of Protected Cultivation

Though protected horticulture has many benefits, it has significant restrictions and obstacles too. High initial investment is still one of the key limitations for farmers. The construction of

- greenhouses, installation of irrigation systems, temperature control equipment and maintenance are associated with large capital investments. Successful greenhouse management also requires technical knowledge and skilled labor. Farmers should be aware of fertigation, pruning, climate adjustment, insect control and

crop monitoring. Poor performance and economic losses can result from inadequate training.

- Another problem is the incidences of insect and disease within protected buildings owing to continuous cropping and high humidity conditions. Good sanitation, crop rotation and integrated pest control are needed to keep crops healthy. Energy expenditures in climate-controlled greenhouses may contribute to manufacturing costs. Emerging advances like as solar-powered systems, automatic ventilation and precision agricultural technology are helping to minimize operating costs, however.
- With the improvement of technologies and rising demand for quality horticultural goods, the future of protected horticulture seems to be quite bright. Automation, artificial intelligence, robots, IoT-based temperature monitoring and hydroponic systems are changing the greenhouse farming into an advanced agricultural industry. Recent study shows an increasing use of intelligent greenhouse systems and automated crop monitoring systems for precision horticulture.
- Moreover, in metropolitan areas, urban farming and rooftop gardening are gaining popularity. Protected cultivation will have a vital role in achieving food security, increasing farmer income and developing sustainable horticulture output in the context of climate change.

Conclusion

Protected farming has emerged as an integral component of contemporary horticulture because of its capacity to effectively produce high-value crops under regulated environmental conditions. Greenhouses, polyhouses, shade net houses and hydroponic systems give prospects for year-round production, increased productivity, better crop quality and better profitability. Historically, protected horticulture grew from simple glasshouses in Europe to sophisticated automated greenhouse systems seen worldwide today. Scientists and horticultural researchers made tremendous contributions to the improvement of greenhouse architecture, fertigation, crop management and temperature control technology. This technique has changed the way vegetables, flowers, fruits, herbs and nursery crops are produced, by extending the production season and safeguarding crops from environmental stress. High value horticultural crops such as tomato, cucumber, capsicum, gerbera, rose, carnation, strawberry and lettuce have enormous potential under covered structures. Protected farming also has an important role in water saving,

nutrient efficiency, decreased pesticide usage and climate resilience. Automation, digital agriculture and precision farming are constantly advancing, making greenhouse production systems more viable and efficient despite constraints such as high investment prices and technologicalcomplications.

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FROM FIELD TO LAB: STANDARD SAMPLING OF SOIL, *JEEVAMRIT*, COW DUNG, COW URINE, AND FODDER FOR QUALITY ANALYSIS IN NATURAL FARMING

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Introduction

Natural farming may be viewed as farming by the microbes, of the microbes, and for the microbes. This perspective reflects the central role of microbes in sustaining the biological processes that underpin healthy soils and productive agroecosystems. It is by the microbes because innumerable microbes carry out the biochemical reactions responsible for decomposing agro residues, cycling nutrients, fixing atmospheric nitrogen, solubilizing mineral nutrients, producing plant growth promoting substances, and maintaining soil fertility. It is of the microbes because the functioning and resilience of natural farming are intrinsically linked to the diversity, abundance, and activity of indigenous microbial communities inhabiting the soil and rhizosphere. It is for the microbes because natural farming practices are designed to create an environment that protects and nourishes beneficial microbes through the regular addition of bio materials, the use of biologically active formulations, no dependence on synthetic chemicals, and management practices that preserve the integrity of the soil ecosystem.

By fostering a healthy microbial habitat, natural farming strengthens the biological processes that ultimately sustain crop growth, environmental quality, and agricultural productivity. Although microbes are invisible to the unaided eye, they constitute the largest and most active biological workforce in agricultural soils. A single gram of fertile soil may contain billions of microbial cells belonging to thousands of species of bacteria, fungi, actinomycetes, archaea, algae, protozoa, and viruses. These diverse communities interact continuously with plant roots, dead and decaying matter, soil minerals, and environmental factors, forming a dynamic living network that regulates numerous ecosystem functions. Through their metabolic

activities, microbes transform complex substances into simpler compounds, release nutrients into plant available forms, improve soil aggregation, enhance water retention, suppress certain soil borne pathogens, and contribute to the maintenance of ecological stability. Thus, soil should not be regarded merely as a physical substrate for plant growth but as a living biological system whose productivity depends largely on microbial activity.

The rhizosphere, the narrow region of soil influenced by plant roots, is among the most biologically active environments on Earth. Plant roots release a wide range of compounds, collectively known as root exudates, which serve as energy sources for surrounding microbes. In return, beneficial microbes improve nutrient acquisition, synthesize phytohormones, enhance stress tolerance, and contribute to natural disease suppression. This intimate association between plants and microbes represents one of the most remarkable examples of biological cooperation in nature and forms the ecological foundation upon which natural farming operates. Natural farming encourages these naturally occurring biological interactions by emphasizing the use of locally available resources.

Biological formulations such as *Jeevamrit*, together with fresh cow dung and cow urine, provide substrates, nutrients, and favorable conditions that stimulate microbial activity within the soil. Crop residues, mulches (Live and dead both), and PSDS (PreSseason Dry Sowing) further enrich the soil with C and energy sources that sustain microbial metabolism. Rather than supplying nutrients directly to plants alone, these materials primarily support the biological community responsible for transforming complex matter into plant available nutrients. Consequently, nutrient availability in natural farming is governed largely by biological processes rather than by the direct application of highly soluble synthetic fertilizers.

As interest in natural farming expands among farmers, researchers, policymakers, and extension professionals, scientific evaluation of its biological inputs and soil health has become increasingly important. Laboratory analysis provides valuable information regarding nutrient status, carbon content, microbial abundance, enzyme activities, biological diversity, and other indicators of soil quality. These analyses help assess the effectiveness of natural farming practices, identify opportunities for improvement, and generate evidence that supports informed decision making. However, the accuracy of every laboratory result depends fundamentally on the quality of the sample submitted for analysis.

Sampling is therefore the most critical step in the entire analytical process. Regardless of the sophistication of laboratory instruments or analytical techniques, meaningful results cannot be obtained from a sample that fails to represent the original material. If soil is collected from an unrepresentative location, if *Jeevamrit* is not mixed thoroughly before sampling, if cow dung or cow urine becomes contaminated during collection, or if fodder samples are taken from only a single portion of a field or storage stack, the resulting laboratory data may not accurately reflect actual conditions. Likewise, inappropriate handling, prolonged storage, excessive heat, direct sunlight, or microbial contamination after collection can alter the physical, chemical, and biological properties of samples before analysis is completed. Such changes may lead to inaccurate interpretation and unreliable recommendations.

Representative sampling seeks to minimize these sources of error by ensuring that the collected material accurately reflects the larger population from which it originates. Standardized procedures for sample collection, handling, preservation, labeling, transportation, and storage are therefore indispensable components of quality assurance in agricultural laboratories. These procedures improve the reproducibility of analytical results, facilitate comparisons among different studies and locations, and enhance confidence in laboratory findings generated for research, extension, and advisory purposes. The need for standardized sampling becomes even more important when evaluating biological inputs used in natural farming. Materials such as *Jeevamrit*, cow dung, and cow urine are dynamic biological systems whose chemical composition and microbial populations may change rapidly under different environmental conditions.

Similarly, soil microbial communities respond continuously to moisture, temperature, crop growth, and management practices. Unless samples are collected and preserved properly, laboratory observations may represent changes that occurred after collection rather than the actual condition in the field. Reliable quality assessment of natural farming inputs begins long before laboratory analysis; it begins in the field with careful and scientific sample collection. Proper sampling preserves the integrity of the original material, reduces analytical variability, and ensures that laboratory results truly represent field conditions. Consequently, standardized methods for collecting soil, *Jeevamrit*, cow dung, cow urine, and fodder samples form the foundation of credible research, effective extension services, quality control programmes, and

evidence based recommendations that strengthen the scientific understanding and wider adoption of natural farming.

Proper Sampling: The Foundation of Quality Analysis in Natural Farming

Reliable laboratory analysis begins long before a sample reaches the laboratory - it begins in the field with proper sampling. In natural farming, where soil, *Jeevamrit*, cow dung, cow urine, and fodder are biologically active materials, their physical, chemical, and microbial characteristics can change rapidly if samples are collected or handled improperly. Consequently, a laboratory can only generate meaningful results when the submitted sample truly represents the original material. Representative sampling minimizes analytical errors, preserves sample integrity, and ensures that laboratory findings accurately reflect field conditions. Careful collection, proper labeling, appropriate storage, and timely transportation are therefore essential for maintaining sample quality. Whether the objective is to evaluate soil health, microbial activity, nutrient status, or the quality of natural farming inputs, standardized sampling procedures provide the foundation for reliable analysis and scientifically sound recommendations. In essence, the quality of laboratory results is determined first by the quality of the sample collected.

The Science Behind Representative Sampling

Representative sampling is the process of collecting a portion of material that accurately reflects the physical, chemical, and biological characteristics of the entire source. In natural farming, materials such as soil, *Jeevamrit,* cow dung, cow urine, and fodder are inherently heterogeneous, with their composition varying across locations and over time. Therefore, a single handful or randomly collected sample rarely represents the true condition of the whole material. Scientific sampling minimizes bias by combining multiple subsamples collected from different locations to form a composite sample. This approach reduces the influence of local variation and provides a more reliable estimate of the average characteristics of the material. Maintaining sample integrity through clean collection tools, proper containers, suitable storage, and timely transportation further ensures that the sample reaching the laboratory closely resembles its original condition. Representative sampling is therefore the scientific foundation for generating accurate, reproducible, and meaningful analytical results that support reliable decision making in natural farming.

Standard Collection of Soil Samples

Soil sampling should always be carried out from a representative area of the natural farming field after excluding unusual locations such as field boundaries, irrigation channels, livestock resting sites, and recently fertilized spots. Surface litter, stones, and plant residues should be removed before sampling. Using a clean stainless steel auger or spade, soil should be collected from the recommended depth, generally 0–15 cm for most agricultural soils. Multiple subsamples (10–15) should be collected randomly across the field, thoroughly mixed in a clean container, and reduced by quartering to obtain a representative composite sample of approximately 500 g. The sample should be placed in a clean, properly labeled polyethylene bag containing details such as location, sampling depth, date, crop, and field identification. Samples intended for chemical analysis may be air dried under shade before processing, whereas samples for microbiological analysis should be stored in sterile containers, transported in an insulated ice box, and analyzed as early as possible to preserve their biological integrity. Following these standardized procedures ensures that the soil sample accurately represents field conditions and provides reliable information for assessing soil fertility, nutrient status, and biological health.

Standard Collection of *Jeevamrit* Samples

Jeevamrit is a biologically active fermented formulation whose microbial composition and biochemical properties vary with fermentation time, temp, aeration, and storage conditions. Therefore, careful sampling is essential to obtain a representative sample for quality analysis. Before sampling, *Jeevamrit* should be stirred thoroughly using a clean, non reactive stirrer to ensure uniform distribution of suspended solids and microbes. The sample should be collected from the middle portion of the container, avoiding surface scum and bottom sediments unless the entire formulation is intended for analysis. Clean, sterile, leak proof containers should be used, particularly for microbiological investigations, to prevent external contamination.

Approximately 500 mL of *Jeevamrit* is generally sufficient for comprehensive analysis. The sample container should be labeled with the date of preparation, sampling date, fermentation age, source, and sample identification no. Samples should be protected from direct sunlight and transported to the laboratory immediately. When immediate analysis is not possible, they should be stored at 4 °C to minimize changes in microbial activity and biochemical composition.

Standard Collection of Cow Dung Samples

Fresh cow dung should be collected hygienically to ensure that it accurately represents its

physical, chemical, and microbiological characteristics. Only freshly voided dung free from soil, bedding material, stones, feed residues, or other foreign matter should be selected. When samples are collected from multiple animals or a dung heap, several subsamples should be taken from different locations and thoroughly mixed to prepare a representative composite sample.

Approximately 500 g of the composite sample should be transferred into a clean, airtight polyethylene bag or sterile container, depending on the intended analysis. Each sample should be properly labeled with details such as sample identification, date of collection, cow breed, feeding system, and collection site. Samples intended for analysis may be transported under ambient conditions for short durations, whereas those for microbiological analysis should be collected aseptically, stored at 4 °C, and transported to the laboratory as quickly as possible to preserve the native microbial community.

Standard Collection of Cow Urine Samples

Cow urine should be collected under clean and hygienic conditions to preserve its original properties. Freshly voided urine should be collected directly into a clean, sterile, wide mouthed container, avoiding contact with soil, dung, feed residues, or other external contaminants. Collection from the ground should be avoided, as it may alter the quality and microbial composition of the sample.

A sample volume of approx. 500 mL is generally adequate for routine quality analysis. Immediately after collection, the container should be tightly sealed and labeled with essential information, including sample identification, date and time of collection, cow breed, feeding regime, and collection site. Samples should be protected from direct sunlight and excessive heat during handling and transportation.

For microbiological and biochemical analyses, samples should be transported to the laboratory as early as possible. If immediate analysis is not feasible, they should be stored at 4°C to minimize changes in microbial activity and nitrogenous compounds. Adherence to standardized sampling procedures helps maintain sample integrity and ensures reliable determination of nutrient composition, physicochemical characteristics, microbial population, and overall quality of cow urine used in natural farming.

Collection of Fodder Samples

Fresh fodder should be collected from 10 -15 randomly selected locations across the field at the normal harvesting height to capture variations in plant growth and composition. For stored

dry fodder, subsamples should be collected from the top, middle, and bottom portions of the stack or bale to account for differences arising during storage. Diseased, mouldy, excessively weathered, or contaminated plant material should be excluded unless the objective is to assess deterioration. The collected subsamples should be thoroughly mixed to prepare a representative composite sample. Approximately 500 g to 1 kg of the composite material should be placed in a clean polyethylene bag or paper bag, depending on the intended analysis. Each sample should be labeled with the crop species, variety, stage of harvest, location, date of collection, and sample identification number.

Samples intended for nutritional analysis should be protected from moisture and excessive heat during transportation. For microbiological evaluation, samples should be collected aseptically, stored at 4 °C, and transported to the laboratory as quickly as possible to preserve their native microbial characteristics. Standardized sampling procedures ensure reliable assessment of fodder quality, including moisture content, crude protein, fibre fractions, mineral composition, digestibility, and microbial status, thereby supporting informed decisions on cow nutrition in natural farming systems.

Sample Handling, Storage, and Transportation

Proper handling, storage, and transportation are essential to preserve the original characteristics of samples collected for quality analysis in natural farming. Immediately after collection, each sample should be placed in a clean, suitable container and labeled with the sample identification number, source, date, time, and location of collection. Proper labeling ensures traceability and prevents sample mix ups during lab processing. Samples should be protected from contamination, excessive heat, direct sunlight, and unnecessary handling, as these factors may alter their physical, chemical, and biological properties. Samples intended for microbiological analysis should be collected aseptically, stored in sterile containers, maintained at approx 4 °C, and transported to the lab at the earliest opportunity to preserve the viability and diversity of indigenous microbes. Samples for chemical analysis should be protected from moisture gain or loss and handled according to the specific analytical requirements.

Common Mistakes During Sampling

Avoid the following common mistakes to ensure reliable quality analysis:

- Allowing contamination of *Jeevamrit*, cow dung, or cow urine during collection.
- Collecting insufficient sample quantity for lab analysis.

- Collecting samples from a single location instead of multiple representative locations.
- Delayed transportation of samples to the lab.
- Exposing samples to direct sunlight, excessive heat, or prolonged storage before analysis.
- Failing to remove surface litter, stones, or plant residues before soil sampling.
- Ignoring recommended sampling depth or collection procedures.
- Improper or missing sample labels leading to misidentification.
- Inadequately mixing subsamples before preparing the composite sample.
- Mixing samples collected from different fields, management practices, or crop conditions.
- Repeated opening of sample containers during storage or transport.
- Sampling from field bunds, irrigation channels, cow resting sites, waterlogged areas, or recently fertilized fields.
- Storing microbiological samples at inappropriate temp.
- Using dirty, rusty, or contaminated sampling tools and containers.
- Using non sterile containers for samples intended for microbiological analysis.

Role of Quality Analysis in Improving Natural Farming

Quality analysis provides the scientific basis for evaluating the effectiveness of natural farming inputs and practices. Accurate analysis of soil, *Jeevamrit*, cow dung, cow urine, and fodder helps in understanding their physical, chemical, and microbiological properties, enabling informed decisions for sustainable crop.

The major benefits of quality analysis include:

- Assessment of soil health by evaluating soil pH, organic carbon, nutrient status, and beneficial microbial activity.
- Detection of contaminants such as undesirable microbes, heavy metals, or other impurities that may affect crop or animal health.
- Evaluation of fodder quality for moisture, crude protein, fibre, minerals, digestibility, and microbial safety.
- Improved nutrient management through evidence-based recommendations for efficient utilization of on farm resources.
- Monitoring changes in soil biological health under long term natural farming systems.

- Nutrient profiling of cow dung and cow urine to determine their suitability.
- Quality assurance and standardization of bio inputs used by farmers and entrepreneurs.
- Quality evaluation of *Jeevamrit* through analysis of microbial load, pH, enzyme activity, and nutrient composition.
- Scientific validation of natural farming practices by generating reliable data for research, extension, and farmer advisories.
- Support for sustainable and climate resilient agriculture by promoting healthy soils, efficient nutrient cycling, and productive agroecosystems.

Recommendations for Farmers and Extension Workers

To ensure reliable quality analysis and maximize the benefits of natural farming, the following practices are recommended:

- Use clean or sterile tools and containers to prevent contamination.
- Strengthen collaboration among farmers, extension personnel, and researchers to promote evidence based adoption of natural farming technologies.
- Store samples intended for microbiological analysis at approx 4 °C and transport them to the laboratory without delay.
- Protect samples from direct sunlight, excessive heat, and moisture during handling and transportation.
- Periodically evaluate the quality of soil and bio inputs to monitor improvements in soil health and farming practices.
- Maintain proper records of sample collection and laboratory reports for future comparison and decision making.
- Label every sample clearly with the sample ID, location, date, crop, and other relevant details.
- Follow recommended sampling depths, collection methods, and storage protocols for each sample type.
- Encourage farmers to utilize accredited laboratories for quality testing and scientific interpretation of analytical results.
- Collect the recommended quantity of soil, *Jeevamrit*, cow dung, cow urine, and fodder for laboratory analysis.
- Collect only representative samples using standardized sampling procedures.

- Avoid sampling from field boundaries, irrigation channels, waterlogged areas, or recently treated sites.

Conclusion

Natural farming is a biologically driven production system in which the quality of soil and bio inputs determines the efficiency of microbial processes that sustain crop productivity. Scientific evaluation of these resources begins with representative sampling. Proper collection, handling, storage, and transportation of soil, *Jeevamrit*, cow dung, cow urine, and fodder samples preserve their original physical, chemical, and microbiological characteristics, ensuring reliable laboratory analysis and meaningful interpretation. Standardized sampling protocols minimize analytical errors, improve the accuracy and reproducibility of results, and provide a sound scientific basis for assessing soil health, bio input quality, and cows nutrition. Reliable quality analysis not only supports research and extension activities but also enables farmers to make informed decisions for efficient resource utilization and sustainable farm management. As natural farming continues to gain importance in sustainable agriculture, adopting scientific sampling practices will strengthen the credibility of lab investigations and facilitate evidence based recommendations. Ultimately, accurate sampling is the first step toward accurate analysis, and accurate analysis is the foundation of successful natural farming.

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CLIMATE-SMART SEEDS: BUILDING RESILIENT AGRICULTURE FOR A CHANGING CLIMATE

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Introduction

Agriculture is becoming increasingly vulnerable to the effects of climate change. Farmers today face numerous challenges such as rising temperatures, erratic rainfall, prolonged droughts, floods, cyclones, and the spread of new pests and diseases. These extreme weather conditions often reduce crop productivity, threaten farmers' livelihoods and create concerns about long-term food security.



Although practices like improved irrigation, efficient soil management and modern crop production techniques help reduce climate-related risks, the success of any crop begins with one essential input—the seed. A healthy, vigorous seed forms the foundation of a productive crop and plays a vital role in ensuring successful harvests. In this context, **climate-smart seeds** have emerged as an effective solution for building resilient agricultural systems capable of withstanding changing environmental conditions.

Understanding Climate-Smart Seeds

Climate-smart seeds are specially developed crop varieties that can grow successfully under adverse climatic conditions. These seeds possess desirable characteristics that enable crops to tolerate drought, excessive heat, flooding, salinity, pests, and diseases while maintaining satisfactory yields. The primary objective of climate-smart seeds is to provide farmers with reliable planting material that ensures stable crop production even when weather conditions become unpredictable.

Why Climate-Smart Seeds Are Becoming Essential

Agricultural production depends greatly on climatic factors such as rainfall, temperature, humidity, and seasonal weather patterns. Even small variations in these conditions can influence seed germination, crop growth, flowering, and grain development. As climate change increases the frequency of extreme weather events, farming has become more uncertain than ever before.

Their adoption offers several important advantages:

- Better and more uniform crop establishment.
- Lower chances of crop failure.
- Stable crop yields despite climatic variability.
- Increased confidence among farmers during uncertain weather.
- Improved food production and national food security.

Major Characteristics of Climate-Smart Seeds

Climate-smart seeds are developed to possess one or more beneficial traits depending on the climatic conditions of a particular region. Their important characteristics include:

- High germination percentage.
- Excellent seed vigour for rapid crop establishment.
- Tolerance to drought and moisture stress.
- Ability to withstand high temperatures.
- Resistance to flooding and temporary water logging.
- Salinity tolerance in coastal and salt-affected soils.
- Resistance to major insect pests and plant diseases.
- Efficient utilization of water and nutrients.
- Early maturity that allows crops to escape late-season drought or heat stress.

Climate-Resilient Seed Development in India

India has made remarkable progress in developing crop varieties that can withstand climatic stresses. Over the years, agricultural scientists have released several improved varieties of rice, wheat, maize, pulses, millets, oilseeds and vegetables that perform well under drought, flooding, heat and saline conditions.

For instance, drought-tolerant pearl millet and sorghum varieties have helped farmers in dry regions such as Rajasthan and Karnataka maintain better yields during years of inadequate rainfall. In eastern India, flood-tolerant rice varieties have reduced crop losses caused by seasonal flooding. Likewise, salt-tolerant rice varieties are proving beneficial in coastal areas where seawater intrusion affects agricultural lands. Heat-tolerant wheat varieties are also becoming increasingly important in northern India, where rising temperatures during grain filling often reduce productivity.



The Role of Seed Technology

Developing a superior crop variety is only one part of the process. Farmers receive maximum benefits only when high-quality seeds are produced, tested, certified and distributed efficiently. This is where seed technology plays a crucial role.

A strong seed production system ensures that farmers receive seeds with:

- High genetic purity.
- Excellent physical purity.
- Good germination capacity.
- Strong seed vigour.

- Freedom from seed-borne pests and diseases.
- Proper storage quality that preserves viability until sowing.

Modern Seed Enhancement Technologies

Several seed enhancement techniques have been developed to further improve seed performance under stressful environmental conditions. These technologies increase seedling survival, improve crop establishment and enhance overall productivity.

Seed Priming

Seed priming is a simple but highly effective technique in which seeds are soaked under carefully controlled conditions before sowing. This process activates early metabolic activities within the seed without allowing complete germination.

Primed seeds germinate faster, emerge more uniformly and develop stronger seedlings. They also perform better under drought and heat stress during the initial stages of crop growth, resulting in healthier crop establishment.

Seed Treatment

Seed treatment involves applying fungicides, insecticides, biofertilizers, or beneficial microorganisms to seeds before sowing. This practice protects emerging seedlings from soil-borne and seed-borne diseases while improving nutrient availability during the early growth period.

Healthy seedlings established through seed treatment are generally more capable of tolerating environmental stress throughout the growing season.

Seed Coating

Advanced seed coating technologies cover seeds with protective materials containing micronutrients, biological agents, growth promoters, or moisture-retaining substances. These coatings create a favorable environment around the seed, supporting better germination and stronger seedling growth under adverse conditions.

Precision Seed Production

Precision seed production follows scientific methods to ensure that seeds maintain high genetic purity, uniform quality and excellent health standards. Proper field inspection, isolation, harvesting, processing and storage help deliver reliable seeds to farmers.

By integrating these modern technologies, seed producers can significantly improve the performance of climate-smart seeds and increase farmers' confidence in adopting improved varieties.

Benefits of Climate-Smart Seeds

The use of climate-smart seeds provides numerous economic and agricultural benefits to farmers.

Some of the major advantages include:

- Improved germination and rapid crop establishment.
- Better tolerance to drought, heat, floods and salinity.
- Reduced crop losses under adverse weather conditions.
- Lower dependence on pesticides in resistant varieties.
- More efficient utilization of irrigation water.
- Higher and more consistent crop yields.
- Increased farm profitability.
- Greater resilience against climate-related risks.

When these improved seeds are combined with appropriate crop management practices, farmers can achieve sustainable productivity while minimizing production risks.

Climate-Smart Seeds Must Be Supported by Climate-Smart Farming

Although climate-smart seeds play a vital role in improving crop resilience, they cannot solve every agricultural problem on their own. Their maximum potential is achieved only when they are combined with appropriate climate-smart farming practices. The integration of quality seeds with sustainable crop management helps farmers obtain higher yields while conserving natural resources.



Climate-smart agriculture focuses on increasing productivity, adapting to climate change and reducing environmental impacts. Some important practices include:

- Conservation tillage to minimize soil disturbance.
- Balanced fertilizer application based on crop requirements.
- Integrated nutrient management using organic and inorganic sources.
- Efficient irrigation methods such as drip and sprinkler systems.
- Rainwater harvesting to improve water availability.
- Crop rotation for maintaining soil fertility and reducing pest incidence.
- Integrated pest management to minimize pesticide use.
- Application of organic manures and biofertilizers.
- Weather-based crop planning for timely agricultural operations.

When these practices are adopted together with climate-smart seeds, farmers can improve productivity while using water, nutrients and other inputs more efficiently.

Challenges in the Adoption of Climate-Smart Seeds

Despite their numerous advantages, climate-smart seeds have not yet reached every farming community. Several practical and economic challenges continue to limit their widespread adoption.

Some of the major constraints include:

- Limited awareness among small and marginal farmers about climate-resilient varieties.
- High prices of improved seeds in certain crops.
- Inadequate seed production and distribution systems.
- Shortage of quality seeds during peak sowing seasons.
- Limited access to certified seeds in remote and tribal areas.
- Insufficient knowledge regarding the selection of varieties suitable for local climatic conditions.
- Continuous changes in climate that require regular development of improved crop varieties.

The Important Role of Farmers

Farmers themselves play an equally important role in ensuring the success of climate-smart agriculture. Even the best-performing seed variety cannot produce satisfactory results unless it is managed properly in the field.

Farmers should therefore adopt the following practices:

- Purchase certified seeds from reliable and authorized sources.
- Select crop varieties that are suitable for local climatic conditions.
- Follow the recommended sowing season and seed rate.
- Treat seeds before sowing to protect young seedlings from pests and diseases.
- Practice integrated crop management throughout the growing season.
- Store unused seeds under suitable conditions to maintain their quality.
- Keep themselves informed about newly released climate-resilient varieties through agricultural extension services.

Future Prospects

As climate change continues to influence agricultural production, the importance of climate-smart seeds will continue to grow. Scientists are working to develop crop varieties capable of tolerating multiple environmental stresses simultaneously while maintaining high productivity and nutritional quality.

Future climate-smart seeds are expected to possess improved drought tolerance, heat resistance, flood tolerance, better nutrient-use efficiency, enhanced nutritional value and stronger resistance against emerging pests and diseases.

Conclusion

Every successful harvest starts with a good-quality seed. In today's changing climate, selecting the right seed is more important than ever. Climate-smart seeds help farmers overcome problems like drought, floods, high temperatures, salinity and attacks from pests and diseases.These improved seeds provide better germination, stronger seedlings, stable crop yields, and higher farm income. They also support food security by helping farmers produce reliable harvests even under difficult weather conditions.

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THE STATUS OF POTATO (*SOLANUM TUBEROSUM* L.) IN 2026: A GLOBAL POWERHOUSE

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Abstract

Few crops have shaped human civilisation more quietly than the potato. It fuelled the Industrial Revolution and today fills more than 380 million tonnes of crates, bags and cold-storage chambers every year. In 2026, the story is entering a new chapter one of processing booms, heat-tolerant varieties, frozen french fries sailing out of Indian ports and a quiet digital revolution on the farms of Uttar Pradesh.

Keywords: Potato, Processing booms, Heat-tolerant varieties and Frozen french fries

Introduction

It began in the Peruvian Andes, somewhere between 8,000 and 10,000 years ago, where indigenous Quechua farmers noticed a starchy tuber growing wild in the high-altitude grasslands and decided to cultivate it. The plant they chose *Solanum tuberosum*, would eventually travel to Europe with the returning Spanish in the 1570s, spread across the continent.

Today, potato is the **fourth** most important food crop globally, after wheat, rice, and maize. According to the latest global production estimates for 2024, world output reached approximately **390 million tonnes**, cultivated on around 18 million hectares across 159 countries. China leads at close to 95 million tonnes followed by India, Ukraine, the United States and Russia. Together, China and India grow more than 40 per cent of the global supply.

India's Record-Breaking Production

Within Asia and increasingly within the global potato economy, India occupies a position that is difficult to overstate. The country produced **58.57 million tonnes** of potatoes in 2024–25, according to the Final Estimates released by the Department of Agriculture and Farmers Welfare

(DA&FW) in March 2026, 2.66 per cent increase over the 57.05 million tonnes of the previous year and a figure that makes potato India's single most important vegetable crop. The current advance estimate for 2025–26 is 58.45 million tonnes, suggesting a broadly stable, mature production plateau rather than a runaway expansion.

This output is the result of a seventy-five-year arc of sustained growth. In 1949–50, the year ICAR's Central Potato Research Institute was founded in Shimla, India grew just 1.54 million tonnes of potatoes on 234,000 hectares. The national yield was a modest 6.58 tonnes per hectare. Seven decades of breeding, irrigation expansion, seed improvement and extension work later, the national average yield now sits at around 24–25 tonnes per hectare and the cultivated area has grown to more than 2.4 million hectares still below the productivity of western European producers (where 40–50 t/ha is routine), but well ahead of where the country was a generation ago.

India grew just 1.54 MT of potatoes in 1950. In 2024–25, it grew 58.57 MT, 38-fold increase in 75 years.

The geographic concentration of Indian production is stark. Uttar Pradesh produces roughly 30–35 per cent of the national crop — over 15 million tonnes annually.

Table 2: Major potato-producing states of India, 2024–25 estimates (NHB / DA&FW, 2026).

State	Approx. Production (MT)	Key Districts
Uttar Pradesh	>15.0	Agra, Mainpuri, Farrukhabad
West Bengal	~12.6	Hooghly, Bankura, Burdwan
Bihar	~9.0	Nalanda, Patna, Rohtas
Gujarat	~4.0	Banaskantha, Mehsana
Punjab	~3.0	Jalandhar, Hoshiarpur
Madhya Pradesh	~2.5	Gwalior, Indore

The Processing Revolution: From Sabzi to French Fries

Processing — chips, french fries, starch and dehydrated flakes were a minor sideshow. That has changed with remarkable speed in the last decade and 2026 finds the processing sector in the middle of what the industry publication PotatoInsights calls a **structural revolution.**

The frozen potato products market in India was valued at approximately **USD 2.07 billion in 2025** and is projected to reach nearly USD 10 billion by 2035, growing at a compound annual rate of 17 per cent one of the steepest growth rates anywhere in the global food industry. The engine of this demand is straightforward: the rapid expansion of quick-service restaurants. Every time McDonald's, KFC, Burger King or Domino's opens a new outlet in a Tier-2 Indian city, frozen fry consumption in that city climbs sharply. India's QSR and cloud-kitchen sector is projected to grow at over 17 per cent annually between 2025 and 2030, a figure that runs in near-perfect parallel to the frozen potato market's own growth rate.

Gujarat: India's Processing Powerhouse

In a development few would have predicted a decade ago, Gujarat has overtaken Uttar Pradesh and Punjab to become India's leading producer of processing-grade potatoes. Mehsana and Banaskantha districts now host modern dehydration plants backed by contract farming networks and cold-chain infrastructure. The model, a processor contracts directly with farmers, provides quality seed and agronomic support and buys at a pre-agreed price has given farmers in these districts income stability that open-market table-potato farming cannot guarantee. It is a template that other states are beginning to study closely.

New Varieties for a Warming World

ICAR's Central Potato Research Institute responded in 2025 with the notification of four new varieties. The Ministry of Agriculture formally cleared them for nationwide seed production and cultivation in January 2026, following the recommendations of the Central Seed Committee: **Kufri Ratan** is a medium-maturing (90 days), red-skinned table potato yielding 37–39 t/ha across north Indian plains and plateau regions, with strong storability, a quality that matters enormously in a country where cold-storage availability, while growing, remains unequally distributed.

Kufri Tejas is, in many ways, the most strategically significant of the four. It is heat-tolerant, medium-maturing (90 days), yields 37–40 t/ha and has been approved for cultivation across Haryana, Punjab, Uttar Pradesh, Madhya Pradesh, Gujarat and Maharashtra.

Kufri Chipbharat-1 and **Kufri Chipbharat-2** are both processing varieties, the first yielding 35–38 t/ha at 100 days and the second slightly earlier at 90 days with comparable yield. They are specifically bred for the dry-matter content and low-sugar specifications that processors whether for crisps or frozen fries demand. Their release signals ICAR-CPRI's deliberate effort to close the gap between breeding priorities and industrial requirements, reducing Indian processors' historical dependence on imported varieties such as Atlantic and Lady Rosetta.

Late Blight in the Andes — A Warning From 2025

The same disease that triggered the Irish Famine is still active in 2026. In November 2025, the International Potato Centre (CIP) in Lima warned that rising temperatures are pushing Phytophthora infestans, the late blight pathogen to higher altitudes in the Andes, threatening varieties and farming communities that never previously needed to worry about it. CIP's response was the release of CIP, a blight-resistant variety developed with Indigenous community participation, ahead of the COP30 climate talks.

Diseases: The Perennial Shadow Over Yield

No account of the potato in 2026 would be complete without an honest look at disease. Globally, potato diseases cause estimated losses of well over USD 10 billion annually. Late blight alone — the same disease that devastated Ireland, remains the single most destructive pathogen worldwide. In India, early blight caused by *Alternaria solani* is the most widely encountered foliar disease of the Rabi crop, causing yield losses ranging from 5 per cent in mild seasons to over 70 per cent when conditions are severe. Other significant threats include potato virus Y (PVY), potato leafroll virus (PLRV), black scurf (*Rhizoctonia solani*) and bacterial wilt (*Ralstonia solanacearum*).

What makes disease management in the Indian potato belt particularly challenging is the combination of factors that converge every Rabi season. The dense, humid canopy of closely planted potato fields creates ideal micro-environments for fungal pathogens. Cool, foggy December nights extend leaf wetness duration to eight hours or more precisely the window that

Alternaria and *Phytophthora* need for successful infection. And the genetic base of commercial production remains narrow: Kufri Bahar, Kufri Jyoti and Kufri Chandramukhi together still account for the majority of cultivated area and all carry some level of susceptibility to the main pathogens.

The Road Ahead: What 2026 Tells Us About the Future

India's potato sector in 2026 is, by most measures, a success story. Production has grown 38-fold since independence. Average yields have risen fourfold. Export competitiveness, unimaginable even fifteen years ago, is now real and growing.

Yet several structural challenges remain and they deserve candid acknowledgement. First, the **seed system**: India produces only a fraction of the certified seed potato it needs from formal sources and most farmers still plant saved seed of uncertain quality and disease status. ICAR-CPRI's seven regional stations work hard on this, but seed availability continues to constrain the uptake of new varieties. Second, **post-harvest losses** remain high, particularly in West Bengal and Bihar where cold-storage capacity lags production growth. Estimates suggest that 5–10 per cent of the harvest is lost annually to storage failures, price crashes and transport bottlenecks. Third, **price volatility**: by April 2026, following a near-record harvest, farm-gate prices had fallen to ₹7–13 per kilogram manageable for a large commercial farmer but painful for the smallholder growing a hectare or two on fragmented landholdings in the central plains. Fourth, **fragmentation**: the potato value chain from field to consumer remains deeply fragmented, with millions of small farmers, thousands of local traders, and an inadequate digital market infrastructure standing between a field in Mainpuri and a processing plant in Mehsana.

India's frozen french fry exports grew 77% in a single year, crossing 222,744 tonnes in 2025. The processing revolution is no longer a forecast — it is already under way

The opportunity, on the other side of these challenges, is equally real. India has the production scale, the growing domestic market, and — with the right investment in seed, cold chain, and digital market linkages — the raw materials for a far more productive and resilient potato sector. The new processing varieties notified in 2026, the expansion of contract farming, the deployment of remote sensing and satellite imagery for crop health monitoring, and the growing interest of global potato companies in the Indian market all point in the same direction.

The potato arrived in India from Europe sometime in the seventeenth century. It took root slowly, then explosively. In 2026, it is not just a crop. It is a cold-storage industry, a frozen foods export business, a smallholder livelihood across five major states, and a subject of active scientific investment at seven regional research stations from Modipuram to Ooty.

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PSEUDOMONAS SYRINGE – A WONDER COOLANT

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Abstract

Pseudomonas syringae is a widespread plant pathogen capable of causing severe agricultural damage through a unique mechanism of frost facilitation. The bacterium expresses specialized ice-nucleating proteins (INPs) on its outer membrane, which structurally align water molecules to promote crystalline ice growth at near-zero temperatures (-2°C to -4°C). By inducing premature freezing, *P. syringae* physically ruptures plant cell walls, causing intracellular nutrients to leak and creating entry points for colonization. We study about their roles, constraints with the evident nature of the bacteria.

Keywords: *Pseudomonas syringae*, ice-nucleating proteins, Pathogen, super coolant.

Introduction

Pseudomonas syringae is a rod-shaped, gram negative bacterium with polar flagella. As a phytopathogen, it can infect a wide range of species, and exists as over 50 different pathovars. The ability of bacteria to initiate water freezing at near-zero temperatures was first discovered in 1974 using *Pseudomonas syringae*. It is a harmful plant pathogen, but some strains have remarkable property that trigger ice formation at relatively warm subzero temperatures through specialized ice-nucleating proteins on their outer surface. This property has attracted attention for cooling and freezing related technologies.

Role of this bacteria

Most pure water droplets remain super cooled below 0℃ unless a nucleator starts ice crystal formation. *P.syringae* can nucleate ice at around - 2℃ in favorable conditions. It say that *P.syringae* is used as an ice nucleator for cooling and freezing process. It does not act as coolant

like water, ethylene etc. but it initiate freezing earlier, which can shorten freezing time and improve process control.

Science Basis

Bacterial ice- nucleating protein often referred to as Ina-type protein, which organizes water molecules into an arrangement that promotes crystal formation. Recent cryo-microscopy work reveal that bacterial ice- nucleating protein can trigger freezing at hydrophobic interfaces which explain their strong activity in droplets and applied sciences.



Ice nucleation on leaves



Pseudomonas syringae

Uses

- **Commercial Snowmaking:** The most common use of these bacterial proteins is in the snow inducer Snomax®**.**
- **Cloud Seeding:** Naturally, high-flying *P. syringae* swept from the ground aid in forming clouds and precipitation by providing nuclei for ice to form at higher sub-freezing temperatures in the atmosphere.
- **Food Preservation/Freezing:** Researchers have explored utilizing its ice-nucleating properties to control and improve freezing operations in the food industry.

Constraints

- *P. syringae* is a notorious phyto pathogen (capable of blighting and cankering hundreds of plant species), releasing the coolant into the environment or wastewater poses a severe biosecurity threat to agriculture
- Bacteria trigger freezing efficiently, their utility is fundamentally limited by the **latent** heat of fusion. Their application is strictly bound to systems relying on phase-change cooling (e.g., slush ice storage)

- The specialized ice-nucleating proteins denature over time, especially under the high-shear, turbulent flow typical of mechanical pumps and industrial heat exchanger

Conclusion

Pseudomonas syringae should not be described as simply as coolant. It is can be describe as biological ice nucleator with useful applications in controlled freezing and other cooling-related technologies.

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GENE EDITING IN AGRICULTURE

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Introduction

Gene editing is a suite of technologies that allow scientists to alter an organism's DNA. By adding, removing, or replacing genetic material at specific locations in the genome, these techniques can be used to treat genetic diseases, improve crop yields, and develop new biomedical models.

The main gene editing techniques vary in precision, mechanism, and how they find and cut DNA:

CRISPR-Cas9: The most widely used system, it utilizes a custom-designed "guide RNA" to direct the Cas9 enzyme (the molecular scissors) to a precise DNA sequence, where it creates a double-strand break. It is highly efficient, cost-effective, and adaptable.

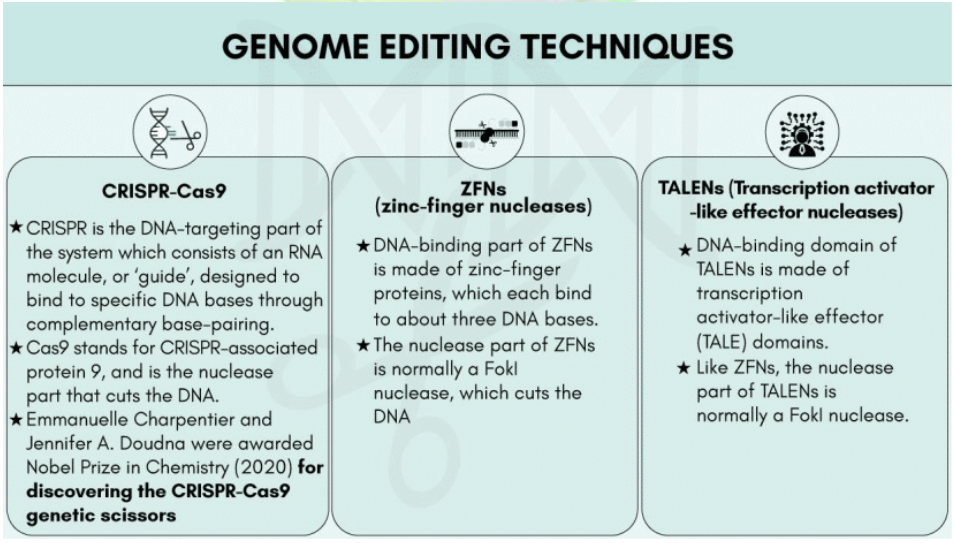


Fig1.Gene editing Techniques

- **Base Editing:** A more advanced evolution of CRISPR, it uses a modified Cas enzyme fused to a deaminase enzyme. Instead of cutting both strands of DNA, it allows scientists to directly change a single DNA base (like converting an A-T base pair to a G-C pair) without double-strand breaks.
- **Prime Editing:** An advanced "search and replace" technique. It uses a modified Cas enzyme and a prime editing guide RNA (pegRNA) to write new genetic information directly into a specified DNA site.
- **TALENs (Transcription Activator-Like Effector Nucleases):** These are synthetic proteins engineered to bind to specific DNA sequences and cut them using a nuclease domain. While highly specific, they require complex protein engineering for each target
- **ZFNs (Zinc Finger Nucleases):** One of the earliest gene-editing tools, they use engineered proteins that bind to specific DNA triplets and utilize a cleavage domain to cut the target.

How the Cell Repairs Edits

Most of these technologies work by creating a targeted break in the DNA. The cell then attempts to repair this break using one of two natural pathways:

- **Non-Homologous End Joining (NHEJ):** The cell simply glues the broken ends back together. This process is somewhat error-prone and often causes insertions or deletions of base pairs (indels), which effectively disables or "knocks out" the gene.
- **Homology-Directed Repair (HDR):** If a DNA template is provided alongside the editing tool, the cell can use it to precisely repair the break. This allows scientists to insert or correct specific gene sequence

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UTILIZATION OF PLANT-BASED FOOD WASTE AS A SUSTAINABLE SOURCE OF DIETARY FIBER: EXTRACTION, HEALTH BENEFITS, AND APPLICATIONS IN NOVEL FOOD PRODUCTS

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Introduction

The global agri-food industry produces massive amounts of waste and by-products, which pose serious environmental, economic and social problems. The Food and Agriculture Organization (FAO) estimates that every year between 1.3 and 1.4 billion metric tons or approximately one third of all food produced for human consumption is lost or wasted (Food and Agriculture Organization [FAO], 2014; Plakantonaki et al., 2023). When these organic materials are dumped in landfills they rot and emit huge quantities of greenhouse gases especially methane which directly causes climate change (Hussain et al., 2020).

Agri-waste valorization is an effective process for converting agricultural residues into valuable secondary resources (Pop et al., 2021). Dietary fiber (DF) is a significant extractable component that is increasingly required in functional meals to assist in preventing chronic non-communicable diseases (Garcia-Amezquita et al., 2018). The recovery of DF from agricultural waste is a sustainable alternative that can address both ecological disposal problems and urgent nutritional needs (Boteju et al., 2026). This article describes the content, green extraction methods, health benefits and novel dietary applications of agri-waste-derived DF.

1. Plant-Based Food Waste as a Source of Dietary Fiber

Processing of fruits, vegetables and grains produces large volumes of waste biomass such as peels, pomace, husks and stems. Dietary fiber is an important component of fruit and vegetable by-products such as apple pomace, citrus peels, carrot residues and cabbage leaves. For instance, dried apple pomace and citrus peels generally contain 40–80% total dietary fiber (TDF) on a dry

weight basis (Maurya et al., 2015). In addition, agricultural residues such as sugarcane bagasse, corn cobs and banana pseudostems are a vast but traditionally underutilized source of lignocellulosic biomass (Boteju et al., 2026).

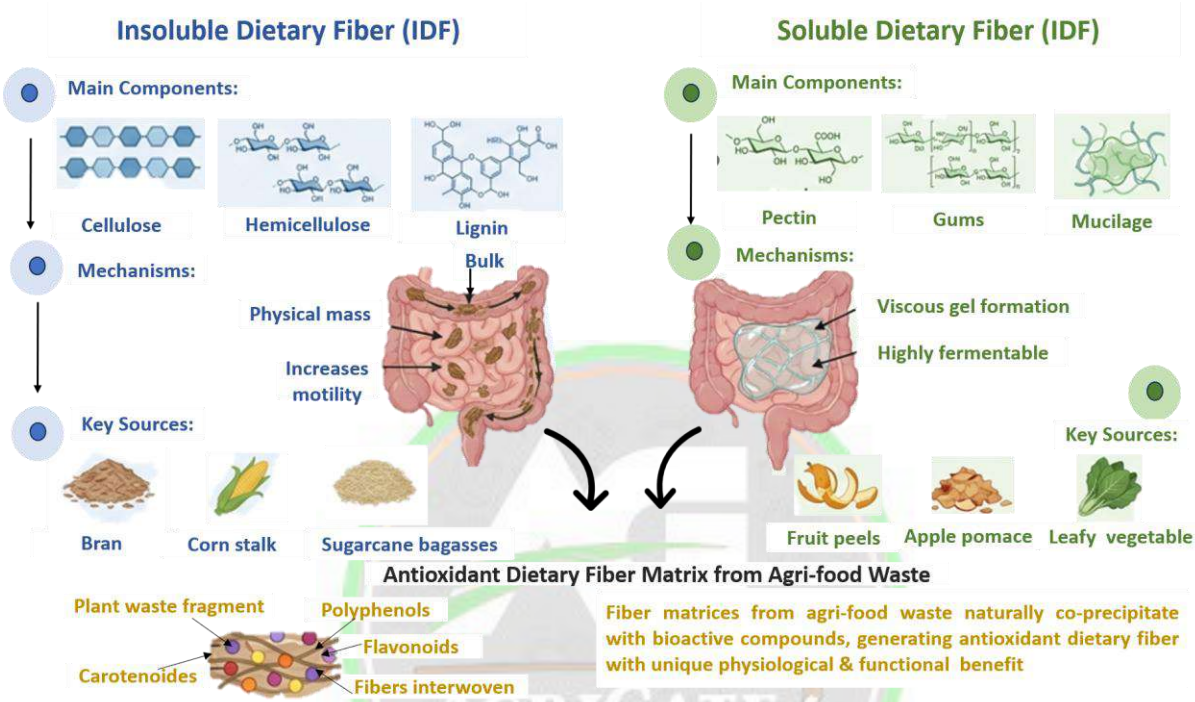


Fig 1: Classification and Functional matrix of Dietary Fiber

Table 1. Common Plant-Based Waste Materials, Major Fiber Types, and Potential Food Applications

Plant-Based Waste Source	Major Fiber Type	Potential Food Applications	References
Apple Pomace	Pectin, Cellulose	Bakery products (cookies, bread), Yogurt stabilizers	(Maurya et al., 2015; Pop et al., 2021)
Citrus Peels	Pectin, Cellulose	Beverages, Functional dairy products	(Hussain et al., 2020; Pop et al., 2021)
Sugarcane Bagasse	Cellulose, Lignin	Noodles, Biscuits, Meat emulsions	(Boteju et al., 2026; Lau et al., 2022)
Banana Pseudostem	Cellulose, Hemicellulose	Pasta, Biscuits, Prebiotic supplements	(Boteju et al., 2026)
Carrot Pomace	Cellulose, Pectin	Bakery (cakes, donuts), Meatballs	(Pop et al., 2021)

Dietary fiber is generally classified into two broad categories based on their solubility in water, i.e. soluble dietary fiber (SDF) and insoluble dietary fiber (IDF). The IDF is mainly composed of cellulose, hemicellulose and lignin. They provide physical mass and stimulate intestinal motility and are most abundant in highly lignified wastes such as cereal bran, corn stalks and sugarcane bagasse (Boteju et al., 2026; Plakantonaki et al., 2023). Conversely, pectins, gums and mucilage are constituents of SDF. SDF is highly fermentable and forms viscous gels in the gastrointestinal system and is mostly found in fruit peels, apple pomace and some vegetables (Maurya et al., 2015). Importantly, the dietary fiber obtained from agri-food waste often co-precipitates with bioactive substances such as polyphenols, flavonoids, and carotenoids, resulting in a matrix of "antioxidant dietary fiber" with physiological and functional benefits that are not present in traditional refined cereal fibers (Sagar et al., 2018).

2. Extraction Techniques

The physicochemical characteristics and functional properties of the recovered dietary fibre are greatly influenced by the extraction technology applied. The primary standard extraction procedures are dry or wet milling and chemical hydrolysis with strong acids or alkalis (Hussain et al., 2020). Alkaline treatments can efficiently dissolve hemicelluloses and break down lignin-carbohydrate complexes but they often require long processing times, high energy consumption and generate toxic chemical effluents damaging the molecular framework of the fiber (Maurya et al., 2015).

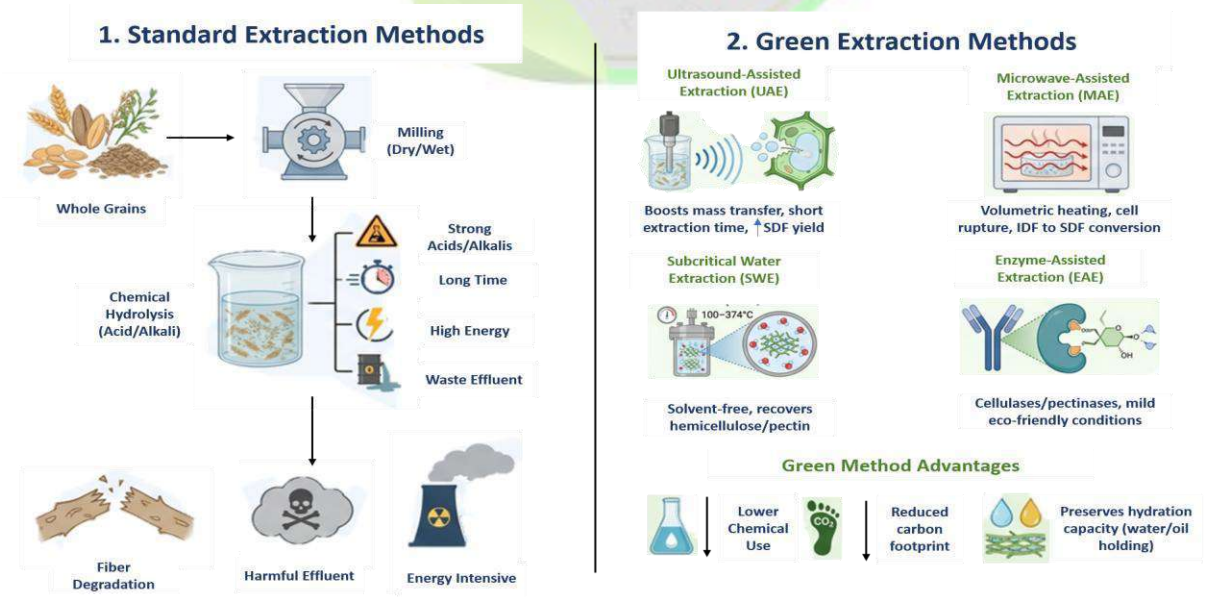


Fig 2: Extraction Techniques for Dietary Fiber: Standard vs. Green Methods

The emergence of green extraction methods has gained industrial importance, overcoming these restrictions in terms of environment and quality (Chemat et al., 2017).

2.1 Ultrasound-assisted extraction (UAE): It uses high-frequency sound waves to cause acoustic cavitation, which forms microjets that aggressively disrupt plant cell walls. The mechanical shearing boosts the solvent mass transfer, minimizes the extraction times and increases the SDF yields (Chemat et al., 2017; Hussain et al., 2020).

2.2 Microwave-assisted extraction (MAE): It employs non-ionizing radiation to create fast, volumetric heating inside the food matrix through dipole rotation. This intracellular steam pressure then leads to cell rupture, and crystalline IDF is successfully converted to highly functional SDF (Boteju et al., 2026).

2.3 Subcritical water extraction (SWE): It uses pressurized hot water (100–374 °C) to hydrolyze recalcitrant plant matrices without organic solvents, providing a purely green way of recovering hemicellulose and pectin (Boteju et al. 2026).

2.4 Enzyme-assisted extraction (EAE): It employs particular biological catalysts (e.g. cellulases, pectinases) to get targeted cell wall disruption under mild, environment friendly conditions (Buljeta et al., 2023). The combination of these green methods increases sustainability by lowering the use of chemical solvents, reducing carbon footprints and conserving critical hydration qualities such as water and oil holding capacities of the recovered fibers.

3. Health Benefits and Food Applications

The consumption of dietary fiber recovered from plant waste associated to a wide range of physiological health advantages.

3.1 Improved gut health and prebiotic effects: Bifidobacterium and Lactobacillus are two examples of the beneficial colonic microbiota that are specifically stimulated by both SDF and IDF, which are indigestible substrates. Microbial fermentation of these fibers results in the production of short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate which increase intestinal barrier integrity, reduce colonic pH, and modify host immunity (Boteju et al., 2026; Pop et al., 2021).

3.2 Glycemic control: Pectin and other SDF fractions from fruit pomace considerably improve the viscosity of gastrointestinal digesta. This reduces stomach emptying and starch hydrolysis, blunting postprandial glucose absorption and boosting insulin sensitivity (Hussain et al., 2020).

3.3 Cardiovascular health: Viscous fibers improve the fecal excretion of dietary cholesterol and bile acids by binding them in the colon. This successfully lowers systemic serum lipid and LDL levels by reducing the absorption of cholesterol and requiring the de novo synthesis of bile acids from hepatic cholesterol (Hussain et al., 2020).

3.4 Weight management: IDF's high water-holding capacity and bulking effect stimulate extended fullness and mechanical satiety, which reduces hunger and helps prevent obesity (Pop et al., 2021).

3.5 Antioxidant and anti-inflammatory potential: Antioxidant dietary fibers reduce systemic inflammation and cellular oxidative stress by releasing bound polyphenols during colon fermentation (Sagar et al., 2018).

These health and techno-functional benefits promote dietary fiber incorporation into novel food-products. Apple pomace, sugarcane bagasse, or potato peels can be used to replace 5–15% of wheat flour in baked products to improve the total fiber and lower the glycemic index without affecting the sensory quality (Ben Jeddou et al., 2017; Hussain et al., 2020). Similarly, the addition of sugarcane bagasse or banana pseudostem for pasta production greatly reduces the glycemic load (Lau et al., 2022).

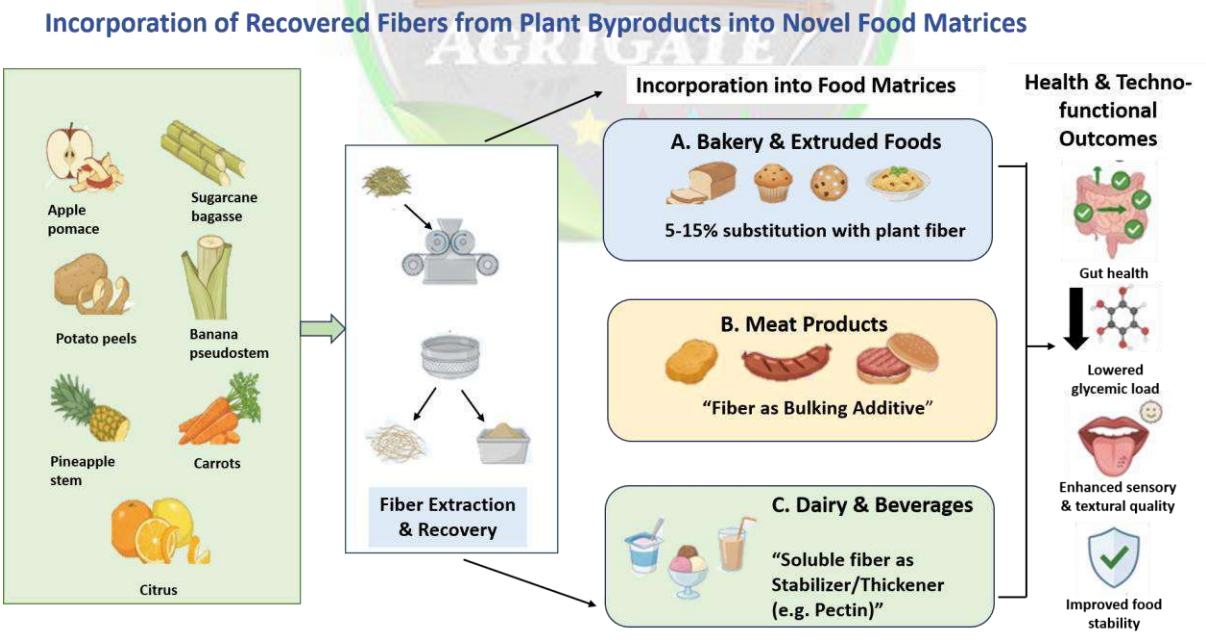


Fig: 3 Health Benefits and Techno-functional Roles

Pineapple, citrus and carrot fibers serve as bulking agents in meats, improving emulsion stability, increasing juiciness and decreasing cooking loss (Garcia-Amezquita et al., 2018).

Finally, soluble fibers, such as citrus and apple pectin, are used as natural stabilizers in dairy products and beverages to avoid syneresis, control ice crystal formation and mimic the mouthfeel of fat (Maurya et al., 2015; Pop et al., 2021).

Conclusion

Plant-based food waste is an important meeting point between agricultural sustainability, environmental responsibility and public health. Circular economy provides opportunities for the food industry to recycle large amounts of peels, pomace, and stems from the environmentally harmful landfills (Plakantonaki et al., 2023). The restored fibers are functional components which are effective against the modern epidemics of metabolic syndrome, diabetes and cardiovascular disease. Future research should be concentrated on the enhancement of green extraction techniques to reduce the operational expenses in industries and standardization of the constituent formulations to overcome the sensory restrictions. Furthermore, strict in vivo clinical studies are necessary to validate the metabolic health claims of some waste-derived fibers (Boteju et al., 2026).

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SMART IOT-BASED SOIL EROSION RISK MONITORING AND EARLY WARNING SYSTEM USING ESP32

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Abstract

Soil erosion is one of the major environmental and agricultural problems that reduces soil fertility, decreases crop productivity, and causes degradation of land resources. Heavy rainfall, increased soil moisture, slope instability, and surface runoff are the primary factors contributing to soil erosion. Conventional monitoring methods mainly depend on manual field inspection, which is time-consuming and does not provide timely warnings. This paper proposes a Smart IoT-Based Soil Erosion Risk Monitoring and Early Warning System using an ESP32 microcontroller. The proposed system integrates a soil moisture sensor, rain sensor, ultrasonic sensor, and tilt sensor to continuously monitor environmental parameters associated with soil erosion. The ESP32 processes the sensor data and determines the level of erosion risk using predefined threshold values. When the measured parameters exceed the safe limits, the system activates a buzzer and warning LEDs while simultaneously transmitting alert notifications to users through the Blynk IoT platform. The proposed system aims to provide farmers and land managers with an affordable, real-time monitoring solution that enables early preventive action to reduce soil erosion and protect agricultural land.

Keywords: Soil erosion, ESP32, IoT, Blynk, Soil moisture sensor, Rain sensor, Ultrasonic sensor, Tilt sensor, Early warning system.

1. Introduction

Soil is one of the most valuable natural resources supporting agricultural production and environmental sustainability. Soil erosion is the process by which the fertile topsoil is removed due to water, wind, or human activities. Water-induced soil erosion is the most common form in agricultural fields, particularly during heavy rainfall events. Loss of topsoil decreases soil fertility, reduces crop yield, increases sedimentation in water bodies, and affects overall agricultural productivity.

Traditional soil erosion monitoring relies on manual observation and periodic field surveys. These methods are labour-intensive and often fail to provide timely warnings before severe erosion occurs. Recent developments in the Internet of Things (IoT) have enabled continuous environmental monitoring using low-cost sensors and wireless communication technologies.

The proposed system uses an ESP32 microcontroller to integrate multiple sensors that monitor soil moisture, rainfall intensity, slope movement, and runoff conditions. The collected data are analysed to determine erosion risk, and alerts are sent to users through the Blynk IoT platform. This system provides a practical, low-cost approach for early warning, allowing farmers to implement preventive soil conservation measures before significant soil loss occurs.

2. Problem Statement

Agricultural lands are increasingly affected by soil erosion due to extreme rainfall events, improper land management, and changing climatic conditions. Existing monitoring techniques are mostly manual and lack real-time warning capabilities. There is a need for a low-cost, automated monitoring system capable of continuously assessing erosion-related parameters and providing timely alerts to farmers.

3. Objectives

General Objective

To develop a Smart IoT-Based Soil Erosion Risk Monitoring and Early Warning System using ESP32 for continuous monitoring of erosion-related parameters.

Specific Objectives

- To monitor soil moisture using a soil moisture sensor.
- To detect rainfall intensity using a rain sensor.
- To monitor runoff conditions using an ultrasonic sensor.

- To detect slope movement using a tilt sensor.
- To process sensor data using the ESP32 microcontroller.
- To classify erosion risk based on predefined threshold values.
- To provide real-time alerts using LEDs, buzzer, and the Blynk IoT application.

4. Literature Review

S.No	Year of Publication	Journal Name	Author(s)	Key Contribution
1.	2022	Science of the Total Environment	Sumudu Senanyake,Biswajeet Pradhan, Abdullah Alamri, Hyuck-park	Developed a hybrid LSTM+RUSLE model for soil erosion prediction. The model forecasted rainfall for 36 months and achieved AUC = 0.93, improved soil erosion susceptibility mapping
2.	2017	Nature Communications	Pasquale Borrelli et al.	Developed a 250 m global soil erosion model using remote sensing, GIS and RUSLE to assess the impact of land-use change on global soil erosion and conversion practices
3.	2013	International journal of Remote Sensing	Maxim shoshany, Naftaly Goldshlegar, Alexandra Chudnovsky	Reviewed remote sensing techniques for monitoring agricultural soil degradation, highlighting direct, indirect and integrated

				approaches for soil erosion assessment
4.	2024	International soil and water conservation research	Dominik Scholand, Britta Schmalz	Proposed an automated image-analysis methods to estimate the RUSLE P-factor using remote sensing, achieving 94.9% detection accuracy for contour farming practices
5.	2019	Environmental Systems research	Mengie Belayneh, Teshome yirgu, Dereja Tsegaya	Applied RUSLE,GIS and Remote Sensing to estimate soil loss and prioritize erosion hotspot areas for watershed conservation planning in Ethiopia
6.	2023	International Journal of Advanced Research in Computer and Communication Engineering (IJARCCE)	Mrs.Priyanka Gupta, Ayush Gupta, Chhaya singh, Sonal Gadewar, Atharav Deore	Proposed an IOT-based landslide detection and monitoring system using ESP32, soil moisture sensor, accelerometer/gyroscope, and cloud monitoring for real-time early warning
7.	2025	International Journal for Research in Applied Science &Engineering Technology (IJRASET)	Mahathi B, Kirthika S.S., Mr.K.Balaji	Developed an AI-enabled IOT landslide prediction system integrating ESP32, soil moisture , rainfall,

				vibration ,and temperature sensors with cloud dashboard and automated alert system
8.	2019	Natural Hazards Review	Robert B. Olshansky & Lisa M.Olsan	Reviewed the causes, consequences, and risk assessment methods of landslides, emphasizing multidisciplinary approaches for effective hazard management.
9.	2019	Remote sensing	Matjaz Miksa et al.	Reviewed terrestrial laser scanning techniques for monitoring landslide movement, deformation, and hazard assessment.
10.	2018	Natural Hazards	Francesco silvestri et al.	Reviewed various landslide risk management strategies and highlighted the importance of monitoring systems, stakeholder participation, and risk communucation

5. Materials and Components

components	purpose
ESP32	Main controller
Soil Moisture sensor	Measures soil moisture
Rain sensor	Detects rainfall

Ultrasonic sensor	Monitors runoff/water level
Tilt sensor	Detects slope movement
Active Buzzer	Audible warning
LEDs	Visual indication
Breadboard	Circuit assembly
Jumper wires	Connections
Blynk Iot platform	Mobile monitoring and alerts

6. Methodology

The methodology of the proposed system is explained step by step as follows:

Step 1: System Initialization

- All sensors (soil moisture, rain, ultrasonic, and tilt) are connected to the ESP32 microcontroller.
- The ESP32 is connected to Wi-Fi.
- Threshold values for each parameter are defined based on safe and critical limits.
- The Blynk lot platform is configured with the required authentication token.
- LEDs and buzzer are initialized for local alert indication.

Step 2: Data Acquisition from Sensors

- The system starts reading data from all four sensors at regular intervals.
- Soil Moisture Sensor measures the water content in the soil.
- Rain Sensor detects the presence and intensity of rainfall.
- Ultrasonic Sensor measures the distance to the water surface to estimate runoff or water level.
- Tilt Sensor monitors the inclination of the land to detect any slope movement.

Step 3: Data Processing

- The ESP32 collects the raw data from all sensors.
- The data is filtered and processed to remove minor fluctuations and noise.
- Each parameter is converted into meaningful values (e.g., moisture in %, distance in cm, tilt in degrees).

Step 4: Threshold Comparison

- The processed values are compared with predefined threshold values.
- Each parameter is classified as SAFE or RISK based on the threshold.
- A score or weight is assigned to each parameter depending on its severity.

Step 5: Erosion Risk Calculation

- The ESP32 calculates the overall erosion risk by combining the status or scores of all parameters.
- If only one parameter is in risk, the risk level is kept low.
- If multiple parameters are in risk, the system increases the risk level.

The final risk level is categorized as:

1. Safe
2. Risk

Step 6: Alert Generation (Local)

1.If the risk level is High:

- The Red LED turns ON.
- The buzzer beeps continuously.

2.If the risk level is Safe:

- The Green LED turns ON.
- The buzzer remains OFF.

Step 7: Data Transmission to Blynk IoT Platform

- The ESP32 sends all sensor values and the calculated risk level to the Blynk cloud using Wi-Fi.
- Data is uploaded to virtual pins created in the Blynk application
- . Users can view real-time sensor readings and risk status on the mobile app dashboard.

Step 8: Mobile Notification

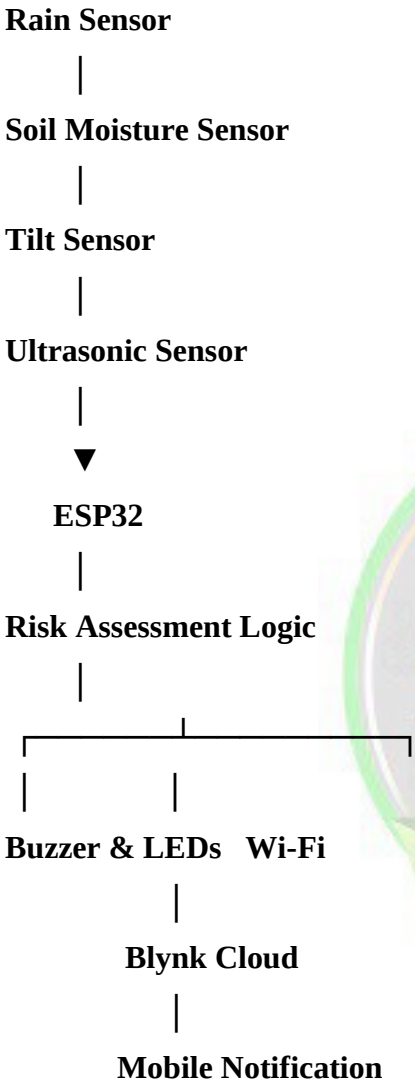
- If the risk level is High, the system triggers a notification.
- Blynk sends an alert message to the user's mobile phone.
- The notification contains the risk level and sensor readings.

Step 9: Continuous Monitoring

- Steps 2 to 8 are repeated continuously.

- The system provides real-time monitoring and early warning.
- Users can take preventive measures before severe soil erosion occurs.

7. System Architecture



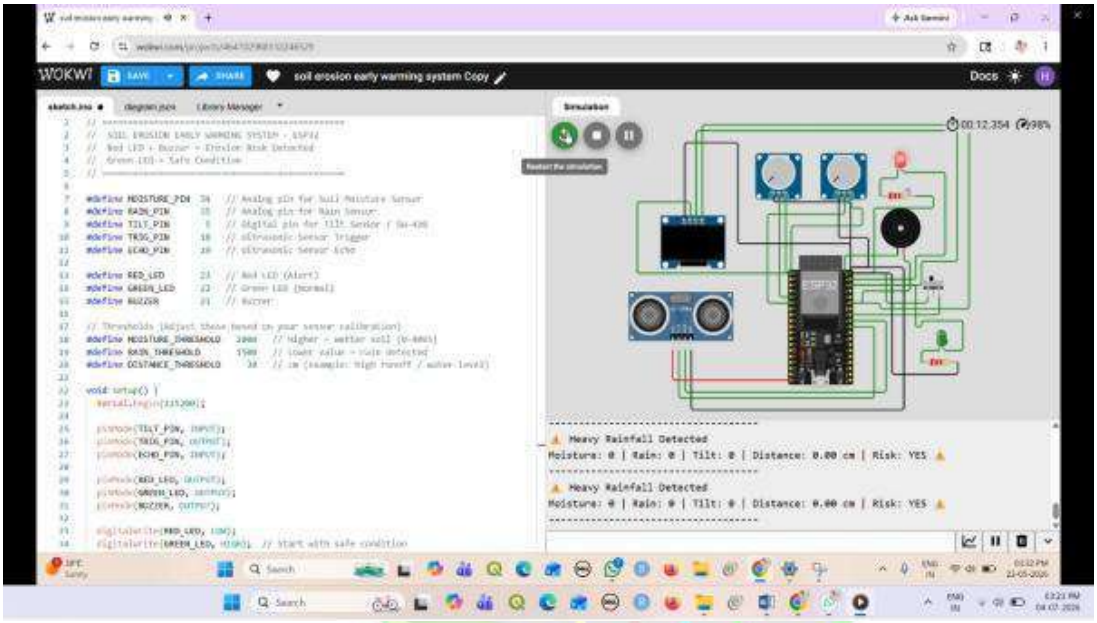
8. Working Principle

The system operates continuously by acquiring data from all connected sensors. Soil moisture and rainfall sensors indicate soil saturation and precipitation levels, while the ultrasonic sensor monitors runoff changes and the tilt sensor detects slope movement. The ESP32 analyses these values using threshold-based logic. If the calculated erosion risk exceeds the predefined limit, warning signals are generated through LEDs and a buzzer. Simultaneously, sensor readings and alerts are transmitted to the Blynk platform, allowing users to monitor conditions remotely.

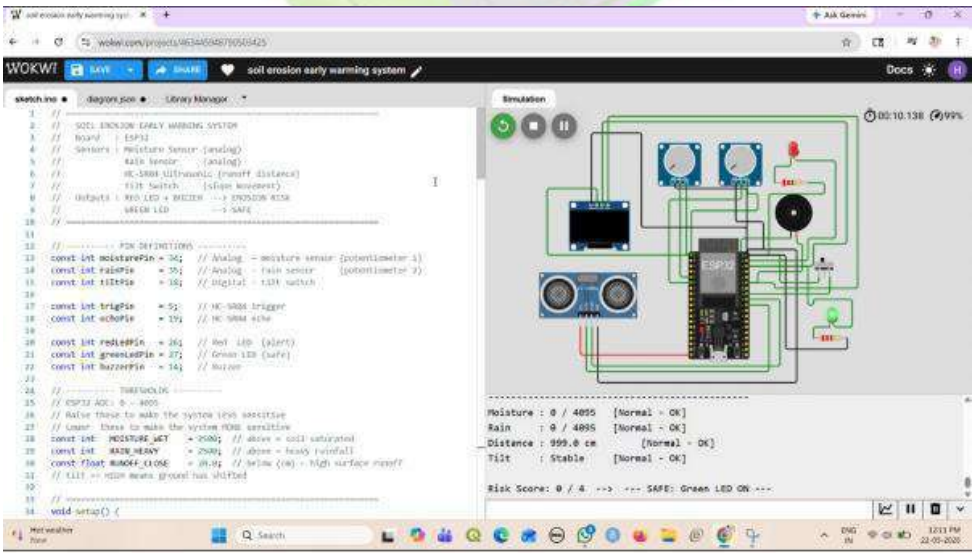
9. Expected Results

The proposed system is expected to:

- Monitor erosion-related parameters in real time.
- Identify conditions associated with increased soil erosion risk.
- Provide visual and audible alerts locally.
- Send mobile notifications through the Blynk application.
- Assist farmers in taking preventive measures to reduce soil loss.



Wokwi model showing soil erosion risk zone(Red LED is on)



Wokwi model showing soil erosion safe zone(Green LED is on)

10. Advantages

- Low-cost implementation.
- Real-time monitoring.
- Continuous data collection.
- Remote monitoring through IoT.
- Easy to operate.
- Portable and scalable.
- Suitable for agricultural fields.

11. Limitations

- Sensor accuracy may vary under field conditions.
- Requires Wi-Fi connectivity for cloud notifications.
- Threshold values require calibration.
- Monitors risk conditions but does not guarantee exact prediction of erosion events.

12. Future Scope

Future enhancements may include:

- Machine learning for predictive analysis.
- Integration with weather forecast APIs.
- Solar-powered operation.
- GSM-based SMS alerts.
- GPS location tracking.
- Cloud database for historical analysis.
- Multiple sensor nodes for large farms.

Conclusion

The proposed Smart IoT-Based Soil Erosion Risk Monitoring and Early Warning System provides a practical approach for monitoring environmental conditions associated with soil erosion. By integrating soil moisture, rainfall, runoff, and slope monitoring with ESP32 and the Blynk IoT platform, the system offers timely alerts that can help farmers implement preventive measures before severe soil degradation occurs. Although the system uses threshold-based decision-making, it establishes a strong foundation for future integration of advanced predictive techniques. The proposed solution is economical, scalable, and suitable for smart agriculture applications.

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BREEDING FOR QUALITY MUSHROOMS

Article ID: AG-V06-I07-114

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Introduction

There are several reports that some of the most widespread strains show signs of degeneration in several countries. It was because spawn laboratories do not preserve the viability and vigour of the strains. Breeding stands at the forefront of this commercial revolution. The primary goal of mushroom breeding is to combine high yield potential with superior quality attributes that meet the rigorous standards of both fresh markets and processing industries. Developing improved strains ensure crop stability, biotic and abiotic stress resistance, and enhanced post-harvest shelf life. Different precautions are advised to be taken for the commercial spawn production:

a) Any change in morphological, physiological and genetical nature, should be observed seriously.
b) Spawn producers must be able to keep the strains in viable conditions and to detect any change well in time.
c) Certain kinds of mycelium which is weak and is growing slowly on agar medium and grows slowly on the spawn substrate and on the compost should be avoided.
d) Spawn producing fluffy cottony mycelium and forming white patches on the compost bed usually yields low- and poor-quality mushroom. Such spawn should be discarded.
e) The simplest way to maintain vigour and productively of the strains, is to subculture them from time to time on suitable nutrient agar media and to store them in refrigerator at 3-5C°.
f) Performance of the strain should be checked carefully and periodically.

g) No spawn should be sold to the growers until it has been thoroughly pre-tested for its good quality.

Physical quality attributes

i. **Colour -** Pure, bright white is highly preferred for Button mushrooms (*Agaricus bisporus*), while uniform, vibrant hues are desired for specialty mushrooms like Oyster Mushroom (*Pleurotus* spp.) and Shiitake Mushroom (*Lentinula edodes*). Breeding aims to eliminate browning tendencies caused by polyphenol oxidases (PPO).

ii. **Cap Shape and Cap-to-Stipe Ratio:** A thick, dome-shaped cap with a short, stout stipe (stem) maximizes the edible biomass and appeals visually to consumers.

iii. **Texture and Firmness:** Firm, crisp flesh is essential to withstand harvesting, packaging, transport, and to prevent premature cap opening (veil splitting).

Chemical & Nutritional quality attributes

i. **Protein and Amino Acid Profile:** Enhancing total crude protein and essential amino acids (like lysine and leucine).

ii. **Bioactive Compounds:** Boosting levels of medicinal compounds such as β-glucans (immunomodulators), ergothioneine (a potent antioxidant), and vitamin D precursors (ergosterol).

iii. **Low Moisture Content:** Higher dry matter content translates directly to a crunchier texture and better cooking recovery.

Post-harvest & storage quality attributes

i. **Shelf Life:** Resistance to post-harvest physiological degradation and microbial spoilage

ii. **Reduced Enzymatic Browning:** Selecting for low-tyrosinase or low-PPO activity lines to prevent the unappealing brown discoloration that occurs upon bruising or storage.

Techniques for strain development

Following breeding techniques are used for strain development:

Biological knowledge of the species to be improved is essential. If the life cycle is not well known, the opportunity for strain development is limited to the selection of mutant varieties. The breeder must know whether the species is homothallic, heterothallic or secondarily homothallic.

In homothallic species, the mycelium from a single type of basidiospore that will lead to the completion of the cycle with the formation of Mushroom and its basidiospores, but in heterothallic species, the mycelia from single spore are sterile and for the completion of the life cycle and formation of the mushroom, compatible mycelia must be brought together.

In secondary homothallism, some of the single basidiospores complete the life cycle while others are self-sterile. When their mycelia are brought together in compatible communication; mushroom may be produced. Genetic manipulation for breeding obviously requires complete detail of the life cycle. Besides life cycle, knowledge of the habitat, the substrate, the temperature range, the relationship with other organism, the nutritional and environmental requirements for both mycelia and fruiting are desirable for breeding programme for strain improvement. The goal of the mushroom breeder, no matter what the species, is to bring together the best possible combination of genes that control characteristics of commercial importance.

Essential for Mushroom Breeding Programme

For successful breeding programme, following points are important to be kept in mind by the breeders interested in strain development of mushrooms.

i. **Provision of wide genetic base –** Many pure cultures should be obtained to provide a wide genetic base and variation in agronomical important traits. Therefore, fruiting bodies should be collected from widespread geographical areas and diverse ecological situations.

ii. **Maintenances of cultures-** The cultures established for breeding work should be maintained in a manner that will maintain genetic stability to the greatest possible extent. The most effective means of maintaining cultures in this way is by storing them in liquid nitrogen.

iii. **Characterization of monosporous mycelia-** If monosporous mycelia (i.e. mycelia derived from single spore) are to be used in recombination experiments, their mating types must be known. Mating types are determined by the determination of compatible or non-compatible reactions when different monosporous mycelia are confronted in pairs.

iv. **Selection of recombinants-** Since the gaol of a breeding programme is to bring together genes controlling characteristics that are desirable in commercial mushroom production. The selection of recombinants from the mating between different strains, each of which has certain desirable trails, is a reasonable approach. Certain techniques are available to facilitate the selection of recombinants.

Desirable traits for which the mushroom breeder may wish to select mutants usually include such things like taste, colour, nutritive value, odour, temperature, tolerance for both mycelia growth and fruiting, yield, a shortened time from spawning to cropping and disease resistance.

Conventional Breeding Methods

1. **Introduction**

Introduction of improved mushroom cultivars of a country may be introduced in another country is the easiest and quickest method of crop improvement.

Introduction provides opportunity for isolation and selection of superior types as genetic base for future breeding programmes.

However extensive care should be exercised to prevent the introduction of new pests and pathogens that may result with the introduction of such improved mushroom strains.

The Introduced cultivars of Button Mushroom are;

Agaricus bisporus – S-11 (Germany), S-310 (USA), S-791 (UK), Horst UI (Holland), Horst U3 (Holland)

Agaricus bitorquis – NCB-1(K-32)- Holland, NCB-2 (K-26) – Holland, NCB-6 (RAB-50) – USA, NCB-13 (PDAB-55) – USA.

2. **Selection**

i. Clonal Selection

Isolating tissue (explants) from an exceptionally high-quality wild or cultivated fruiting body to establish a pure culture. This fixes the existing genetic combination but does not generate new genetic variation.

ii. Single spore selection

Single-spore selection is highly effective in pseudo-homothallic *Agaricus bisporus*. Breeders isolate rare single, trinucleate, or tetra nucleate spores that yield monokaryons or unique dikaryons, screening them for specific cap colours or firmness.

iii. Multi spore selection

Multi-spore selection involves germinating mass spores together, which allows for natural recombination and re-pairing, followed by screening for robust, high-yielding lines.

3. **Hybridization**

It is one of the more efficient methods of creating variability by combining desirable

traits from genetically diverse strains into a new heterokaryon. It usually involves mating of self-sterile and compatible homokaryotic lines.

Development of hybrids may consist of;

Selection of parental lines,
↓
Isolation of homokaryons,
↓
Identification of hybrids and
↓
Evaluation of hybrids.

Identification of hybrids – In Button Mushroom, *A. bisporus & A. bitorquis,* the hybrids may be recognized by the different tests such as;

- Fructification tests,
- Autotrophic markers,
- Allozyme markers,
- DNA markers (RFLP & RAPD).

Non-conventional/ Advanced breeding methods

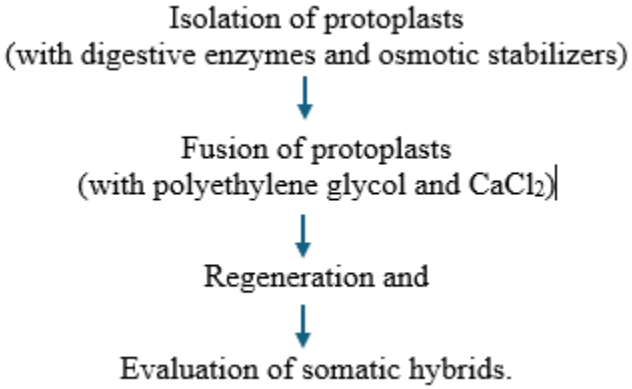
1. Mutation Breeding

Mutagenesis is attempted to create new variability required for selection and hybridization programme. Exposing mycelia or spores to physical mutagens (like UV rays, Gamma rays) or chemical mutagens (like Ethyl Methyl Sulfonate) to induce random nucleotide alterations.

Mutation breeding is successfully employed to isolate non-browning strains of *Agaricus bisporus* by disabling or downregulating the specific genes encoding polyphenol oxidases, resulting in mushrooms that stay white longer after harvest.

2. Protoplast fusion

When two highly desirable mushroom species are sexually incompatible (inter-specific or inter-generic barriers), protoplast fusion bypasses the restriction. Transfer of genes through using protoplasts is a non-conventional method used to breakdown the natural barrier of gene exchange encountered in conventional breeding system. This technology involves different steps such as;



Now, the fusion of protoplasts can be achieved by using electric pulsation (electro fusion). Protoplasts of two strains are mixed and subjected to a high frequency alternating current because of which protoplasts are charged. These are now attracted to each other and make firm contact with each other. There after actual fusion takes place under direct current pulses.

3. Genetic engineering

It involves the isolation, cloning and insertion of desirable genes into the genome of the targeted mushroom strain. Successful exploitation of transgenic mushroom usually depends upon the integration and constitutive expression if engineered genes in the mushroom chromosomes.

Besides all above mentioned techniques, Marker assisted selection (MAS), Back crossing strategy and use of quantitative trait loci have also been suggested.

Mushroom Species	Primary quality breeding targets	Specific breeding approach used
Button Mushroom (*Agaricus bisporus*)	Pure white colour, delayed veil opening, high dry matter, resistance to *Trichoderma* (Green Mould).	Single-spore selection from rare uninucleate spores; Marker-Assisted Selection; CRISPR for PPO knockout.
Oyster Mushroom (*Pleurotus* spp.)	Firm texture (reducing fragility), rich spore less or low-spore strains (to protect growers from spore allergies/mushroom worker's lung)	Hybridization of compatible monokaryons; Protoplast fusion; UV mutation for spore less mutants.
Shiitake Mushroom (*Lentinula edodes*)	Dark, thick, highly cracked cap patterns (Donko type), high lentinan (β-glucan) content, rapid substrate colonization.	Tetrapolar hybridization; Di-mon mating (Buller phenomenon); Clonal selection of wild robust strains.

Paddy Straw Mushroom (*Volvariella volvacea*)	Extended shelf life (normally liquefies within 24–48 hours), low-temperature tolerance (chilling resistance).	Protoplast fusion with temperate strains; Chemical mutagenesis for cell-wall stability.

Mushroom varieties / strains released from TNAU / India for commercial cultivation

Scientific Name	Variety / Strain	Year of Release	Scientists responsible
Oyster mushroom			
Pleurotus sajor caju	M 2	1983	Jandaik *et al.*, 1975 Bano *et al.*, 1965
P. florida	Pf CO 1	1983	Sivaprakasam *et al.*,1986 Marimuthu *et al.*, 1990
P. citrinopileatus	Pp APK 1	1986	Muthusamy *et al.*, 2000
P. platypus		1990	Geetha *et al.*, 1996
P. eous *(= P. salmoneo stramineus)*	MDU 1 MDU 2 Ooty 1 CO (OM)2	2000	Sivaprakasam *et al.*,2000 Mohan *et al.*, 1995 Krishnamoorthy *et al.*, 2004 Ramamoorthy et al., 2024
P. djamor	KKM 1	1996	
P. flabellatus		2000	
P. ostreatus		1995	
Hypsizygus ulmarius P. djamor		2004 2024	
Milky mushroom			
Calocybe indica	APK 2	1998	Krishnamoorthy *et al.*, 1998
Tricholoma giganteum	CO(TG) 3	2012	Prakasam *et al.*, 2012

Button mushroom			
Agaricus bisporus	AB1 (Ooty1)	1998	Mohan *et al.*, 1998
Agaricus bisporus	AB1 (Ooty2)	2005	Ramaraj *et al.*,2005

Conclusion

The commercial mushroom industry relies heavily on systematic strain development to reverse genetic degeneration and protect crop stability. By integrating conventional methods like single-spore selection with advanced techniques like protoplast fusion and genetic engineering, breeders can precisely target essential market traits. These include enhancing post-harvest shelf life, eliminating enzymatic browning, and boosting nutritional value across major species like Button, Oyster, and Shiitake mushrooms. Ultimately, securing the future of global cultivation requires combining these advanced breeding toolkits with rigorous quality control and strict culture preservation techniques in spawn laboratories.

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Volume: 06 Issue No: 07

SPATIO-TEMPORAL ANALYSIS OF LONG-TERM DROUGHT USING THE STANDARDIZED PRECIPITATION INDEX (SPI) IN SELECTED AGRO-CLIMATIC DISTRICTS OF TAMIL NADU

Article ID: AG-VO6-I07-115

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Abstract

Drought is a recurring climatic hazard that severely affects agriculture, water resources, and rural livelihoods in semi-arid regions such as Tamil Nadu. This study evaluates long-term drought variability across five districts of Tamil Nadu — Dharmapuri, The Nilgiris, Tiruchirappalli, Tirunelveli, and Ramanathapuram covering the plateau, hilly, delta, southern, and coastal agro-climatic zones of the state, using the 36-month Standardized Precipitation Index (SPI-36) computed for the period 1983–2025 from five long-term rainfall monitoring locations. Gridded precipitation data were obtained from the Climate Engine platform, and annual SPI values were classified into standard McKee drought categories, mapped spatially using Inverse Distance Weighting (IDW) interpolation in a GIS environment, and analysed for spatial distribution, temporal trend, district-wise severity, and time-series behaviour. Results reveal a pronounced multi-year drought spell through the 1980s and early 1990s affecting all five districts simultaneously, with Ramanathapuram recording the most extreme deficit (SPI = -2.50 in 1988) and Tiruchirappalli showing the highest overall drought frequency (25.6% of years in drought). A statistically significant increasing (wetting) trend was observed across all districts from the mid-1990s onward, indicating a shift toward more favourable moisture conditions in recent decades, although short dry spells persisted intermittently. The findings provide a spatio-

temporal baseline for drought risk assessment, water resource planning, and climate-resilient agricultural advisory in the study districts.

***Keywords*:** Standardized Precipitation Index (SPI); Drought Severity; Spatio-temporal Analysis; Tamil Nadu; Agro-climatic Zones; GIS; IDW Interpolation.

Introduction

Drought is among the most complex and least understood natural hazards, arising from a sustained deficiency of precipitation relative to the long-term average of a region. Unlike other natural disasters, drought develops slowly, has no distinct onset, and its impacts on crop yields, groundwater levels, reservoir storage, and rural economies often become apparent only after considerable damage has occurred (Mishra & Singh, 2010). Tamil Nadu, located in the rain-shadow region of the Western Ghats and heavily dependent on the North-East and South-West monsoons, is particularly vulnerable to recurrent meteorological drought, especially in its interior plateau and rain-shadow districts.

Among the various drought indices developed for quantifying moisture deficits, the Standardized Precipitation Index (SPI), proposed by McKee *et al*. (1993) and further described by Edwards and McKee (1997), remains the most widely adopted due to its simplicity, requirement of only precipitation data, and flexibility across multiple timescales (3, 6, 12, 24, and 36 months). The World Meteorological Organization (WMO) has formally recommended SPI as the reference index for meteorological drought monitoring worldwide (WMO, 2012). The index standardizes precipitation anomalies fitted to a Gamma probability distribution. (Thom, 1958) into a standard normal distribution, allowing comparison of drought severity across regions with different climatic regimes. Longer timescales such as SPI-36 are particularly useful for identifying prolonged, multi-year hydrological and agricultural drought conditions that affect groundwater recharge, reservoir storage, and long-duration crops (Guttman, 1999).

A growing body of literature has applied SPI to Indian and Tamil Nadu conditions specifically. Studies in the Southern Agro-Climatic Zone of Tamil Nadu have used SPI to quantify rainfall-deficit frequency and its impact on crop failure (Agro Climate Research Centre, TNAU, Coimbatore), while more recent work has combined SPI with the Standardized Precipitation Evapotranspiration Index (SPEI)- Vicente Serrano, et al. (2010) and vegetation indices to improve drought monitoring across Tamil Nadu's districts (drought monitoring studies using SPEI, Tamil Nadu Agricultural University). Comparative evaluations of composite

drought indices in Tamil Nadu districts such as Chengalpattu have similarly confirmed SPI's utility relative to the Decile Indicator, Effective Drought Index, and Rainfall Anomaly Index. Nationally, Pandey *et al*. (2024) assessed the suitability of the McKee classification scheme across 36 meteorological subdivisions of India, underscoring the need for regionally validated drought thresholds.

This study aims to (i) compute and classify long-term (1983–2025) SPI-36 values for five districts spanning distinct agro-climatic zones of Tamil Nadu using Climate Engine-derived precipitation data, (ii) map the spatial distribution of drought severity across the associated Districts and Taluks for the eight most drought-affected years using IDW interpolation, and (iii) assess temporal, district-wise, and time-series trends to determine whether drought conditions have intensified or ameliorated over the last four decades. The outcomes are intended to support district-level drought preparedness and inform agricultural and water-resource planning.

Study Area

The present study focuses on five administrative districts of Tamil Nadu, selected to represent the State's principal agro-climatic zones: (i) Dharmapuri district (4 Taluks: Dharmapuri, Palakkodu, Pennagaram, Harur) in the northern plateau zone; (ii) The Nilgiris district (4 Taluks: Udagamandalam, Gudalur, Kotagiri, Coonoor) representing the high-altitude hilly zone; (iii) Tiruchirappalli district (5 Taluks: Tiruchchirappalli, Musiri, Lalgudi, Turaiyur, Manapparai) in the Cauvery delta-fringe zone; (iv) Tirunelveli district (5 Taluks: Tirunelveli, Palayankottai, Ambasamudram, Nanguneri, Radhapuram) in the southern agro-climatic zone; and (v) Ramanathapuram district (5 Taluks: Ramanathapuram, Paramakkudi, Kamudi, Tiruvadanai, Rameswaram) in the coastal, rain-shadow south-eastern zone.

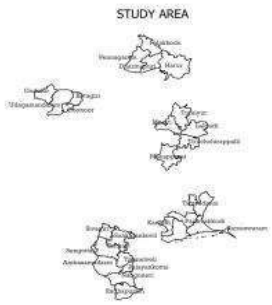


Figure 1. Study area showing the five districts (five representative rainfall stations) selected for SPI-based drought analysis.

Materials and Methods

Data Sourse

Precipitation data for the period 1983–2025 were obtained from the Climate Engine platform (climateengine.org), a cloud-based application built on Google Earth Engine that provides on-demand access to gridded climate and remote-sensing datasets for environmental and drought monitoring (Huntington et al., 2017). Gridded monthly rainfall values were extracted for five representative monitoring locations corresponding to the five districts described in Section 2, yielding a 43-year annual SPI-36 record for each district.

Spi Computation

The Standardized Precipitation Index was computed following the method of McKee et al. (1993), in which the long-term precipitation record for a given timescale is fitted to a Gamma probability distribution (Thom, 1958) and subsequently transformed to a standard normal distribution with a mean of zero and standard deviation of one. This study uses the 36-month SPI (SPI-36), which reflects long-term precipitation deficits or surpluses relevant to reservoir storage, groundwater recharge, and multi-year agricultural planning, and is well suited to detecting sustained drought episodes rather than short-term dry spells. Computed SPI values were classified into seven standard categories: Extreme Drought (SPI ≤ -2.0), Severe Drought (-1.99 to -1.5), Moderate Drought (-1.49 to -1.0), Near Normal (-0.99 to 0.99), Moderately Wet (1.0 to 1.49), Very Wet (1.5 to 1.99), and Extremely Wet (≥ 2.0).

Spatial Interpolation and Mapping

Annual SPI-36 point values at the five stations were spatially interpolated across the corresponding taluk-level administrative boundaries using the Inverse Distance Weighting (IDW) method, a deterministic interpolation technique in which the estimated value at an unsampled location is a distance-weighted average of surrounding known values, with nearer points exerting proportionally greater influence (Shepard, 1968). IDW was selected for its simplicity, computational efficiency, and its established suitability for interpolating rainfall and drought-index surfaces from sparse station networks (Chen & Liu, 2012). Interpolated surfaces were classified using a standardized seven-class colour scheme and rendered as drought severity maps in QGIS.

Trend and Time-Series Analysis

Temporal trends at each station were assessed using linear regression of annual SPI-36

values against year, with statistical significance evaluated at the 95% confidence level. Decadal mean SPI values were computed to characterize inter-decadal variability, and the full 1983–2025 time series was plotted for all five stations to visualize drought and pluvial phases. District-wise severity was compared using the frequency distribution of SPI categories, and the eight most severely drought-affected years in the record (1984, 1986, 1987, 1988, 1989, 1990, 1991, and 1992) were mapped individually to characterize the spatial evolution of the 1980s–early-1990s drought episode.

Results

Spatial Variation of Drought Severity

The IDW-interpolated drought severity maps for the eight most affected years (1984–1992) reveal that drought impact in Tamil Nadu during this period was not spatially uniform but consistently centered on the Ramanathapuram coastal district, which recorded the deepest deficits in five of the eight mapped years (Table 4). In 1988, Ramanathapuram alone fell into the Extreme Drought category (SPI = -2.50) while the Nilgiris and Tirunelveli districts remained in the milder Near-Normal-to - Moderate range, illustrating the marked spatial heterogeneity that can exist even within a single drought year. By contrast, years such as 1986 and 1990 show a more spatially widespread but less intense pattern, with three to four districts simultaneously registering moderate drought.

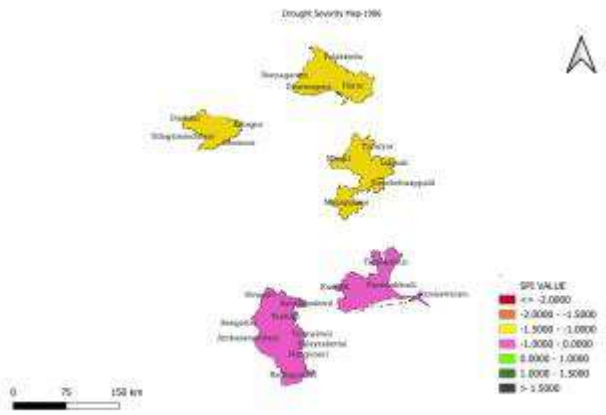


Fig. 2.: Drought severity distribution in 1984 — Nilgiris records the deepest deficit (Severe, SPI = - 1.60).

Fig. 3.: Drought severity distribution in 1986 - widespread moderate drought across the northern, hilly, and delta-fringe districts.

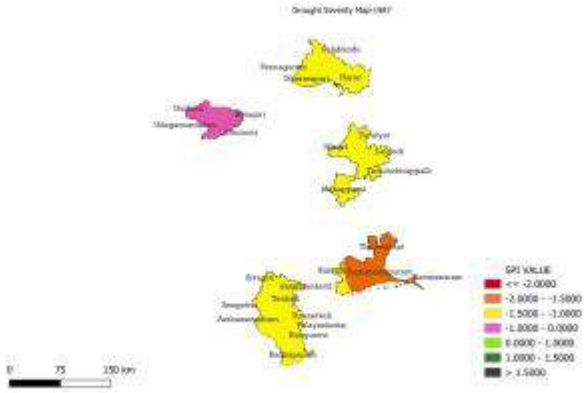


Fig. 4.: Drought severity distribution in 1987 - Ramanathapuram enters severe drought while other districts remain moderate.

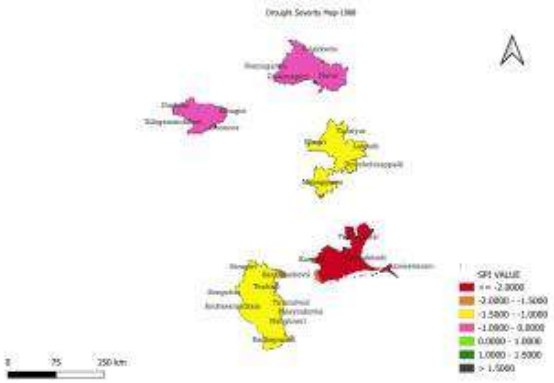


Fig. 5.: Drought severity distribution, 1988 - the most extreme single-year event recorded (Ramanathapuram, SPI = -2.50).

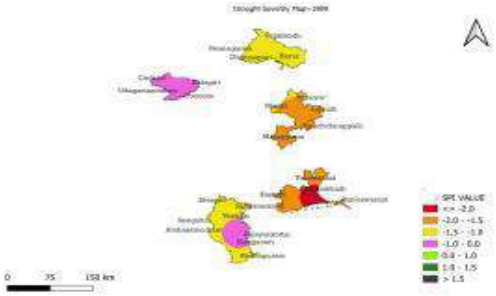


Fig. 6.: Drought severity distribution in 1989 - Ramanathapuram remains in the extreme category; Trichy district reaches Severe.

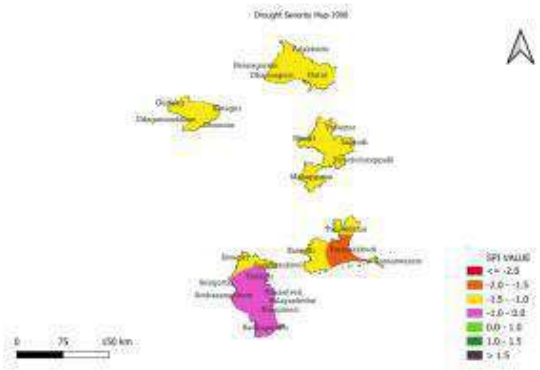


Fig. 7.: Drought severity distribution in 1990 - partial recovery in the northern and hilly districts; persistent severe drought in the Ramanathapuram-Paramakkudi Taluk.

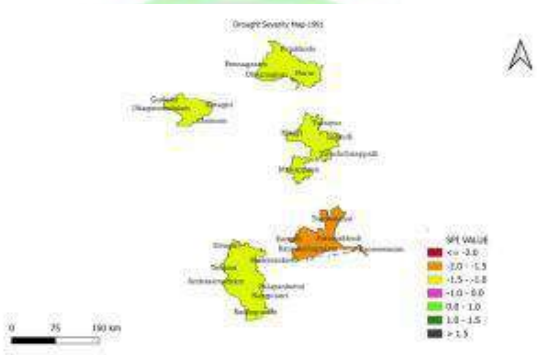


Fig. 8:. Drought severity distribution in 1991 - Ramanathapuram district severe; remaining districts moderate.

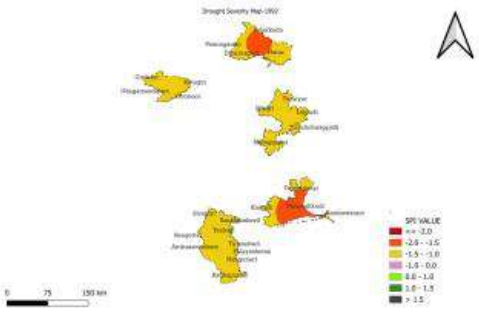


Fig. 9.: Drought severity distribution, 1992 — Dharmapuri records its most severe year on record alongside continued severe conditions in Ramanathapuram.

Table 1: Summary of the eight most drought-affected years, 1984–1992.

Station (District)	Mean SPI (1983–2025)	Trend slope (SPI/decade)	% Years in Drought (≤ -1)	Most Severe Year	Minimum SPI Value
Dharmapuri	-0.001	+0.524	20.9	1992	-1.52
Nilgiris	-0.002	+0.257	20.9	1984	-1.60
Trichy (Tiruchirappalli)	-0.025	+0.556	25.6	1989	-1.67
Tirunelveli	-0.001	+0.620	16.3	1983	-1.48
Ramanathapuram	0.001	+0.440	16.3	1988	-2.50

Table 2: Station-wise SPI-36 summary statistics, 1983–2025.

Year	District(s) Most Severely Affected	Peak SPI Category	Peak SPI Value	Approx. Spatial Extent
1984	Nilgiris	Severe	-1.60	1 of 5 districts (Severe); rest Moderate/Near-Normal
1986	Nilgiris, Dharmapuri, Trichy	Moderate	-1.10	3 of 5 districts in Moderate class
1987	Ramanathapuram	Severe	-1.61	4 of 5 districts in Moderate–Severe class
1988	Ramanathapuram	Extreme	-2.50	Most severe single event in the record
1989	Ramanathapuram	Extreme	-2.06	Ramanathapuram Extreme; Trichy Severe
1990	Ramanathapuram	Severe	-1.55	Ramanathapuram–Paramakkudi Taluk Severe
1991	Ramanathapuram	Severe	-1.75	Ramanathapuram district

Trichy (Tiruchirappalli)	-0.025	+0.556	25.6	1989	-1.67
Tirunelveli	-0.001	+0.620	16.3	1983	-1.48
Ramanathapuram	0.001	+0.440	16.3	1988	-2.50

				Severe; others Moderate
1992	Dharmapuri, Ramanathapuram	Severe	-1.56	Dharmapuri and Ramanathapuram cores Severe

Temporal Variation

The Table 2 summarizes the long-term SPI-36 statistics for the five stations over 1983–2025. All stations show a near-zero long-term mean SPI, as expected for a standardized index, but differ considerably in drought frequency and intensity. Trichy recorded the highest proportion of drought years (25.6%), followed closely by Dharmapuri and Nilgiris (20.9% each), while Tirunelveli and Ramanathapuram recorded comparatively fewer drought years (16.3% each). Notably, Ramanathapuram despite having fewer drought years overall experienced the single most extreme deficit in the entire record (SPI = -2.50 in 1988), highlighting its susceptibility to episodic but intense drought events typical of coastal rain-shadow climates. Linear trend analysis confirms a statistically significant increasing (wetting) trend at all five stations ($p < 0.05$), with the strongest wetting trend at Tirunelveli (+0.62 SPI per decade) and the weakest, though still significant, at Nilgiris (+0.26 SPI per decade).

District-wise Analysis

The Table 3 presents the frequency distribution of SPI categories at each district. Ramanathapuram is the only district to register extreme drought years (2 occurrences) within the record, consistent with its exposure to failed North-East monsoons, and it also recorded the highest number of severe drought years (5). Trichy and Dharmapuri show the highest counts of moderate drought years (10 and 8 respectively), reflecting more frequent but less intense moisture deficits typical of interior plateau and delta-fringe climates. Tirunelveli, in contrast, recorded no severe or extreme years across the 43-year record, indicating comparatively greater climatic buffering, likely associated with its dual exposure to both South-West and North-East monsoon rainfall.

Table 3: Frequency (number of years) of SPI drought/wet categories by district, 1983–2025.

District	Extreme (≤-2.0)	Severe (-1.99 to -1.5)	Moderate (-1.49 to -1.0)	Near Normal (-0.99 to 0.99)	Moderately Wet to Extremely Wet (≥1.0)
Dharmapuri	0	1	8	23	11
Nilgiris	0	3	6	25	9
Trichy	0	1	10	23	9
Tirunelveli	0	0	7	25	11
Ramanathapuram	2	5	0	28	8

Time-Series Analysis

The annual SPI-36 time series (Fig.10) shows a clearly defined negative (dry) phase from 1983 to the mid-1990s across all five stations, followed by a progressive shift toward positive (wet) SPI values from the late 1990s onward, with a temporary reversal toward drier conditions between approximately 2014 and 2018. The decadal mean values shown in Table 4 confirm this pattern quantitatively in all stations recorded negative decadal means in the 1980s (ranging from -1.15 to -1.01) and the 1990s (ranging from -0.85 to -0.18), transitioning to positive decadal means from the 2000s onward, with all five stations recording their highest decadal mean SPI in the 2020s (range: +0.29 to +1.28, based on 2020-2025 data.

*Table 3. Decade-wise mean SPI-36 by district (*2020s based on 2020–2025 data only*

Decade	Dharmapuri	Nilgiris	Trichy	Tirunelveli	Ramanathapuram
1980s	-1.04	-1.02	-1.15	-1.07	-1.01
1990s	-0.79	-0.18	-0.85	-0.67	-0.50
2000s	+0.69	+0.85	+0.55	+0.23	+0.51
2010s	+0.27	-0.13	+0.47	+0.42	+0.16
2020s*	+0.93	+0.29	+0.87	+1.28	+0.89

Despite the overall ameliorating long-term trend, short-duration dry episodes recurred intermittently in the recent record (e.g., 2016–2018 across most stations and a brief dip in the Nilgiris around 2010–2011), underscoring that a positive long-term trend does not eliminate the risk of future drought years.

Conclusion

This study analysed long-term (1983–2025) SPI-36 based drought variability across five agro-climatically distinct districts of Tamil Nadu using Climate Engine-derived precipitation data and IDW-interpolated drought severity maps. The results show that the 1980s and early 1990s constituted a sustained, spatially widespread drought phase,with Ramanathapuram experiencing the most extreme single-year deficit (SPI = -2.50, 1988) and Tiruchirappalli showing the highest overall drought frequency (25.6% of years). A statistically significant increasing (wetting) trend was detected at all five districts from the mid-1990s onward, though short dry spells continued to recur intermittently. These findings establish a spatio-temporal drought baseline that can inform district-level water resource management, drought contingency planning, and climate-resilient agricultural advisory across Tamil Nadu's diverse agro-climatic zones. Future work incorporating shorter SPI timescales (SPI-3, SPI-6), the Standardized Precipitation Evapotranspiration Index (SPEI), soil moisture data, and climate model projections would further strengthen drought early-warning capability in the region.

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AQUATIC WEED HARVESTING FOR IRRIGATION CANALS AND AGRICULTURAL DRAINAGE: A SUSTAINABLE SOLUTION FOR EFFICIENT WATER MANAGEMENT

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Introduction

Water is one of the most precious natural resources supporting agriculture, ecosystems, and rural livelihoods. In India, millions of hectares of agricultural land depend on irrigation canals, distributaries, field channels, tanks, reservoirs, and agricultural drainage systems for crop production. However, these water bodies are increasingly threatened by the rapid spread of aquatic weeds. Excessive weed growth obstructs water movement, reduces irrigation efficiency, increases maintenance costs, degrades water quality, and affects agricultural productivity. The problem has become more severe due to nutrient enrichment, climate change, reduced water flow, and improper maintenance of canal systems.

Aquatic weed harvesting has emerged as an environmentally sustainable and economically viable solution for managing invasive aquatic vegetation. Unlike chemical herbicides that may contaminate irrigation water or biological methods that require long periods for effectiveness, mechanical harvesting provides immediate removal of unwanted vegetation while preserving water quality. Modern aquatic weed harvesters can efficiently remove large quantities of floating, submerged, and emergent weeds, ensuring uninterrupted water delivery to farms and improving the overall efficiency of irrigation infrastructure.

Understanding Aquatic Weeds

Aquatic weeds are plants that grow partially or completely in water and often proliferate rapidly under favorable environmental conditions. While some aquatic plants play beneficial ecological roles by providing habitat for aquatic organisms and improving water quality, excessive growth becomes problematic. Nutrient-rich irrigation canals and drainage channels provide ideal conditions for the multiplication of invasive aquatic weeds.

The most troublesome aquatic weeds found in Indian irrigation systems include water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), duckweed (*Lemna* spp.), hydrilla (*Hydrilla verticillata*), coontail (*Ceratophyllum demersum*), salvinia (*Salvinia molesta*), alligator weed (*Alternanthera philoxeroides*), and cattails (*Typha* spp.). Among these, water hyacinth is considered one of the world's most invasive aquatic plants because of its extraordinary reproductive capacity. Under favorable conditions, its population can double within two weeks, quickly covering entire water surfaces.

The dense mats formed by aquatic weeds significantly reduce water conveyance efficiency, increase evaporation losses, restrict sunlight penetration, decrease dissolved oxygen levels, and create breeding grounds for mosquitoes and disease vectors. In agricultural drainage channels, weed infestation slows water removal from fields, leading to waterlogging, delayed planting, and reduced crop yields.

Why Irrigation Canals Need Regular Weed Harvesting

Efficient irrigation depends on the smooth movement of water from reservoirs to agricultural fields. Aquatic weeds reduce the carrying capacity of canals by narrowing the effective waterway and increasing hydraulic resistance. Even moderate weed infestations can reduce water flow by 30–60%, while severe infestations may almost completely block smaller distributaries. Blocked canals result in unequal water distribution among farmers. Head-reach farmers may receive adequate water, whereas tail-end farmers experience shortages, leading to conflicts over irrigation scheduling. Reduced water flow also increases seepage losses and sediment deposition, further reducing canal efficiency.

Agricultural drainage systems face similar challenges. Poor drainage caused by excessive weed growth prolongs water stagnation after rainfall or irrigation. Waterlogged soils reduce root respiration, limit nutrient uptake, increase disease incidence, and negatively affect crop growth. Timely harvesting of aquatic weeds therefore plays a crucial role in maintaining both irrigation and drainage efficiency.

Mechanical Aquatic Weed Harvesting Technology

Mechanical aquatic weed harvesting is an advanced technique designed to remove excessive vegetation directly from water bodies. Modern aquatic weed harvesters function similarly to floating mowing machines. They cut, collect, transport, and unload aquatic vegetation in a single operation.

A typical aquatic weed harvester consists of a floating platform, propulsion system, conveyor belt, horizontal cutter bar, vertical side cutters, onboard storage compartment, hydraulic lifting mechanism, operator cabin, and unloading conveyor. The machine moves slowly through the water while submerged cutting blades shear aquatic plants. The conveyor system lifts the cut vegetation onto the storage deck. Once fully loaded, the harvester transports the biomass to the shore for unloading and further utilization.

Depending on the size of irrigation canals and reservoirs, harvesters are available in compact, medium, and large models. Small harvesters are suitable for village ponds and narrow irrigation channels, whereas large self-propelled harvesters are capable of removing several tonnes of biomass per hour from reservoirs, lakes, and major canal networks. Technological improvements have introduced GPS-assisted navigation, hydraulic depth control, energy-efficient engines, remote monitoring systems, and automated biomass unloading mechanisms. These innovations improve operational efficiency while reducing fuel consumption and labor requirements.

Advantages of Mechanical Weed Harvesting

Mechanical harvesting offers several advantages over chemical and biological weed control methods. The most significant benefit is the immediate restoration of water flow. As weeds are physically removed rather than merely killed, there is no decomposition within the canal that could reduce dissolved oxygen or release nutrients back into the water. Harvesting also removes nutrients stored within plant tissues, particularly nitrogen and phosphorus. This nutrient export helps reduce eutrophication and limits future weed growth. Because no herbicides are used, irrigation water remains safe for agricultural use, livestock, fisheries, and domestic applications.

Another important advantage is the selective nature of harvesting. Operators can remove invasive weeds while leaving desirable aquatic vegetation intact where necessary for ecological balance. Mechanical harvesting also minimizes risks to fish, beneficial insects, and aquatic biodiversity when conducted properly. From an economic perspective, harvested biomass represents a valuable renewable resource rather than waste. This biomass can be converted into compost, vermicompost, biogas, biochar, organic manure, livestock bedding, handicraft materials, mushroom substrate, and renewable energy feedstock, creating additional income opportunities for rural communities.

Harvesting Different Types of Aquatic Weeds

Floating weeds such as water hyacinth, water lettuce, and duckweed are relatively easy to harvest because they remain on the water surface. Conveyor-equipped harvesters efficiently collect these plants with minimal sediment disturbance. Submerged weeds including hydrilla and coontail require adjustable underwater cutting systems capable of operating below the water surface. These weeds must be completely removed to prevent regrowth from remaining plant fragments.

Emergent weeds such as cattails, reeds, and bulrushes require stronger cutting mechanisms because of their tougher stems. Periodic harvesting prevents excessive encroachment into irrigation channels while maintaining structural stability of canal banks. Integrated harvesting schedules based on weed species, growth stage, and seasonal climate conditions maximize operational efficiency and reduce overall management costs.

Aquatic Weed Harvesting in Agricultural Drainage Systems

Agricultural drainage channels play an essential role in removing excess water from cultivated fields. During monsoon seasons, drainage systems must function efficiently to prevent flooding and prolonged waterlogging. Unfortunately, weed infestation often reduces drainage capacity precisely when maximum flow is required.

Mechanical harvesting before the onset of monsoon ensures unrestricted drainage. Regular maintenance also reduces sediment accumulation, prevents blockage of culverts and sluice gates, and improves the overall resilience of agricultural infrastructure. Improved drainage directly contributes to healthier crop growth, earlier field operations, better soil aeration, increased fertilizer use efficiency, and higher farm productivity.

Environmental Benefits

Mechanical aquatic weed harvesting contributes significantly to environmental conservation. By removing excessive vegetation, harvesting restores aquatic ecosystem balance, improves oxygen exchange, enhances sunlight penetration, and supports fish populations. Removal of nutrient-rich biomass decreases phosphorus and nitrogen loading, thereby reducing algal blooms and improving overall water quality. Improved water circulation also reduces mosquito breeding habitats, contributing to better public health in rural communities.

Harvesting helps maintain biodiversity by preventing invasive weeds from replacing native aquatic plant communities. Healthy aquatic ecosystems support birds, amphibians,

beneficial insects, and numerous aquatic organisms that contribute to ecological stability. In addition, converting harvested weeds into compost or renewable energy supports circular economy principles and reduces greenhouse gas emissions associated with open burning or uncontrolled decomposition.

Utilization of Harvested Aquatic Weed Biomass

One of the most attractive aspects of aquatic weed harvesting is the productive utilization of removed biomass. Water hyacinth and several other aquatic weeds possess high organic matter content, making them suitable for compost production. After proper decomposition, compost improves soil organic carbon, water-holding capacity, microbial activity, and nutrient availability. Vermicomposting converts harvested weeds into high-quality organic fertilizer rich in plant nutrients and beneficial microorganisms. Some aquatic weeds also serve as feedstock for anaerobic digestion, producing biogas for cooking, electricity generation, and rural energy applications.

Research has demonstrated the suitability of aquatic weeds for biochar production, paper manufacturing, handicrafts, animal bedding, mushroom cultivation, phytoremediation, and wastewater treatment materials. These value-added applications transform weed management from a maintenance expense into a potential income-generating enterprise.

Smart Technologies in Aquatic Weed Harvesting

The integration of digital technologies is revolutionizing aquatic weed management. Drones equipped with multispectral cameras can rapidly identify weed-infested areas and estimate weed coverage before harvesting operations begin. Satellite imagery enables seasonal monitoring of large irrigation networks and reservoirs. Artificial Intelligence (AI) algorithms can classify weed species, predict infestation patterns, and optimize harvesting schedules. Internet of Things (IoT)-based water level sensors continuously monitor canal performance and detect flow restrictions caused by weed growth.

GPS-guided autonomous harvesters improve operational accuracy while minimizing fuel consumption. Cloud-based management platforms enable irrigation authorities to coordinate harvesting operations across extensive canal networks using real-time field data. Future robotic weed harvesters may operate autonomously with minimal human intervention, significantly reducing operational costs while improving harvesting precision.

Challenges and Future Prospects

Despite its many advantages, aquatic weed harvesting faces several challenges. High initial investment costs, limited availability of specialized harvesting equipment, inadequate operator training, seasonal weed growth patterns, and disposal logistics remain important constraints, particularly in developing countries. Future research should focus on designing lightweight, energy-efficient harvesters suitable for narrow irrigation canals, improving autonomous navigation systems, developing electric and solar-powered harvesters, and creating decentralized biomass processing units near harvesting locations.

Public-private partnerships, government support programs, farmer cooperatives, and community participation can accelerate adoption of mechanized aquatic weed harvesting across India's irrigation systems. Integration of harvesting with watershed management, precision irrigation, nutrient management, and renewable energy production will maximize environmental and economic benefits.

Conclusion

Aquatic weed harvesting has become an indispensable component of sustainable irrigation and drainage management. Mechanical harvesting provides rapid, environmentally friendly, and highly effective removal of invasive aquatic vegetation while maintaining water quality and protecting aquatic ecosystems. Regular harvesting restores canal efficiency, improves irrigation reliability, enhances agricultural productivity, reduces maintenance costs, and supports climate-resilient water resource management.

The productive utilization of harvested biomass through composting, bioenergy, vermicomposting, and other value-added applications further strengthens the economic viability of this approach. With continued technological innovation involving artificial intelligence, drones, remote sensing, GPS guidance, and autonomous harvesting systems, aquatic weed management is entering a new era of smart and sustainable water resource management. Adoption of these technologies will help ensure reliable irrigation, efficient drainage, improved crop production, and healthier aquatic ecosystems for future generations.

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MECHANIZED PADDY TRANSPLANTING - BOON FOR THE SMALL AND MARGINAL FARMERS OF ANDHRA PRADESH

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Abstract

Rice is an important staple food crop for about half of the people who lives in the world. Because of several reasons i.e., labor shortage, climate risk, market price fluctuations, increased cost of production and stabilized yields etc., rice area in the country decreasing continuously. In this context, there is an immense need to increase the area under rice crop with less man power. Hence, popularization of MSRI planting technology in rice was demonstrated by the Krishi Vigyan Kendra, Srikakulam under Front Line Demonstrations, Skill training programmes and Demonstartions in the farmer fields. As part of the FLD, comparison was made between MSRI planting and manual planting. This trial carried out for three years form 2022 and 2024 during *kharif*. The results reveled that, the maximum no of productive tillers (16, 20 & 22 per hill) and yield (6000, 6975 &7832 kg ha^{-1}) were recorded with the MSRI planting when compared to the Manual planting method (11, 13 &14 productive tillers per hill and 5600, 6252 & 6324 kg ha^{-1}) respectively in the three years of the study. In economics also MSRI planting recorded less cost of cultivation (Rs. 52570, Rs.55875 and Rs. 54783 ha^{-1}), higher net returns (Rs. 69500, Rs. 92981 & Rs.125200 ha^{-1}) and B:C ratio (2.3:1, 2.66:1 & 3.2:1) respectively, when compared to the manual planting in the three years of the trial.

Key Words: Rice, Machine planting, labour scarcity, Yield, Economics.

Introduction

In India, rice is grown in an area of 43.90 million hectares with a production of 114.45 million tonnes and productivity of 2.6 t ha^{-1}. In Andhra Pradesh, it is grown in an area of 2.25

million hectares with a production of 7.79 million tonnes and productivity of 3.4 t ha^{-1} (Agricultural Statistics at a Glance 2022, Ministry of Agriculture & Farmers Welfare, Govt of India). Andhra Pradesh contributes to 4.84 per cent of total area and 5.98 percent to total rice production in India. For transplanting of rice crop requires nearly 25% of the labor for irrigated rice production.

Though the rice is prime staple crop to the world's population, due to several reasons area under paddy cultivation decreasing with increasing rate. Due to timely labour availability is a major constraint to the farmer, high cost of cultivation. To resolve the above said crises, Krishi Vigya Kendra, Srikakulam taken one impactful intervention in paddy cultivation viz., Mechanized System of Rice Intensification (MSRI). By introduction of MSRI planting with the help of four row and six row MSRI planters in the farmers fields they are very much happy to realize high yields in the district.

Implementing the Technology:

Krishi Vigyan Kendra Srikakulam, conducted Front Line Demonstrations (FLD) on Paddy mechanization with MSRI was conducted three years during *kharif* from 2022-2024 in the farmers fields in 5 clusters in 10 locations across the Srikakulam district. The soils of the trail were clay loam in texture, low in available nitrogen, medium in phosphorus, potassium and low in organic carbon.

Treatment Details:

T1: Paddy transplanting with MSRI Planter

T2 : Manual transplanting.

Each treatments was imposed in 0.4 ha in the farmers fields and recorded the yield attributes, yield and work out economics. For this trail was MTU 1061 (Indra) variety was selected. It is a non lodging, long duration (155 days), suitable for over aged seedling planting, tolarent to BPH, with stands under inundated conditions even slightly saline soils also.

Nursery Rising:

For MSRI planting nursery rising is the important management practice. For nursery rising following precautions should be taken

- The tray with the dimensions of 60cm x 30 cm x 2.5 cm. size selected and nursery should be raised in the tray only.

- Every tray filled with 2.0-2.5 kg of pulvarized fine soil as first layer after that 130 g of seed (fine variety)-160 g (medium fine variety) of over night soaked seed will be placed with the help of Automatic Seeding Machine/Manual seeding machine.
- After the seed placement seeding tray will be moistened by sparkling water
- Finally 1.0 to 1.5 kg fine soil along with vermicompost will be the top layer of the tray which can fecilitate the covering the seed also. After filling, all the rays are allow to stake over night in the shade. Next day, trays are shifted to the field and spread them on the plain peddled field covered with paddy straw for three days.
- After seedling emergence, paddy straw removed from the trays and regularly watering them.
- Mean while to enhance the seedling growth, spraying of 19:19:19 @ 3-5 g per lit is advisable.
- For planting of one ha 200 trays were required
- Age of the nursery should be 18 days. After 18 days nursery was ready to transplanting with MSRI Planter.
- Seed requirement for one hectares of land was 30-35 kg
- The Entire process tray filling can operated with the help of automatic seeding mechine or manual seeding mechine also with the support of skilled staff.

MSRI Planter:

The Krishi Vigyan Kendra Amadalavalasa purchased four row and six row MSRI planter from Kubota Manufracture Company and made them available to the farmers under custom hiring centres on rental basis. The planters have 18-22 HP capacity, operated by petrol. These planters can plant 2.4 hectares per man day. The planter can plant 4 seedlings per hill with a spacing of 30 cm X 14-18 cm.

Main field Preparation:

Main field should be properly puddle and leveled. First puddling to be done at 5-6 days prior to planting and second puddling should be done at one day before planting.

Weed management:

Immediately after planting pre emergence application of Pretilaclore @ 2 ml/lit in 500 lit water per ha was recommended. At 15 DAT, bispyribac sodium @ 250 ml/ha and metsulfuron

methyl+ Chlorimuron Ethyl 20 g/ha was recommended as tank mix for control of Grasses, Sedges, BLW control.



Tray filling with Automatic Seeding machine



Tray nursery Maintainance at field level upto 18 days







Planting with MSRI Machine







Recording of Biometrics in Paddy

Field Day in Paddy

Nutrient Management:

As per recommendations of ANGRAU for North coastal zone of Andhra Pradesh, 80:60:50 kg NPK/ha was recommended.

Data Collection:

The observations were recorded from 5 randomly selected plants in each field. plant population per m^{-2} was taken in the field randomly with the help quadrant. Yield attributes viz.,

No. of productive tillers/ plant and m^{-2} were also taken.

Grain yield was taken with help of Crop Cutting (CC) experiment. In CC experiment 5 m x 5 m plot was marked in the field and crop was harvested, threshing was completed and grain yield was noted in kgs and it will converted into kg/ ha.

Yield Attributes of Rice:

The data on plant population m^{-2}, No of Productive tillers per hill and yield of rice depicted in table 1. revealed that, in manual planting method (without proper spacing), no of productive tillers per hill was less (11, 13 and 14 respectively in 2022, 2023 and 2024) it was due to high intra competition within the hill among the seedlings, deep placement of the seedlings in the muddy fields. In manual planting, generally the workers kept more no of seedlings (6 or more) per hill, also inadequate plant stand per m^{-2} due to deep placement of seedlings, tillers producing node of the rice plant kept very deep (>4-5 cm) in the mud reduces tillering ability of the plant which inturn reduce the productive tillers too. While in the MSRI planting, no of seedlings per hill we can adjust as per our requirement. Generally 4 seedlings per hill was kept uniform inter and intra row spacing (30 cm X 14 cm) and shallow depth placement of rice seedlings resulted more no of tillers per hill was observed which inturn increase productive tillers also (16, 20 and 22 respectively) in three years of the study.

Uniform wider spacing in MSRI planting method inturn improves the solar radiation interception in all the directions of the rice plant and CO_2 replacement may happens in plant micro climate, Which could be attributed to increase photosynthetic rate, photosynthate translocation also. This will increased no of filled grains per panicle that will inturn increase the yield in the MSRI planting (6000, 6975 and 7832 kg ha^{-1}) when compared to manual planting (5600, 6252 and 6324 kg ha^{-1}).

In manual method of planting aged seedlings at least 30 days or even more aged seedlings were used to be planted in the main field but in MSRI planting, young aged (18 days) seed lings are used because of age advantage, these younger seedlings have more vigour potential to futforth high tillering ability in main field. Mechanically transplanted rice had the most effective tillers m^{-2} because younger seedlings (less than 25 days old) were transplanted at the proper distance and depth, minimizing transplanting tremors and allowing early establishment and growth factor exploitation.

Table.1:Yield attributes and yield of paddy influenced by normal and MSRI planting methods.

Treatment	Plant population m^{-2}			No. of Productive tillers/hill			Yield kg/ha			Average
	2022	2023	2024	2022	2023	2024	2022	2023	2024	
T1: Paddy transplanting with MSRI Planter	24	24	24	16	20	22	6000	6975	7832	6935
T2: Manual transplanting	28	27	27	11	13	14	5600	6252	6324	6058
% Increase				45.4	53.8	57.1	7.1	11.5	23.8	14.4

Economic parameters:

Economic parameters of both systems were depicted in table 2 and compared in table 3. The results revealed that, in normal planting cost of cultivation was high due to the following reasons.

1. Seed cost
2. High labour involvement
3. Nursery pulling and planting
4. More pest and disease incidence
5. Low yield

But ,in the MSRI planting savings on expenditure noticed on the following

1. Seed
2. Labour
3. Pesticides

In addition to the above advantages, added advantage is that increased yield also noticed in MSRI Planting.

Higher cost of cultivation (Rs. 57850, 66375 and 59892 ha^{-1} respectively) was recorded in manual planting in both the years respectively. In MSRI planting highest net returns (Rs. 69500, Rs. 92981 and 125200 ha^{-1} respectively) was noticed in three years of Study. Similar trend was

noticed in B: C ratio also. The FLD trials at KVK, Srikakulam indicated that the yield parameters and yield were higher in mechanized transplanting than manual transplanting.

Table.2: Economic parameters of Paddy influenced by normal and MSRI planting methods.

Treatment	Cost of Cultivation (Rs./ha)			Net returns (Rs./ha)			B:C ratio		
	2022	2023	2024	2022	2023	2024	2022	2023	2024
T1: Paddy transplanting with MSRI Planter	52570	55875	54783	69500	92981	125200	2.3:1	2.6:1	3.2:1
T2: Manual transplanting	57850	66375	59892	56250	66375	85308	1.9:1	2:1	2.45:1

Table.3: Expenditure per ha on paddy influenced by Manual and MSRI planting methods.

S.No.	Particulars	Manual Method	MSRI
1	Seed	3000	1500
2	Nursery raising (including ploughing)	2250	-
3	Field preparation	3750	3750
3	Trays filling @ 20 per tray (200 trays)	-	4000
4.	19:19:19 spray	-	500
5.	Nursery pulling and spreading of nursery	8000	3000
6.	Transplanting	7500	6500
7	Fertilizers	6410	6410
8	Formation of Alley ways and one	3500	3000

	hand weeding		
8	weedicides	7050	6400
9	Pesticides	8500	5500
10	Harvesting	8750	8750
11	Labour charges for fertilizers and irrigation	4600	4600
	Total	**63310**	**53910**

Summery

Currently rice is being transplanted manually in north coastal Andhra Pradesh increasing the cost of cultivation. The use of small scale machinery in wet transplantation is inevitable to reduce the expenditure. In conclusion the results of this study recommends use of mechanization in rice transplantation for higher productive tillers, grain yield, reduced cost for small and marginal farming community.

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AI AGENTS IN AGRICULTURE: THE NEXT REVOLUTION IN SMART FARMING

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Abstract

Agriculture is undergoing a significant transformation with the integration of Artificial Intelligence (AI). Among the latest innovations, AI Agents are emerging as intelligent systems capable of making autonomous decisions, learning from experience, and solving complex agricultural problems in real time. Unlike conventional AI tools that perform single tasks, AI agents can analyze multiple sources of information, plan suitable actions, and continuously improve their performance. By combining machine learning, computer vision, IoT sensors, drones, satellite imagery, and weather data, AI agents support farmers in crop planning, irrigation scheduling, pest and disease detection, nutrient management, and yield prediction. These technologies improve productivity while reducing input costs and environmental impacts. AI agents are expected to become indispensable digital partners for sustainable and climate-resilient agriculture.

Keywords: AI Agents, Smart Farming, Precision Agriculture, Artificial Intelligence, Internet of Things (IoT), Machine Learning, Sustainable Agriculture.

Introduction

Agriculture is the backbone of food security and rural livelihoods, but it faces growing challenges such as climate change, labour shortages, water scarcity, declining soil fertility, and

increasing food demand. To overcome these challenges, modern farming is rapidly adopting advanced digital technologies.

Artificial Intelligence (AI) has become one of the most influential technologies in agriculture. While traditional AI systems assist farmers in specific tasks such as disease detection or weather forecasting, the emergence of **AI Agents** has introduced a new level of intelligence. AI agents can collect information, analyze different situations, make decisions, and even perform tasks with minimal human intervention.



By integrating machine learning, computer vision, IoT devices, drones, and satellite data, AI agents help farmers optimize crop production, reduce resource wastage, and improve decision-making. As agriculture enters the era of intelligent automation, AI agents are expected to play a vital role in achieving sustainable and efficient farming systems. According to the Food and Agriculture Organization (FAO), global food production must increase by nearly 60% by 2050 to meet the demands of the growing population.

What are AI Agents?

AI Agents are advanced intelligent software systems that can independently observe their environment, analyze available information, make decisions, and perform actions to achieve specific goals. Unlike traditional computer programs that simply follow predefined instructions, AI agents are designed to think, learn, adapt, and improve based on new data and changing conditions.

In agriculture, AI agents act as digital farm assistants. They continuously collect information from sensors, drones, weather stations, satellite images, and farm management systems. Using this information, they identify problems, evaluate different solutions, and recommend or execute the best farming practices.

For example, if soil moisture levels become critically low, an AI agent can automatically recommend irrigation or activate a smart irrigation system. Similarly, when early symptoms of a plant disease are detected through drone images, the AI agent can identify the disease, estimate its severity, and suggest appropriate control measures.

The ability of AI agents to perform multiple tasks, learn from experience, and make intelligent decisions makes them one of the most important innovations in modern agriculture.

Why are AI Agents Different from Traditional AI?

Traditional AI systems are designed to perform specific tasks based on fixed rules or trained models. For example, an AI model may identify a disease from a leaf image or predict tomorrow's weather. However, these systems generally require human input for every decision and cannot independently plan multiple actions.

AI agents are much more advanced because they combine reasoning, planning, memory, and continuous learning. They do not simply answer questions—they analyze situations, decide what needs to be done, and take appropriate actions. An AI agent can gather weather forecasts, soil moisture data, crop growth information, and market prices simultaneously before recommending the best irrigation schedule, fertilizer application, or harvesting time.

This ability to make autonomous decisions and continuously improve performance makes AI agents more suitable for complex agricultural environments, where multiple factors influence crop production every day.

Comparison between Traditional AI and AI Agents:

Feature	**Traditional AI**	**AI Agent**
Decision Making	Limited	Autonomous
Learning	Fixed Model	Continuous Learning
Task	Single Task	Multiple Tasks
Human Intervention	High	Low
Adaptability	Low	High

Applications of AI Agents in Agriculture

Artificial Intelligence (AI) agents are transforming modern agriculture by supporting farmers in making accurate, timely, and data-driven decisions. Unlike conventional farming methods, AI agents continuously collect, analyze, and interpret data from multiple sources such as sensors, drones, weather stations, satell, and farm machinery. Based on this information, they provide real-time recommendations or automatically perform specific farming operations. Some of the major applications of AI agents in agriculture are discussed below.

Crop Planning and Decision Support

Successful farming begins with proper crop planning. AI agents analyze soil characteristics, climate conditions, rainfall patterns, previous cropping history, and market demand to recommend the most suitable crop and variety for a specific location. They also assist farmers in selecting the ideal sowing time, seed rate, and cultivation practices, reducing risks associated with poor planning and unpredictable weather conditions.

Smart Irrigation Management

Water scarcity is one of the biggest challenges in agriculture. AI agents help farmers optimize irrigation by monitoring soil moisture, temperature, humidity, weather forecasts, and crop water requirements in real time. Instead of following fixed irrigation schedules, AI agents recommend the exact amount of water needed by the crop. This improves water-use efficiency, reduces unnecessary irrigation, lowers energy consumption, and supports sustainable water management.



Pest and Disease Detection

Early detection of pests and diseases is essential for minimizing crop losses. AI agents use computer vision and deep learning algorithms to analyze images captured by smartphones,

drones, or field cameras. They can identify disease symptoms at an early stage, estimate the severity of infection, and recommend suitable management practices. Early diagnosis enables farmers to take timely action, reducing yield losses and limiting excessive pesticide use.

Precision Nutrient Management

Efficient fertilizer management is essential for improving crop productivity while protecting the environment. AI agents combine information from soil testing, crop growth stages, weather conditions, and nutrient availability to provide site-specific fertilizer recommendations. This helps farmers apply the right nutrient, in the right quantity, at the right time, improving nutrient use efficiency and reducing production costs.

Yield Prediction and Harvest Planning

AI agents analyze weather forecasts, crop growth patterns, soil conditions, and satellite imagery to estimate crop yield before harvest. Accurate yield prediction helps farmers plan harvesting operations, storage facilities, transportation, and marketing strategies. It also enables governments and agricultural organizations to improve food supply planning and reduce postharvest losses.

Weed Identification and Control

Weeds compete with crops for nutrients, water, sunlight, and space. AI-powered cameras mounted on drones or robotic weeders can distinguish weeds from crop plants with high accuracy. AI agents then recommend or perform targeted weed control, reducing herbicide usage and lowering environmental pollution while improving crop productivity.

Weather Forecasting and Climate Risk Management

Weather is one of the most unpredictable factors affecting agriculture. AI agents continuously monitor meteorological data and generate localized weather forecasts. They provide early warnings about droughts, floods, heat waves, heavy rainfall, or frost, allowing farmers to take preventive measures. These predictions improve climate resilience and reduce production risks.

Market Intelligence and Farm Management

In addition to field operations, AI agents also support farmers in economic decision-making. They analyze market prices, demand trends, transportation costs, and storage availability to recommend the best time and place to sell agricultural produce. Some advanced AI agents can also assist in maintaining digital farm records, financial planning, and supply chain

management, helping farmers maximize profitability.

Real-World Applications and Case Studies

The adoption of AI agents is no longer limited to research laboratories. Today, governments, agricultural institutions, agritech companies, and farmers across the world are implementing AI-driven solutions to improve productivity, reduce costs, and enhance sustainability.

India:

India is rapidly adopting AI in agriculture through government initiatives and private agritech companies. AI-based advisory platforms provide farmers with location-specific recommendations on crop selection, irrigation scheduling, fertilizer application, and pest management. Smartphone applications powered by AI help identify crop diseases from leaf images, while satellite-based systems monitor crop growth and drought conditions. These technologies enable small and marginal farmers to make informed decisions and reduce production risks.

United States:

Large-scale farms in the United States use AI agents integrated with autonomous tractors, drones, and precision farming equipment. These systems monitor field conditions, identify nutrient deficiencies, detect weeds, and optimize irrigation with minimal human intervention. AI-powered farm management software also assists in planning, harvesting, and supply chain operations.

Japan and the Netherlands:

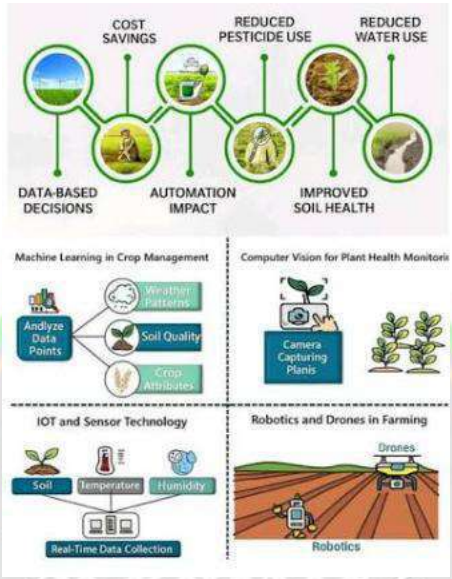
Countries such as Japan and the Netherlands are pioneers in smart farming. AI agents are used inside greenhouses to regulate temperature, humidity, lighting, and irrigation automatically. Agricultural robots equipped with AI perform harvesting, grading, and quality assessment, reducing labour dependency while maintaining high productivity.

These examples demonstrate that AI agents are becoming an essential part of modern agriculture, improving both farm efficiency and environmental sustainability.

Real-World AI Applications in Agriculture

Company / Organization	AI Application	Benefit
Microsoft FarmBeats	Uses AI, IoT sensors, and drones for precision farming	Improves irrigation and crop monitoring
John Deere	AI-powered autonomous	Reduces labour and input

	tractors and precision sprayers	costs
Blue River Technology	"See & Spray" AI system for weed detection	Reduces herbicide use through targeted spraying
Fasal (India)	AI-driven irrigation and farm advisory system	Optimizes water use and improves productivity
CropIn (India)	AI-based digital farm management platform	Supports crop monitoring and yield prediction



Benefits of AI Agents in Agriculture

1. **Increases crop productivity** by enabling accurate and timely farm management decisions.
2. **Optimizes the use of water, fertilizers, and pesticides**, reducing resource wastage.
3. **Detects pests and diseases at an early stage**, minimizing crop losses.
4. **Supports precision farming** through real-time monitoring of field conditions.
5. **Improves irrigation efficiency** using soil moisture and weather-based recommendations.
6. **Reduces labour requirements** by automating routine agricultural operations.
7. **Predicts crop yield accurately**, helping farmers plan harvesting and marketing.
8. **Lowers production costs** through efficient input management and automation.
9. **Enhances climate resilience** by providing weather forecasts and early warning alerts.
10. **Promotes sustainable agriculture** by improving resource efficiency and reducing environmental impact.

Major Applications of AI Agents in Agriculture

Agricultural Activity	Role of AI Agent	Expected Benefits
Crop Planning	Recommends suitable crops and varieties	Improved productivity
Smart Irrigation	Monitors soil moisture and schedules irrigation	Water conservation
Disease Detection	Identifies diseases using image analysis	Early disease management
Pest Monitoring	Predicts pest outbreaks and recommends control measures	Reduced crop losses
Nutrient Management	Provides site-specific fertilizer recommendations	Efficient fertilizer use
Weed Management	Detects weeds using AI vision systems	Reduced herbicide use
Yield Prediction	Estimates crop yield before harvest	Better marketing decisions
Weather Forecasting	Provides localized weather alerts	Climate risk reduction

Challenges of AI Agents

i. High initial investment
ii. Internet connectivity issues
iii. Lack of digital literacy
iv. Data privacy concerns
v. Maintenance cost
vi. Limited adoption among small farmers

Future Scope of AI Agents in Agriculture

Artificial Intelligence (AI) agents are expected to play a key role in the future of smart farming. By integrating with robotics, drones, IoT sensors, and satellite technologies, AI agents will automate farm operations and improve decision-making. They will help farmers monitor crop health, optimize irrigation and fertilizer use, predict pest outbreaks, and increase productivity with minimal human intervention.

AI agents will also support climate-smart agriculture by analyzing weather patterns and recommending suitable farming practices. As digital infrastructure improves and AI technologies become more affordable, AI agents are expected to become reliable partners for farmers, promoting sustainable, efficient, and profitable agriculture. Future AI agents may collaborate with autonomous robots, digital twins, and generative AI assistants to create fully autonomous farms.

Conclusion

Agriculture is entering a new phase of digital transformation, and AI agents are emerging as one of the most powerful innovations in modern farming. Unlike traditional AI systems, AI agents can observe, analyze, learn, and make intelligent decisions with minimal human intervention. Their ability to integrate data from sensors, drones, satellites, and weather forecasting systems enables farmers to manage crops more efficiently and accurately.From crop planning and irrigation management to disease detection, nutrient optimization, and market forecasting, AI agents provide practical solutions to many challenges faced by modern agriculture. They not only improve productivity but also promote sustainable resource management, reduce production costs, and strengthen climate resilience.

Despite challenges such as high investment costs, digital infrastructure limitations, and the need for technical training, the future of AI agents in agriculture is highly promising. As technologies become more affordable and accessible, AI agents are expected to become valuable digital partners for farmers worldwide.The successful adoption of AI agents has the potential to revolutionize agriculture by making farming more intelligent, efficient, profitable, and environmentally sustainable. Their continued development will play a vital role in ensuring global food security and supporting the future of smart farming.

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SHIFTING SANDS, FIXED STANDARDS: MORPHOLOGICAL DYNAMICS OF CERTIFIED BLUE FLAG BEACHES

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Abstract

Blue Flag is the world's most recognised beach eco-label, awarded by the Foundation for Environmental Education (FEE) on the basis of thirty-three criteria spanning water quality, environmental education, environmental management, and safety and services. Conspicuously absent from this checklist is any direct measure of beach morphodynamics, the physical state of the beach in terms of slope, sediment grain size and dissipative-to-reflective character, that governs sediment transport, dune stability and the ecological carrying capacity of the shore. This article reviews the interaction between Blue Flag certification practices and beach morphology, drawing on the classical morphodynamic framework of Wright and Short (1984) and on empirical studies of certified and uncertified beaches in Spain, and considers the implications for India's growing portfolio of Blue Flag beaches. Evidence indicates that certification-linked management activities, particularly mechanical grooming, the removal of wrack and macroalgae, and infrastructure placement on or near the foredune, can measurably alter sediment budgets and accelerate dune erosion even as the beach continues to meet its water-quality and cleanliness criteria. We argue that morphodynamic monitoring deserves a formal place alongside the existing four pillars of certification if Blue Flag is to certify beaches that are geomorphologically and not merely chemically and administratively, sustainable.

Keywords

Beach morphodynamics, Blue Flag certification, Foredune erosion and Mechanical beach cleaning.

1. Introduction

A beach carries two identities at once. To a regulator or a tourist board, it is a checklist: water clean enough to swim in, bins emptied, lifeguards on duty, signage in place. To a coastal geomorphologist it is a sediment budget in constant motion, a slope and a grain size responding hour by hour to wave energy, tide and wind. The Blue Flag programme, run internationally by the **Foundation for Environmental Education** since 1987, has become the dominant instrument through which the first identity is assessed and rewarded, with certified sites now spanning more than eighty countries and, as of 2025, Spain alone carrying over six hundred Blue Flags. In India, beaches including Shivrajpur, Ghoghla, Kasarkod, Padubidri and Golden Beach have joined this list in the past decade.

Yet the criteria that decide whether a flag is raised or lowered say almost nothing about the beach as a physical, morphodynamic system. This omission matters because the very practices that keep a beach eligible for certification, most visibly the daily mechanical removal of litter, seaweed and wrack, can act directly on the sediment budget and the foredune, categories of impact that the certification process was never designed to detect (Fraguell *et al*., 2016, as reported in Botero, 2015). This article synthesises the morphodynamic literature and the growing body of work that has specifically examined Blue Flag beaches as physical systems, in order to ask a simple question: does meeting the Blue Flag's standards help, hinder, or say nothing at all about the morphological health of a beach?

2. The Blue Flag Programme: Origins, Criteria and Global Reach

2.1 A Voluntary, Award-Based Instrument

Beach certification schemes emerged as a market-based response to growing pressure on coastal tourism destinations, evaluating beach characteristics against measurable compliance criteria and, in return, licensing the use of a recognisable name and logo (Zielinski and Botero, 2015; Botero *et al*., 2015). The Blue Flag eco-label, first implemented in 1987, remains the oldest and most widely adopted of these schemes and is today administered by FEE, a non-profit international NGO with member organisations in over a hundred countries.

2.2 The Four Pillars of Certification

Escherichia coli and intestinal enterococci, alongside a requirement that the site be free of industrial and sewage influence. Environmental management criteria require a functioning waste-management system, information on local ecosystems, and cleanliness of the sand itself.

None of the thirty-three criteria, however, prescribes limits on beach slope, foredune width, sediment grain-size distribution or shoreline change rate; the physical template of the beach is, in effect, outside the frame of assessment.

3. Beach Morphodynamics: The Physical Foundation Certification Does Not Measure

3.1 The Reflective-Dissipative Continuum

Wright and Short (1984) established the morphodynamic classification that remains the reference framework for sandy beach science, arranging beaches along a continuum from steep, coarse-grained reflective states with plunging waves to flat, fine-grained dissipative states with wide, spilling surf zones. The dimensionless fall velocity (Ω), relating breaker height to sediment settling velocity, operationalises this continuum and correlates strongly with beach slope, swash climate and ultimately, the ecological communities a beach can support (Defeo and McLachlan, 2005).

3.2 Why Morphodynamic State Matters for a Certified Beach

Beach morphodynamic state governs more than ecology: it determines how readily a beach recovers from storm erosion, how resilient its dune system is to trampling and vehicle damage, and how sensitive it is to further disturbance from grooming or infrastructure (Schlacher *et al*., 2007; McLachlan and Defeo, 2018). A reflective beach with a narrow, steep profile has comparatively little sediment reserve to absorb additional stress; a dissipative beach with a wide, gently sloping profile is more physically forgiving. Certification programmes that reward high visitor numbers and intensive daily management without reference to this underlying physical template risk placing the greatest management pressure precisely on the beaches least able to absorb it.

4. Certification Practices and Their Morphological Footprint

4.1 Mechanical Cleaning and the Removal of Wrack

Blue Flag's cleanliness requirement is commonly met through mechanised raking and sifting that removes litter together with stranded seaweed and other natural wrack from the beach face (Fraguell *et al*., 2016, as reported in Botero, 2015). Because wrack contributes organic matter that stabilises sand and anchors incipient dune vegetation, its systematic removal has been linked to reduced sandy-shore biodiversity and to changes in coastal morphology and erosion dynamics on certified beaches (Boevers, 2008; Mir-Gual *et al*., 2015, as reported in Botero, 2015). Independent of ecological effect, repeated heavy-machinery passage has itself been

associated with increased deflation-surface area and sediment loss in dunefields adjoining managed beaches, even where the managed beach face appears artificially stable (long-term vehicle-track monitoring studies of aeolian sedimentary dynamics).

4.2 Foredune and Infrastructure Disturbance

The installation of beach services, walkways, kiosks and access points, often placed on or immediately behind the foredune to satisfy safety-and-services criteria, has been shown to generate erosive dune morphologies at numerous Mediterranean sites (Roig-Munar *et al*., 2012). Their space-time analysis of beach-dune systems in the Balearic Islands between 1956 and 2004 found that management based on geomorphological criteria improved conservation of the natural dune system and encouraged vegetation recovery, whereas management driven mainly by commercial and visitor-capacity considerations correlated with sustained erosion of the foredune.

4.3 Nourishment and Beach Narrowing

Where certified beaches face chronic erosion, nourishment with imported sediment is frequently used to maintain the beach width and amenity value that certification and tourism depend upon. Peterson and Bishop (2005) documented that nourishment using sediment coarser than the native grain-size distribution produces significant and prolonged disruption to the intertidal community and to the natural morphodynamic state of the beach, effects that persist well beyond the immediate construction period.

5. Evidence from Certified Beaches: The Spanish Experience

The most direct empirical test of the relationship between certification and morphology comes from Spain, which holds more Blue Flags than any other country. Mir-Gual *et al*. (2015) compared environmental variables across Blue Flag and non-certified beaches and found that certification status did not reliably predict better geomorphological or ecological condition; several certified beaches showed comparable or greater signs of dune degradation than nearby uncertified sites, indicating that the certification criteria capture cleanliness and service provision more consistently than physical shoreline health. Complementing this, Roig-Munar *et al*. (2012) linked the most heavily frequented and intensively managed beach sectors of Majorca and Menorca to the most eroded portions of their associated dune systems, using multi-decadal shoreline analysis, and concluded that geomorphological criteria, not visitor amenity criteria, were the stronger predictor of long-term beach-dune stability.

6. Blue Flag Beaches in India: Morphological Considerations

India's Blue Flag beaches, including Shivrajpur (Gujarat), Ghoghla (Diu), Kasarkod and Padubidri (Karnataka), and Golden Beach (Odisha), sit on coastlines with markedly different wave climates, tidal ranges and sediment supplies, from the microtidal, monsoon-driven west coast to the meso-tidal east coast. Applying a uniform international checklist across such physically diverse settings raises the same concern documented in Spain: certification can be achieved and maintained through cleaning and service-provision effort without any accompanying assessment of whether the underlying beach slope, sediment budget or dune line is stable, accreting, or eroding. Monsoon-season morphodynamic reversals, common on India's dissipative to intermediate west-coast beaches, add a seasonal dimension that a single annual certification audit is not designed to capture.

7. Toward an Integrated Certification: A Missing Morphodynamic Criterion

The evidence reviewed here suggests that Blue Flag, as presently constituted, functions as an effective proxy for water quality and visitor safety but only a weak and indirect proxy for the morphological health of the beach it certifies. Incorporating a fifth, morphodynamic pillar, periodic beach-profile surveys, sediment grain-size sampling, and shoreline-change tracking, alongside the existing four categories, would allow the certification process to distinguish between beaches that are stable under their current management regime and those that are being maintained in an artificially groomed, but physically degrading, state (Defeo and McLachlan, 2005; Schlacher *et al*., 2007).

8. Management Recommendations

First, national Blue Flag operators should require baseline and annual beach-profile and grain-size data as a condition of certification renewal, following the low-cost field protocols already established in the morphodynamic literature (McLachlan *et al*., 1993). Second, mechanical cleaning frequency and method should be calibrated to wrack input and dune sensitivity rather than applied uniformly, drawing on the phased hybrid manual-mechanical approaches shown to reduce sediment disturbance while still meeting litter-removal standards. Third, siting of new beach infrastructure should be assessed against dune stability criteria before, not after, installation, in line with the geomorphological management approach shown to reduce erosion in the Balearic Islands (Roig-Munar *et al*. 2012). Finally, where nourishment is unavoidable, imported sediment should be matched to native grain-size distribution to protect

both the morphodynamic state and the ecological function of the beach (Peterson and Bishop, 2005).

Conclusion

A Blue Flag tells a visitor that the water is clean, the sand is free of litter and help is close at hand. It does not tell them and was never designed to tell them, whether the beach beneath their feet is holding its ground. The studies reviewed here indicate that these two conditions, chemical and administrative compliance on one hand, physical stability on the other, can diverge, sometimes because the very practices used to satisfy certification criteria act against the sediment budget of the shore. A certification system built to reward sustainable beaches should, in the end, be able to recognise when a beach is sustaining itself and when it is merely being kept tidy while it erodes.

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CLIMATE-SMART RAINFED AGRICULTURE: PATHWAYS TO SUSTAINABLE PRODUCTIVITY AND RURAL PROSPERITY

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Abstract

Rainfed agriculture is the cornerstone of Indian agriculture, supporting the livelihoods of nearly half of the farming population and contributing significantly to the production of pulses, oilseeds, millets, cotton and coarse cereals. However, climate change, erratic rainfall, soil degradation and declining groundwater resources have intensified the challenges faced by rainfed farmers. Recent technological advances and sustainable agricultural practices have transformed rainfed farming from a high-risk production system into a resilient and resource-efficient enterprise. Climate-smart agriculture, integrated farming systems, precision agriculture, watershed management, digital advisory services, drought-resilient crop varieties and improved soil and water conservation practices are emerging as key interventions to enhance productivity and livelihood security. This article discusses current trends in rainfed agriculture, highlights recent technological developments and outlines future opportunities for achieving sustainable agricultural growth under changing climatic conditions.

Introduction

Rainfed agriculture occupies a pivotal position in Indian agriculture, with nearly 52–55 per cent of the country's cultivated land depending entirely on rainfall. These rainfed areas contribute approximately 80 per cent of pulse production, 70 per cent of oilseed production, and nearly 85 per cent of millet cultivation, making them indispensable for ensuring the nation's food and nutritional security. The majority of rainfed farmers are small and marginal landholders who depend heavily on the timely onset and equitable distribution of monsoon rainfall for successful crop production. However, in recent years, climate change has intensified production challenges

through delayed monsoon onset, prolonged dry spells, rising temperatures, erratic rainfall, and frequent droughts, resulting in lower crop productivity, increased production risks, and reduced farm profitability. Consequently, enhancing the resilience, productivity, and sustainability of rainfed agriculture has become a key priority of agricultural research, development, and policy initiatives in India.

Scientific institutions, extension agencies, and policymakers have introduced a wide range of innovative technologies and sustainable management practices to enhance water-use efficiency, conserve natural resources, and improve crop productivity in rainfed regions. The integration of traditional knowledge with modern scientific innovations is enabling farmers to better adapt to climatic uncertainties while maintaining environmental sustainability. Advances in climate-smart agriculture, precision farming, digital advisory services, integrated farming systems, watershed management, and improved soil and water conservation practices are accelerating the transformation of rainfed agriculture into a more productive, climate-resilient, resource-efficient, and economically viable farming system. Strengthening collaboration among research institutions, extension agencies, policymakers, and farming communities will further accelerate the adoption of these technologies, thereby enhancing food security, rural livelihoods, and the long-term sustainability of rainfed agriculture.

Climate-Smart Agriculture: Building Resilience to Climate Change

Climate-smart agriculture (CSA) has emerged as one of the most promising approaches for enhancing the resilience and sustainability of rainfed farming systems. It aims to simultaneously increase agricultural productivity, strengthen resilience to climate variability and change, and, wherever feasible, reduce greenhouse gas emissions. Farmers are increasingly adopting climate-smart practices such as conservation tillage, crop diversification, integrated nutrient management, agroforestry, conservation agriculture, and weather-based crop planning to minimize the adverse impacts of drought, erratic rainfall, and rising temperatures. These practices improve soil organic carbon, enhance rainwater infiltration, conserve soil moisture, and reduce soil erosion, thereby improving crop productivity and resource-use efficiency under rainfed conditions. In addition, weather-based agro-advisories and digital climate information services provide real-time recommendations on sowing time, crop selection, fertilizer application, irrigation scheduling, and pest and disease management, enabling farmers to make timely and informed decisions. The widespread adoption of climate-smart agriculture is

strengthening the adaptive capacity of rainfed farming while promoting sustainable natural resource management, enhancing food security, and improving farmers' livelihoods under changing climatic conditions.

Integrated Farming Systems for Sustainable Livelihoods

Integrated Farming Systems (IFS) are increasingly recognized as one of the most effective approaches for enhancing farm income, resource-use efficiency, and livelihood security in rainfed regions. Integrating crop production with dairy, goat rearing, poultry, horticulture, agroforestry, fisheries, and fodder cultivation ensures diversified and year-round income while minimizing production risks associated with climatic variability. Crop residues are efficiently utilized as livestock feed, whereas animal manure and other farm wastes are recycled to improve soil fertility, nutrient availability, and overall soil health. Such integrated systems promote efficient resource recycling, optimize the use of available land and water resources, generate additional employment opportunities, and reduce dependence on external inputs. Recent studies have demonstrated that Integrated Farming Systems significantly enhance farm profitability, water productivity, nutrient-use efficiency, and climate resilience while contributing to environmental sustainability and long-term agricultural productivity under rainfed conditions.

Efficient Soil and Water Conservation Practices

Efficient rainfall management is fundamental to the success of rainfed agriculture. Farmers are increasingly adopting soil and water conservation practices such as summer ploughing, broad bed and furrow (BBF) systems, compartment bunding, contour farming, mulching, conservation furrows, and farm pond construction to maximize rainwater use. These practices enhance rainwater infiltration, reduce surface runoff, improve soil moisture retention, and minimize soil erosion. Watershed development programmes involving check dams, percolation ponds, recharge structures, and contour trenches have significantly improved groundwater recharge, enhanced water availability, and stabilized agricultural production in many dryland regions. In addition, rainwater harvesting and in-situ moisture conservation not only increase crop productivity and water-use efficiency but also support livestock, horticultural enterprises, and supplementary irrigation during prolonged dry spells. Collectively, these integrated soil and water conservation measures strengthen climate resilience, conserve natural resources, and promote sustainable agricultural production in rainfed ecosystems.

Climate -Resilient Crop Varieties and Crop Diversification

The development of drought-tolerant, heat-tolerant, and early-maturing crop varieties has significantly enhanced the adaptive capacity of rainfed agriculture. Improved varieties of millets, pulses, oilseeds, cotton, and other climate-resilient crops are capable of producing stable yields even under moisture-stress conditions. In parallel, crop diversification has emerged as a key strategy for reducing production risks, improving resource-use efficiency, enhancing soil fertility, and increasing farm income. Farmers are increasingly adopting intercropping, mixed cropping, and sequential cropping systems involving cereals, pulses, oilseeds, vegetables, and fodder crops to optimize the use of available resources. Intercropping systems such as cotton–blackgram, sorghum–pigeonpea, and maize–cowpea improve land-use efficiency, suppress pest and disease incidence, enhance soil fertility through biological nitrogen fixation, and provide multiple income streams. Furthermore, diversified cropping systems improve system resilience, enhance soil health and biodiversity, promote efficient nutrient cycling, and contribute to sustainable agricultural production under rainfed conditions. The adoption of climate-resilient crop varieties, combined with diversified cropping systems, is strengthening the resilience and sustainability of rainfed agriculture while ensuring stable productivity under changing climatic conditions.

Digital Agriculture and Precision Farming

Rapid advances in digital agriculture are transforming decision-making in rainfed farming systems. Mobile-based advisory services, satellite imagery, drone technology, artificial intelligence (AI), Internet of Things (IoT) sensors, and Geographic Information Systems (GIS) are enabling farmers to make timely and informed management decisions. Weather forecasting applications provide real-time information on rainfall, temperature, and pest and disease outbreaks, allowing farmers to plan agricultural operations more efficiently and minimize production risks. Precision nutrient management, based on soil testing and digital decision-support tools, optimizes fertilizer application, reduces input wastage, and enhances nutrient-use efficiency. Furthermore, remote sensing, AI-driven analytics, and mobile applications are improving crop monitoring, early warning systems, and farm management. Collectively, these digital technologies are making agricultural extension services faster, more accessible, accurate, and farmer-centric, thereby enhancing the productivity, resilience, and sustainability of rainfed farming systems.

Millets and Nutri-Cereals: The Future of Dryland Farming

The growing emphasis on millets has renewed interest in these traditional rainfed crops because of their exceptional nutritional value, climate resilience, and adaptability to marginal environments. Millets require comparatively less water, tolerate drought and heat stress, and thrive in poor and degraded soils where many other crops fail. The increased awareness generated through the International Year of Millets has significantly boosted consumer demand for millet-based products, creating new market and value-addition opportunities for farmers. In addition to their nutritional benefits, millets contribute to climate adaptation by requiring fewer external inputs, improving resource-use efficiency, and maintaining stable yields under adverse environmental conditions. Promoting millet cultivation, along with value addition, processing, branding, and strengthened market linkages, can substantially enhance farmers' income, improve nutritional and food security, generate rural employment, and support sustainable agricultural development. Furthermore, integrating millets into diversified farming systems can strengthen climate resilience, conserve natural resources, and contribute to the long-term sustainability of rainfed agriculture.

Government Initiatives and Future Prospects

Government initiatives such as the National Mission for Sustainable Agriculture (NMSA), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Integrated Watershed Management Programme (IWMP), Soil Health Card Scheme, and Farmer Producer Organizations (FPOs) have significantly strengthened rainfed agriculture across India. These programmes promote sustainable natural resource management, efficient water use, climate-resilient agricultural technologies, soil health improvement, and collective marketing, thereby enhancing the productivity and profitability of rainfed farming systems. Looking ahead, greater investments in digital agriculture, artificial intelligence (AI), precision agriculture, carbon farming, integrated farming systems, climate-resilient crop breeding, and weather-based decision-support systems will further improve the resilience, sustainability, and competitiveness of rainfed agriculture. Strengthening partnerships among research institutions, extension agencies, policymakers, the private sector, and farming communities will be essential for accelerating technology dissemination, enhancing farmers' capacity, promoting innovation, and improving rural livelihoods. Such collaborative efforts will play a pivotal role in achieving

sustainable agricultural development, ensuring food and nutritional security, and building climate-resilient farming systems for the future.

Conclusion

Rainfed agriculture remains the backbone of Indian agriculture, playing a pivotal role in ensuring food and nutritional security, sustaining rural livelihoods, and supporting the nation's agricultural economy. Despite the challenges posed by climate change, natural resource degradation, erratic rainfall, and increasing production risks, recent advances in climate-smart agriculture, integrated farming systems, precision agriculture, digital technologies, watershed management, and climate-resilient crop varieties offer tremendous opportunities for sustainable transformation. Future strategies should focus on strengthening climate resilience, enhancing rainwater harvesting and efficient water management, promoting diversified and integrated farming systems, encouraging value addition and market linkages, and expanding farmers' access to modern technologies and digital advisory services. Strong collaboration among research institutions, extension agencies, policymakers, the private sector, and farming communities will be essential to accelerate technology adoption and foster innovation. By integrating scientific advancements with traditional knowledge and supportive policy interventions, rainfed agriculture can evolve into a more productive, profitable, climate-resilient, and environmentally sustainable production system, ensuring long-term food security, sustainable rural development, and resilient livelihoods for millions of farming families.

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CYANOTOXINS: SOURCES, HEALTH EFFECTS, AND TREATMENT METHODS

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Abstract

Cyanotoxins, potent natural toxins produced by cyanobacteria (blue-green algae), pose significant threats to public health and aquatic ecosystems worldwide. This article provides a comprehensive overview of cyanotoxins, detailing their diverse sources, the various health effects they induce in humans and animals, and the current treatment methods employed to mitigate their presence in water sources. We explore the common cyanobacterial genera responsible for toxin production, the environmental factors contributing to harmful algal blooms (HABs), and the classification of cyanotoxins based on their chemical structure and target organs. Furthermore, we discuss the challenges associated with cyanotoxin removal in water treatment and evaluate the effectiveness of both conventional and advanced treatment technologies, emphasizing the need for a multi-barrier approach to ensure water safety.

Keywords: Cyanotoxins, Cyanobacteria, Harmful Algal Blooms (HABs), Microcystins, Hepatotoxins, Neurotoxins, Water Treatment, Eutrophication, Advanced Oxidation Processes (AOPs), Public Health.

Introduction

Cyanobacteria, commonly known as blue-green algae, are photosynthetic prokaryotes that play a crucial role as primary producers in aquatic ecosystems. However, under specific environmental conditions, certain species can proliferate rapidly, forming dense accumulations known as harmful algal blooms (HABs). These blooms are a growing global concern due to their potential to produce a diverse array of toxic secondary metabolites, collectively termed cyanotoxins. The increasing frequency and intensity of HABs, driven by factors such as nutrient enrichment (eutrophication) and climate change, have led to widespread contamination of freshwater and brackish water bodies, posing substantial risks to human health, animal welfare, and ecosystem integrity.

Sources of Cyanotoxins

Cyanotoxins are produced by a wide variety of cyanobacterial species, which can be broadly categorized into planktonic (free-floating) and benthic (bottom-dwelling) forms. The presence and concentration of these toxins are influenced by both the specific cyanobacterial genera present and a complex interplay of environmental factors.

Cyanobacteria Species

- Microcystis: Often forms greenish, paint-like scums and is a primary producer of microcystins, the most common cyanobacterial toxins.
- Dolichospermum (formerly Anabaena): Known for forming slimy blooms and producing a range of toxins, including microcystins, cylindrospermopsins, and anatoxins.
- Planktothrix: Forms long, slender filaments and can produce microcystins and anatoxins, often associated with an earthy odor.
- Microseira, Nostoc, and Microcoleus: These are primarily benthic cyanobacteria that form mats on the bottom of water bodies and can produce various toxins, including microcystins and saxitoxins.

Environmental Factors Contributing to Blooms and Toxin Production

- Nutrient Enrichment (Eutrophication): Excess nitrogen and phosphorus from agricultural runoff, wastewater discharge, and other anthropogenic sources are primary drivers of cyanobacterial proliferation.
- Temperature: Warmer water temperatures favor the growth of many cyanobacterial species over other algae, extending the bloom season and potentially increasing toxin

production.

- Light Intensity: Optimal light conditions are crucial for photosynthesis and can influence the rate of cyanotoxin synthesis.
- Salinity: While most HABs occur in freshwater, some cyanobacteria (e.g., Nodularia) thrive in brackish or saline environments, producing toxins like nodularins.

Intracellular vs. Extracellular Toxins: Cyanotoxins are initially contained within the cyanobacterial cells (intracellular). They are primarily released into the surrounding water (extracellular) upon cell death, lysis (rupture), or senescence. However, some species can actively excrete toxins into the water without cell rupture. The ratio of intracellular to extracellular toxins can vary significantly, impacting treatment strategies.

Types of Cyanotoxins and Their Health Effects

Cyanotoxins are a chemically diverse group, typically classified based on their chemical structure and the primary organ system they affect. Exposure to these toxins can occur through ingestion of contaminated water or food, inhalation of aerosols, or direct skin contact.

Classification and Specific Effects

Cyanotoxin Class	Primary Toxins	Target Organ/System	Key Health Effects	Bioaccumulation	Carcinogenic Potential (Human)
Hepatotoxins	Microcystins (e.g., MC-LR), Nodularins	Liver, Kidney	Liver damage, inflammation, hemorrhage; gastrointestinal symptoms (diarrhea, vomiting); kidney damage; oxidative stress	Yes (in aquatic organisms)	Inadequate information to assess (for Microcystins)
	Cylindrospermopsin	Liver, Kidney	Liver and kidney damage;	Yes (in aquatic	Inadequate information

			cellular stress; DNA damage; developmental effects; gastrointestinal symptoms	organisms)	to assess
Neurotoxins	Anatoxins (e.g., Anatoxin-a, Homoanatoxin-a), Guanitoxins (formerly Anatoxin-a(S))	Nervous System	Muscle twitching, loss of coordination, salivation, convulsions, respiratory paralysis, death	Yes (in aquatic organisms)	Insufficient information
	Saxitoxins (Paralytic Shellfish Poisoning toxins)	Nervous System	Tingling, numbness, vertigo, respiratory paralysis, death	Yes (in aquatic organisms)	No information available
Dermatotoxins & Irritants	Aplysiatoxin, Lyngbyatoxin, Lipopolysaccharides (LPS)	Skin, Respiratory System	Skin irritation, rashes, eye irritation, upper respiratory irritation, allergy, fever	Not typically	Not typically

Impact on Human Health

Human exposure to cyanotoxins can lead to a range of adverse health outcomes, from mild irritation to severe organ damage and even death. The most commonly reported symptoms include gastrointestinal issues (diarrhea, vomiting), neurological effects (headaches, dizziness, muscle weakness), and dermatological reactions (rashes, skin irritation) . While confirmed

human deaths from recreational exposure are rare, illness outbreaks are well-documented. For instance, a significant outbreak in a dialysis clinic in Brazil in 1996, linked to microcystin-contaminated water, resulted in numerous fatalities, highlighting the severe risks associated with high-level exposure. Children are particularly vulnerable, with a substantial percentage of reported illnesses occurring in individuals under 18.

Impact on Animal Health

Animals, especially domestic animals like dogs and livestock, are highly susceptible to cyanotoxin poisoning due to their tendency to drink directly from contaminated water bodies. Numerous animal illnesses and deaths have been reported globally. Aquatic organisms also suffer significant impacts, including mortality and sub-lethal effects. Bioaccumulation of cyanotoxins, particularly microcystins and nodularins, has been observed in various aquatic invertebrates and vertebrates (e.g., zooplankton, mussels, fish, crayfish), leading to concerns about trophic transfer through the food web and potential risks to wildlife and human consumers of contaminated seafood.

Treatment Methods for Cyanotoxins

Effective removal of cyanotoxins from drinking water and recreational sources is critical for public health protection. However, water treatment plants face several challenges due to the variability of cyanotoxins and the complexity of their removal.

Challenges in Treatment

Variability: Cyanotoxin concentrations and types can fluctuate significantly based on cyanobacteria species, environmental conditions, and time of year, making it difficult to design universally effective treatment strategies.

Resistance to Conventional Methods: Many conventional water treatment processes are not fully effective against dissolved (extracellular) cyanotoxins, and some toxins are resistant to standard disinfection methods like chlorination.

Cell Disruption: Certain pre-oxidation processes, while effective at removing cyanobacterial cells, can inadvertently cause cell lysis, releasing intracellular toxins into the water and increasing the treatment burden.

Cost and Complexity: Advanced treatment options, though highly effective, often entail significant capital and operational costs, requiring specialized equipment and expertise.

Regrowth Potential: Even after successful treatment, the potential for new blooms and subsequent toxin production necessitates continuous monitoring and adaptive management.

Conventional Water Treatment Processes

Coagulation, Flocculation, Sedimentation, and Filtration: These processes are effective at removing intact cyanobacterial cells, thereby preventing the release of intracellular toxins. However, their efficacy against dissolved extracellular toxins is generally limited.

Chlorination: While chlorine is a common disinfectant, its effectiveness against cyanotoxins varies. Some cyanotoxins, particularly microcystins, can be degraded by chlorination, but others may be more resistant, and the process can sometimes lead to the formation of undesirable disinfection byproducts.

Advanced Treatment Options

Activated Carbon Adsorption: Both granular activated carbon (GAC) and powdered activated carbon (PAC) are highly effective at adsorbing a wide range of dissolved cyanotoxins. PAC can be dosed intermittently during bloom events, while GAC filters provide continuous removal.

Advanced Oxidation Processes (AOPs): AOPs, such as ozonation, UV-peroxide, and sulfate radical-based AOPs (SR-AOPs), generate highly reactive radicals (e.g., hydroxyl radicals, sulfate radicals) that can effectively degrade various cyanotoxins. SR-AOPs, in particular, have shown high efficiency and selectivity for cyanotoxin degradation with fewer harmful byproducts.

Membrane Filtration: Technologies like ultrafiltration, nanofiltration, and reverse osmosis can physically remove both cyanobacterial cells and dissolved cyanotoxins due to their small pore sizes. Nanofiltration and reverse osmosis are particularly effective for comprehensive toxin removal but are also the most energy-intensive and costly.

Biological Degradation: Certain microorganisms possess enzymes capable of degrading cyanotoxins. While biological treatment is an emerging area, it is often slower and more difficult to control in a municipal water treatment setting.

Multi-Barrier Approach

A multi-barrier approach, integrating prevention, source control, and optimized treatment, is recommended for robust cyanotoxin management. This involves managing nutrient inputs to reduce bloom formation, monitoring water bodies for cyanobacteria and toxin levels,

and employing a combination of conventional and advanced treatment processes tailored to the specific cyanotoxin profile and water quality characteristics.

Conclusion

Cyanotoxins represent a persistent and escalating environmental and public health challenge. Originating from diverse cyanobacterial species, their production is intricately linked to anthropogenic activities and changing climatic conditions. The wide spectrum of health effects, ranging from acute gastrointestinal and neurological symptoms to chronic liver damage and potential carcinogenicity, underscores the urgency of effective management. While conventional water treatment methods offer partial solutions, the complex nature of cyanotoxins necessitates the implementation of advanced treatment technologies and a comprehensive multi-barrier strategy. Continuous research into cyanotoxin ecology, toxicology, and innovative removal techniques remains paramount to safeguarding water resources and protecting global health against the growing threat of harmful algal blooms.

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KVKS: PROPELLING RURAL DEVELOPMENT THROUGH AGRICULTURE

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Introduction

India has been predominantly a rural country with two thirds of its population still residing in rural areas. India's 70% workforce belongs to rural areas. Father of Nation Late Mahatma Gandhi had once remarked that India lives in her villages. The rural growth and development drive the overall growth and development of India as the rural economy of India constitutes around 50% in national income of India, thus, the rural economy of India is backbone of the Indian economy. Agriculture is a sector which is the source of livelihood for about 50% of the country's population living in rural settings. In some families all the members are engaged in this noble profession. Agricultural development is crucial to the development of country as well as for rural development. With a focus on the agriculture sector and ensuring that the relevant technologies reach out to the farmers well in time, rural development can be more inclusive as well as more effective.

Krishi Vigyan Kendras

The Krishi Vigyan Kendras are district level units catering to the diverse needs of a district, some of which have different agro-climatic zones, different farming situations, and consequently different needs of different stakeholders. Presently, each KVK has a team of six scientists of different disciplines with each one taking care of the subject matter of his/her domain. Although, the initial idea of setting up of these KVKs was to provide vocational training to rural youths in agriculture and other allied sectors; but with the passage of time the roles and responsibilities of these KVKs has changed. Today KVKs provide a platform for interface between farmers, researchers and extension functionaries to address the problems of agriculture and allied sectors. These institutions are engaged in on farm testing to assess the location specific needs of the farm sector, front line demonstrations to establish production potential of

technologies on farmers' fields; to conduct training programmes for farmer, youths, farm women for their skill development, to act as a resource and knowledge centre of agricultural technologies for supporting initiatives of public and private sector for improving the agricultural economy of the country and the state in particular in which they are located and to provide agro advisories to the farming community using Information and Communication Technologies (ICTs) and other tools.

Technology Assessment and Refinement (TAR)

With the passage of time KVKs mandate has underwent a transformation from a single commodity approach to a broad based that now includes not only cereal crops but to other crops like horticultural, medicinal, oilseed, pulses and all other crops that are grown within the concerned district. From Technology Assessment and Refinement (TAR), the mandate of KVKs has now changed to Technology Assessment and Demonstration for its for its wider Application and Capacity Development (TADA-CD). Besides, KVKs are now training young person to become entrepreneurs, providing farm and weather advisory services, celebration of important days, and in devising technologies that help in drudgery reduction. There is also a lot of reporting work in the KVKs. So a meagre strength of six, finds itself overloaded and difficult to cope with the increasing responsibilities. Also a single KVK in districts having population in crores is not sufficient to cater to the needs of all.

Press Information Bureau (PIB)

A statement of the Press Information Bureau (PIB) reveals that there are 731 Krishi Vigyan Kendras' in the country of which 38 are under the control of state governments, 66 under ICAR institutes, 103 under NGOs, 506 under State Agricultural Universities, 3 under Central universities, 3 under Public Sector Undertakings, 7 under deemed to be universities and 5 under other Educational institutes. Uttarpradesh leads the states in having the maximum 89 KVKs. All the KVKs are now under 11 different Agricultural Technology Application Research Institutes (ATARI) previously called as Zonal Project Directorates (ZPDs).

National Institute of Labour Economics Research and Development (NILERD)

A third party evaluation of KVKs was carried out by National Institute of Labour Economics Research and Development (NILERD), an autonomous institute under NITI Aayog in 2018 came out with findings which reveal that the KVKs all across the country are doing a tremendous job accomplishing and achieving many milestones. The evaluation found that KVKs

are playing a proactive role in transferring new technology at field level with beneficial impacts and that these institutes have an edge over other service providers by virtue of having better technical expertise and demonstration abilities. The technologies demonstrated by KVKs were immediately adopted by 40 percent of the farmers and 25 percent adopted them by the next agricultural season. On an average a KVK covers 43 villages and 4300 farmers every year and 80% of villages covered are 10 kilometers away from KVK. The evaluation further said that 96 percent of the farming queries were attended by the KVKs and 42% technologies adopted by farmers resulted in higher productivity and 20 percent resulted in drudgery reduction. About 25% of the persons trained by KVKs started their own self employment ventures.

A meta-analysis study by Bhuvana and his associates in 2019 also revealed that the farmers who are beneficiaries of KVK activities like 'on farm testing', 'front line demonstration', 'training' and other KVK activities are 2.62 times, 3.40 times, 1.37 times and 2.01 times more probable to fall in high socio-economic status, knowledge level, the extent of adoption and farmer's income score category, compared to non-beneficiary farmers and the KVK's activities have a positive impact on farmers of India to have higher socio-economic status with improved knowledge level, the extent of adoption of scientific technologies and farmer's income. Another study by Rathore and Sadana (2023) concluded that Krishi Vigyan Kendra is contributing a lot to rural development through its multidisciplinary teamwork in a participative mode with different farming communities and provides training and proper guidance to improve the skills of rural people.

On-Farm Testing

Overall KVKs drive rural development by Transfer of Technology. KVKs conduct On-Farm Testing (OFT) and Frontline Demonstrations (FLD) which prove the viability of modern technologies and practices directly to rural farmers. The Skill Development & Entrepreneurship programmes of the Kendras providing training to farmers, rural youth, and women, focusing on allied agricultural sectors like dairy, poultry, bee-keeping, and food processing to establish various ventures thereby enabling youths to become job providers instead of job seekers. As a Resource Centers, they **o**perate as district knowledge hubs and provide real-time agro-advisories (e.g., weather updates, soil testing, pest control), ensuring rural communities have the data needed to protect their harvests and increase productivity. KVKs also help in empowerment of farming communities by Promoting Collectivization through Self

Help Groups (SHGs), Farmer Producer Companies (FPCs) and Farmer Producer Organizations (FPOs) allowing small-scale rural farmers to access better markets and negotiate prices. Key digital programmes of KVKs like Kisan Sarthi, m Kisan & Digital Outreach platforms help them to send millions of advisories annually to registered farmers, offering timely, localized solutions. Through initiatives like 'ATTRACTING AND RETAINING YOUTH IN AGRICULTURE (ARYA)' KVKs are equipping rural youth to start independent agri-enterprises and creation of assets, curbing rural-to-urban migration. To tackle climate change, KVKs are also spearheading the establishment of 'Climate Smart Villages' promoting resource-saving farm practices like zero-tillage, integrated farming systems (IFS), and recycling of organic wastes.

Conclusion

It can thus be concluded that as engines of growth, the KVKs are propelling rural development through agricultural development. These institutions have on every occasion lived up to the expectations of farming community as well as of the government and its various agencies. As front line extension institutions, they have no substitute and thus have to be strengthened. At the same time it is also necessary that the human resources working there should not feel discriminated and a victim of apathy and neglect.

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POTASSIUM-RELEASING BACTERIA FOR SUSTAINABLE AGRICULTURE

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Introduction

Agriculture has undergone remarkable transformation over the past century through the adoption of improved crop varieties, mechanization, irrigation technologies, and intensive fertilizer use. These advances have substantially increased food production and contributed to global food security. However, the excessive and continuous application of chemical fertilizers has also created several environmental and agronomic challenges, including soil degradation, nutrient imbalance, declining microbial diversity, groundwater contamination, and increasing production costs. These concerns have intensified the search for environmentally friendly technologies that enhance nutrient-use efficiency while preserving soil health. Among the promising biological approaches, potassium-releasing bacteria (KRB), also known as potassium-solubilizing bacteria (KSB), have emerged as an effective component of sustainable nutrient management.

Potassium is one of the three primary macronutrients required by plants, alongside nitrogen and phosphorus. It plays a central role in numerous physiological and biochemical processes, including photosynthesis, enzyme activation, protein synthesis, carbohydrate metabolism, water regulation, and stress tolerance. Although potassium is abundant in the Earth's crust, nearly 90–98% of soil potassium exists in mineral forms such as feldspar, mica, biotite, muscovite, illite, orthoclase, vermiculite, and smectite, which are inaccessible to plants. Consequently, farmers depend heavily on potash fertilizers to satisfy crop potassium requirements. Unfortunately, a considerable proportion of applied potassium becomes fixed within clay minerals, reducing fertilizer-use efficiency and increasing cultivation costs.

Beneficial soil microorganisms capable of releasing potassium from insoluble minerals offer an environmentally sustainable alternative to chemical fertilizers. These microorganisms mobilize native soil potassium, thereby enhancing nutrient availability, improving crop productivity, and reducing fertilizer dependency.

Importance of Potassium in Plant Growth

Potassium is often referred to as the "quality nutrient" because of its extensive influence on plant growth, yield, and produce quality. Unlike nitrogen, which primarily promotes vegetative growth, and phosphorus, which supports root development and reproductive processes, potassium regulates numerous metabolic activities essential for healthy plant development.

More than sixty enzymes involved in photosynthesis, respiration, protein synthesis, starch formation, and energy metabolism require potassium for activation. Potassium maintains cellular osmotic balance, regulates cytoplasmic pH, and controls stomatal opening and closing, thereby influencing transpiration, carbon dioxide exchange, and water-use efficiency. Adequate potassium nutrition enhances photosynthetic efficiency, promotes efficient transport of sugars through the phloem, strengthens stems, improves root growth, and supports grain filling and fruit development.

Furthermore, potassium plays a critical role in protecting plants against abiotic stresses such as drought, salinity, high and low temperatures, and waterlogging. It also enhances resistance to diseases and insect pests by strengthening cell walls and improving plant defence mechanisms. Potassium deficiency reduces crop productivity, causes chlorosis, scorching of leaf margins, poor grain filling, shortened internodes, and poor fruit quality. Therefore, maintaining sufficient potassium availability is essential for sustainable crop production.

Potassium Forms in Soil

Although soils contain substantial potassium reserves, only a very small proportion is immediately available for plant uptake. Soil potassium exists in four forms: mineral potassium, non-exchangeable potassium, exchangeable potassium, and solution potassium.

Mineral potassium constitutes approximately 90–98% of total soil potassium and is tightly bound within silicate minerals such as feldspar and mica. Non-exchangeable or fixed potassium accounts for about 1–10% and is trapped between clay mineral layers, becoming available only gradually through weathering. Exchangeable potassium represents approximately

1–2% of total soil potassium and is weakly adsorbed on soil colloids. Solution potassium, dissolved in soil water, is the only form directly absorbed by plant roots.

Natural weathering slowly converts mineral potassium into exchangeable and solution forms. However, this process is too slow to satisfy the potassium demand of modern high-yielding crops. Consequently, farmers frequently apply potash fertilizers. Unfortunately, much of the added potassium becomes fixed again within clay minerals, decreasing fertilizer efficiency and increasing production costs. These limitations have stimulated research into biological alternatives capable of unlocking native soil potassium reserves.

Potassium-Releasing Bacteria

Potassium-releasing bacteria are beneficial rhizosphere microorganisms capable of transforming insoluble mineral potassium into soluble forms available for plant uptake. Rather than adding potassium to the soil, these microorganisms enhance the utilization of naturally occurring potassium reserves through biochemical weathering processes.

Several bacterial genera have demonstrated efficient potassium-solubilizing ability, including ***Bacillus, Pseudomonas, Paenibacillus, Burkholderia, Enterobacter, Klebsiella, Arthrobacter, Rhizobium, Agrobacterium, Pantoea, Microbacterium, Myroides, and Acinetobacter.*** Certain fungi, particularly ***Aspergillus, Penicillium, and Streptomyces***, also contribute significantly to potassium mobilization. These microorganisms are naturally present in agricultural soils, particularly in the rhizosphere where they interact closely with plant roots.

Mechanisms of Potassium Release

Potassium-releasing bacteria employ several complementary mechanisms to dissolve potassium-bearing minerals and increase potassium availability.

The primary mechanism involves the production of low-molecular-weight organic acids such as gluconic, citric, oxalic, tartaric, malic, succinic, and lactic acids. These acids lower the pH surrounding mineral particles and release hydrogen ions that replace potassium ions trapped within mineral lattices. Simultaneously, organic acids form stable metal-organic complexes with aluminium, silicon, iron, and calcium, destabilizing the crystal structure of minerals such as feldspar and mica and accelerating mineral weathering.

Another important mechanism involves the production of extracellular polysaccharides (EPS), which facilitate bacterial attachment to mineral surfaces and biofilm formation. Biofilms retain organic acids close to mineral particles, increasing the efficiency of potassium dissolution.

Several bacteria also produce extracellular enzymes and chelating compounds that dissolve silicate minerals and enhance nutrient release.

Research has demonstrated that species such as BACILLUS EDAPHICUS and BACILLUS MUCILAGINOSUS efficiently solubilize feldspar through the production of capsular polysaccharides and gluconic acid. Among all organic acids, gluconic acid is considered one of the most effective compounds responsible for potassium solubilization.

Plant Growth Promotion Beyond Potassium

The benefits of potassium-releasing bacteria extend far beyond potassium nutrition. Most KRB belong to the group of Plant Growth-Promoting Rhizobacteria (PGPR), possessing multiple traits that stimulate plant growth through several mechanisms.

Many KRB produce phytohormones such as indole-3-acetic acid (IAA), gibberellins, and cytokinins that stimulate root elongation, root branching, and overall plant growth. Improved root architecture enables plants to absorb water and nutrients more efficiently.

Several strains simultaneously solubilize phosphorus and zinc, fix atmospheric nitrogen, produce siderophores for iron acquisition, synthesize ammonia, hydrogen cyanide, and hydrolytic enzymes, and suppress plant pathogens through the production of antimicrobial compounds. These multifunctional characteristics improve nutrient-use efficiency while reducing dependence on chemical fertilizers and pesticides.

Role in Stress Tolerance

Climate change has increased the frequency of drought, salinity, heat stress, flooding, and emerging plant diseases, making crop resilience an important objective of sustainable agriculture. Potassium-releasing bacteria contribute significantly to enhancing plant tolerance against both abiotic and biotic stresses.

Under drought conditions, adequate potassium maintains cellular osmotic balance, improves stomatal regulation, and increases water-use efficiency. During salinity stress, potassium helps maintain favourable sodium-to-potassium ratios within plant cells, reducing ionic toxicity and preserving membrane stability.

Several stress-tolerant potassium-solubilizing microorganisms have been identified from extreme environments. Halophilic ACINETOBACTER SOLI, drought-tolerant ACINETOBACTER CALCOACETICUS, PSEUDOMONAS LIBANENSIS, STREPTOMYCES LAURENTII, and PENICILLIUM species have demonstrated excellent potassium-solubilizing abilities under adverse

environmental conditions. Studies have also shown that BACILLUS PUMILUS and PSEUDOMONAS PSEUDOALCALIGENES improve membrane stability, carbohydrate accumulation, and salt tolerance in rice. Similarly, BACILLUS AMYLOLIQUEFACIENS has been reported to alleviate cold stress in wheat while improving potassium uptake.

Agricultural Applications

Numerous greenhouse and field experiments have confirmed the effectiveness of potassium-releasing bacteria across a wide range of crops.

In cereals such as rice, wheat, maize, sorghum, and barley, microbial inoculation improves root development, chlorophyll content, photosynthetic efficiency, nutrient uptake, biomass production, grain filling, and final yield. In vegetable crops including tomato, potato, cucumber, pepper, eggplant, okra, and onion, KRB enhance root growth, foliage development, flowering, fruit quality, and productivity.

Fruit crops and plantation crops also respond positively to microbial inoculation. Increased potassium uptake improves fruit size, sweetness, colour, nutritional quality, shelf life, and market value. Studies have demonstrated improved nutrient absorption and biomass accumulation in apple, tea, banana, tobacco, black pepper, and cotton following inoculation with potassium-solubilizing bacteria.

Co-inoculation strategies have shown even greater benefits. For example, combined application of BACILLUS MUCILAGINOSUS and the nitrogen-fixing bacterium AZOTOBACTER CHROOCOCCUM significantly increased Sudan grass growth. Similarly, KLEBSIELLA VARIICOLA enhanced nutrient uptake in tobacco, while PSEUDOMONAS GESSARDII improved barley growth under field conditions.

Contribution to Sustainable Agriculture

Potassium-releasing bacteria represent an important biological resource for sustainable agriculture. By mobilizing native soil potassium, they reduce dependence on costly chemical fertilizers while improving nutrient-use efficiency. Their application contributes to improved soil fertility, enhanced microbial diversity, increased organic matter decomposition, better nutrient cycling, and healthier rhizosphere ecosystems.

The use of KRB aligns closely with the principles of integrated nutrient management, organic farming, regenerative agriculture, and climate-smart agriculture. Reduced fertilizer application lowers greenhouse gas emissions associated with fertilizer production and

transportation while minimizing nutrient losses through leaching and runoff. These microorganisms also improve long-term soil productivity by maintaining biological activity and promoting balanced nutrient cycling.

Rather than replacing fertilizers completely, potassium-releasing bacteria complement existing nutrient management practices by increasing the availability and utilization efficiency of both native and applied potassium.

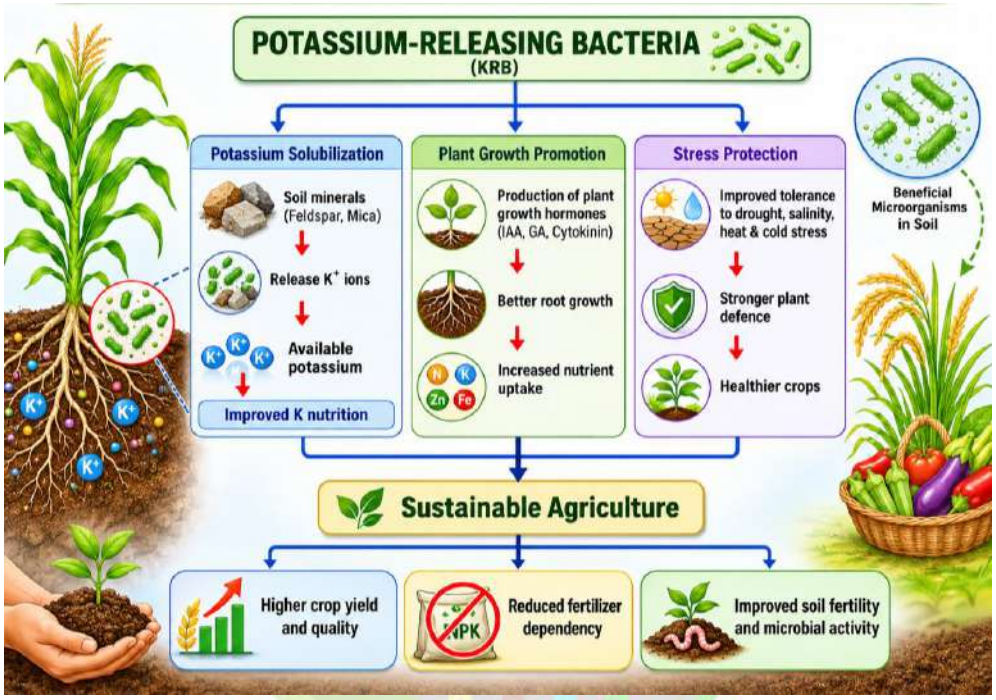


Fig. Roles of Potassium-Releasing Bacteria in Sustainable Agriculture

Future Perspectives

Rapid advances in microbial biotechnology, genomics, and biofertilizer formulation are accelerating the development of highly efficient potassium-solubilizing inoculants. Future research should focus on identifying elite microbial strains adapted to different agro-climatic regions, understanding plant–microbe interactions at the molecular level, and developing stable multi-strain biofertilizer formulations compatible with modern farming systems.

Combining potassium-releasing bacteria with other beneficial microorganisms such as nitrogen fixers, phosphate-solubilizing bacteria, arbuscular mycorrhizal fungi, and plant growth-promoting rhizobacteria may further enhance nutrient-use efficiency and crop resilience under changing climatic conditions.

Conclusion

Potassium-releasing bacteria are emerging as one of the most promising biological tools for sustainable agriculture. By converting insoluble soil potassium into plant-available forms, these beneficial microorganisms improve nutrient uptake, enhance crop productivity, strengthen resistance to environmental stresses, and reduce dependence on chemical fertilizers. Their multifunctional plant growth-promoting properties, including phytohormone production, nutrient solubilization, disease suppression, and stress alleviation, make them valuable components of integrated nutrient management systems. As agriculture seeks environmentally friendly solutions to meet increasing food demands under climate change, potassium-releasing bacteria offer an effective strategy for improving soil health, enhancing fertilizer-use efficiency, reducing production costs, and ensuring long-term agricultural sustainability.

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RESTORING AQUATIC ECOSYSTEMS FOR FUTURE GENERATIONS: AN INDIAN PERSPECTIVE

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Introduction

India is blessed with diverse aquatic ecosystems, including rivers, lakes, reservoirs, wetlands, estuaries, mangroves, lagoons, and an extensive coastline of over 7,500 km. These ecosystems support rich biodiversity, sustain fisheries, provide drinking water, regulate climate, and support the livelihoods of millions of people. Tamil Nadu, with its long coastline, numerous reservoirs, estuaries, and wetlands such as the Pulicat Lagoon, Point Calimere wetlands, and Pichavaram mangrove forests, plays a significant role in India's fisheries and aquatic biodiversity (Alongi, D. M. 2008).

However, increasing population, rapid urbanization, industrial development, intensive agriculture, and climate change have placed tremendous pressure on these valuable ecosystems. Restoring aquatic ecosystems has therefore become one of the most important environmental priorities for ensuring sustainable fisheries, water security, biodiversity conservation, and the well-being of future generations.

Importance of Aquatic Ecosystems in India

Aquatic ecosystems contribute significantly to India's economy and environmental health. They provide fish, shellfish, freshwater resources, transportation, recreation, tourism, and numerous ecosystem services. Inland fisheries and aquaculture contribute substantially to India's fish production, making the country one of the world's leading fish-producing nations.

Wetlands recharge groundwater, mangroves protect coastal villages from cyclones and erosion, estuaries serve as breeding grounds for commercially important fish species, while coral

reefs support marine biodiversity and tourism. Healthy aquatic ecosystems are therefore essential for achieving sustainable development (Barbier, E. B. et al., 2011).

Major Threats to Aquatic Ecosystems

Water Pollution

Untreated domestic sewage, industrial effluents, agricultural runoff containing fertilizers and pesticides, and plastic waste degrade water quality. Heavy metals released from industries accumulate in sediments and aquatic organisms, affecting fish health and posing risks to human consumers (Vörösmarty, C. J. et al., 2010).

Habitat Destruction

Urban expansion, encroachment of wetlands, sand mining, dam construction, dredging, and deforestation alter natural habitats and reduce biodiversity. The destruction of mangrove forests decreases nursery grounds for fish and crustaceans (Dudgeon, D., et al., 2006).

Climate Change

Rising temperatures, irregular rainfall, sea-level rise, marine heatwaves, and ocean acidification are changing aquatic ecosystems. These changes affect fish migration, breeding seasons, species distribution, and overall ecosystem productivity (IPCC. 2023).

Overexploitation of Fisheries

Unsustainable fishing practices, juvenile fishing, destructive fishing gears, and overharvesting reduce fish stocks and threaten long-term fisheries sustainability (FAO. 2024).

Restoration Strategies for Sustainable Aquatic Ecosystems

Pollution Prevention and Water Quality Improvement

Effective wastewater treatment, strict enforcement of pollution control regulations, reduction of single-use plastics, and promotion of eco-friendly agricultural practices are essential for restoring water quality.

Wetland Conservation

Protecting and restoring wetlands improves biodiversity, groundwater recharge, flood control, and carbon sequestration. Wetlands also act as natural filters by removing excess nutrients and pollutants from water (Zedler, J. B. 2000).

Mangrove Restoration

Mangroves are often called the "green shield" of the coast. In Tamil Nadu, mangrove restoration in areas such as Pichavaram and Muthupet has improved fish nursery habitats, protected

coastlines from erosion, and enhanced carbon storage (Kathiresan, K., and Rajendran, N., 2005).

Sustainable Fisheries Management

Science-based fisheries management includes seasonal fishing bans during breeding periods, mesh size regulations, protection of spawning grounds, stock enhancement programmes, and community participation in fisheries conservation (Hilborn R., et al., 2020).

River and Lake Restoration

Removing solid waste, treating sewage before discharge, restoring riverbanks with native vegetation, maintaining environmental flows, and controlling invasive aquatic plants improve ecosystem health (Turner, W, et al., 2003).

Role of Modern Technology

Technological innovations are revolutionizing aquatic ecosystem restoration.

- Geographic Information Systems (GIS) help identify degraded habitats.
- Remote sensing monitors changes in wetlands and coastal ecosystems.
- Environmental DNA (eDNA) enables rapid biodiversity assessment.
- Artificial Intelligence assists in predicting fish stock changes.
- IoT-based water quality sensors provide real-time monitoring of dissolved oxygen, pH, temperature, and other parameters.

These technologies improve scientific decision-making and support ecosystem-based management (Geetha, S., & Gouthami, S. J. S. W. 2016; Thomsen, P. F., & Willerslev, E. 2015; Turner, W, et al., 2003).

Government Initiatives in India

India has launched several programmes to restore aquatic ecosystems.

- ✓ Namami Gange Programme for river rejuvenation.
- ✓ National Plan for Conservation of Aquatic Ecosystems (NPCA).
- ✓ Integrated Coastal Zone Management Programme.
- ✓ Mangrove and Coral Reef Conservation Programme.
- ✓ Wetland conservation under the Wetlands (Conservation and Management) Rules.
- ✓ Blue Economy initiatives promoting sustainable marine resource utilization.
- ✓ PMMSY (Pradhan Mantri Matsya Sampada Yojana) supporting sustainable fisheries and aquatic resource development.

These initiatives encourage integrated management involving government agencies, scientists, local communities, and stakeholders.

Tamil Nadu: A Model for Coastal Ecosystem Restoration

Tamil Nadu possesses one of India's richest coastal ecosystems. The Pichavaram and Muthupet mangroves protect coastal villages from cyclones while supporting fisheries. Pulicat Lagoon serves as an important habitat for migratory birds and commercially valuable fish species (Ramsar Convention Secretariat. 2018). Gulf of Mannar Marine Biosphere Reserve is internationally recognized for its exceptional marine biodiversity, including coral reefs, seagrass meadows, sea cucumbers, dugongs, and ornamental fishes (Edward, J. P., et al., 2019). Community participation, scientific monitoring, habitat restoration, and sustainable fisheries management have demonstrated that ecosystem restoration can simultaneously improve biodiversity conservation and the livelihoods of coastal communities.

Role of Citizens

Every citizen can contribute to aquatic ecosystem restoration by reducing plastic use, conserving water, preventing waste disposal into water bodies, participating in wetland and beach clean-up programmes, supporting sustainable seafood consumption, and spreading environmental awareness. Public participation is essential for long-term conservation success.

Conclusion

Restoring aquatic ecosystems is essential for ensuring ecological balance, food security, climate resilience, and sustainable fisheries. India's rich aquatic resources, particularly those of Tamil Nadu, require coordinated efforts involving governments, researchers, industries, fishing communities, and the public. Scientific management, strong environmental policies, modern technologies, and active community participation can revive degraded ecosystems and secure healthy rivers, lakes, wetlands, estuaries, mangroves, and coastal waters for future generations. Protecting aquatic ecosystems today is an investment in the environmental, economic, and social well-being of tomorrow.

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URBAN BEEKEEPING: A SUSTAINABLE APPROACH FOR POLLINATOR CONSERVATION AND LIVELIHOOD IMPROVEMENT

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Introduction

Urban beekeeping refers to the maintenance of honey bee colonies in cities, towns, rooftops, educational institutions, residential complexes, and urban farms. Rapid urbanization has transformed natural landscapes into residential, industrial, and commercial areas, leading to a decline in pollinator habitats. However, cities are not entirely devoid of floral resources. Urban parks, home gardens, institutional campuses, roadside plantations, botanical gardens, terrace gardens, and recreational green spaces provide abundant nectar and pollen sources for honey bees. Consequently, urban beekeeping has emerged as an innovative and environmentally friendly activity that supports biodiversity conservation, improves pollination, and provides Supplementary income to urban households.

WHY URBAN BEEKEEPING?

Honey bees play an indispensable role in pollination. Approximately one-third of the food consumed by humans depends directly or indirectly on insect pollination, with honey bees contributing significantly (Klein et al., 2007). Urban green spaces containing flowering trees, shrubs, herbs, vegetables, medicinal plants, and ornamentals create favourable conditions for bee foraging. In Indian cities, flowering plants such as neem, drumstick, bottlebrush, pongamia, gulmohar, coconut, mango, ixora, hibiscus, sunflower, marigold, and several ornamental species provide nectar and pollen throughout the year. Native bees such as *Apis cerana indica* and stingless bees (*Tetragonula iridipennis*) are particularly suitable for urban conditions due to their adaptability and relatively gentle nature.

OPPORTUNITIES IN URBAN BEEKEEPING

Enhancing Pollination

Honey bees improve pollination in home gardens, rooftop vegetable gardens, fruit orchards, medicinal plant gardens, and ornamental landscapes. Increased pollination leads to better fruit set, seed production, and improved plant diversity.

Production of Pure Honey

Urban honey is often multifloral and possesses unique flavour, colour, and aroma due to the diversity of flowering plants available in cities. Demand for natural and locally produced honey is increasing among health-conscious consumers.

Additional Income Generation

Urban beekeeping can provide supplementary income through the sale of honey, beeswax, pollen, propolis, queen bees, nucleus colonies, and value-added products such as candles, soaps, cosmetics, lip balms, and medicinal preparations.

Environmental Conservation

Urban apiaries contribute to biodiversity conservation by supporting pollinator populations and increasing awareness about ecological sustainability. Bees help maintain green spaces and improve ecosystem services.

Educational Value

Apiaries established in schools, colleges, universities, and public parks serve as living laboratories for teaching pollination biology, biodiversity conservation, and environmental science. They also encourage citizen participation in pollinator conservation.

Supporting Urban Agriculture

The increasing popularity of terrace gardens, community gardens, and urban farming creates opportunities for integrating beekeeping with food production systems.

CHALLENGES IN URBAN BEEKEEPING

Pesticide Exposure: Mosquito-control programmes, domestic insecticides, and pesticide applications in ornamental plants may negatively affect bee colonies. Awareness regarding pollinator-safe pest management is essential.

Human–Bee Interactions: Improper placement of hives may lead to bee stings and public concern. Colonies should be installed in suitable locations away from crowded areas with adequate flight barriers.

Diseases and Pests: Urban colonies are susceptible to pests and diseases such as wax moths, ants, mites, and microbial pathogens. Regular inspection and colony management are necessary.

Limited Floral Resources: Seasonal shortages of flowering plants can reduce colony strength. Planting nectar- and pollen-rich species that flower throughout the year is important.

Heat Stress: Urban heat island effects can increase hive temperature and affect brood development. Shade and water sources should be provided near colonies.

Lack of Awareness and Regulations: Many cities do not have clear guidelines for urban beekeeping. Public education and supportive policies can promote safe and successful beekeeping practices.

MANAGEMENT TIPS FOR URBAN BEEKEEPERS

- Select suitable bee species such as *Apis cerana indica* or stingless bees.
- Place hives on rooftops, educational campuses, or gardens away from heavy human activity.
- Ensure availability of clean water.
- Plant bee-friendly flowering species throughout the year.
- Avoid pesticide application during flowering periods.
- Conduct regular colony inspection.
- Educate neighbours and communities about the importance of bees.
- Follow local regulations and safety measures.

FURTURE PROSPECTS

Urban beekeeping has immense potential as a component of sustainable city development. Modern technologies such as smart hive sensors, mobile applications, and remote monitoring systems can improve colony management. Pollinator-friendly landscaping and urban Agriculture initiatives will further strengthen urban bee populations.
In India, the integration of beekeeping into educational institutions, public parks, residential communities, and urban farming systems can contribute to biodiversity conservation, nutritional security, and livelihood improvement. Native bees, particularly stingless bees, offer excellent opportunities for promoting eco-friendly beekeeping practices in cities.

Conclusion

Urban beekeeping is more than a honey-producing activity; it is an important tool for environmental conservation, pollinator protection, and sustainable urban development. Proper

management, public awareness, and supportive policies can help transform cities into pollinator-friendly habitats. By integrating beekeeping with urban greening programmes, cities can contribute significantly to biodiversity conservation and ecological resilience.

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CRISPR-CAS9: REVOLUTIONISING AQUACULTURE THROUGH GENE EDITING

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Abstract

Aquaculture currently supplies more than half of the fish consumed worldwide, making it a vital contributor to global food and nutritional security. However, the industry faces significant challenges, including disease outbreaks, slow growth rates, poor feed conversion efficiency, environmental degradation, and the impacts of climate change, all of which reduce productivity and increase production costs. Conventional selective breeding has improved desirable traits in cultured species, but genetic improvement often requires several generations. The emergence of CRISPR-Cas9 genome-editing technology offers a rapid, precise, and efficient alternative for improving economically important traits in fish and shellfish. By enabling targeted modifications of specific genes, CRISPR-Cas9 has shown great potential in enhancing disease resistance, accelerating growth, improving feed utilisation, increasing tolerance to environmental stress, controlling reproduction, and improving product quality. Current research in species such as Nile tilapia, Atlantic salmon, common carp, channel catfish, Pacific oyster, whiteleg shrimp, and zebrafish highlights its expanding role in aquaculture. Despite its numerous advantages, challenges including off-target genetic effects, ethical concerns, regulatory restrictions, public acceptance, and the need for long-term environmental risk assessment must be addressed before widespread commercial application. With continued research, robust regulatory frameworks, and responsible implementation, CRISPR-Cas9 is expected to complement conventional breeding strategies and contribute significantly to sustainable aquaculture, enhanced production efficiency, and global food security in the coming decades.

Keywords: CRISPR-Cas9, genome editing, aquaculture, disease resistance, fish breeding, feed efficiency, sustainable aquaculture, climate resilience.

Introduction

Aquaculture contributes over 50% of the fish consumed globally and is crucial in global food security. To meet the growing demand for aquatic food, fish farmers are faced with several challenges, including outbreaks of disease, poor feed conversion ratio, slow growth rate, environmental degradation, and climate change. These problems cause a loss of productivity and higher production costs. Traditional breeding has also played an important role in enhancing fish production, with changes taking several generations to be seen. In recent advances in molecular biotechnology, a new technology known as CRISPR-Cas9 has emerged, which is a new method of gene editing that can make very precise changes in the DNA of living organisms. It's making big strides in biomedical and agricultural research, and is rapidly becoming more significant in aquaculture due to its potential to contribute to economically important traits in fish and shellfish.

What is CRISPR-Cas9?

The CRISPR (Clustered Regularly Interspaced Short Palindromic Sequence) is a regular short sequence of palindromic repeats, and the Cas9 is a DNA-cutting enzyme. In combination, they make a potent gene-editing tool that was first identified as a natural defence system in bacteria against viruses. Scientists used this defence mechanism to create a genome editing device that can be used to tweak the genes that control particular traits. Unlike traditional breeding, which can take several generations to bring to fruition, CRISPR-Cas9 directly modifies a gene of interest, thus providing faster and more precise genetic improvement. One way to describe it is like a book with thousands of instructions—that's what DNA is. If the sentence is wrong, the CRISPR-Cas9 is like a good editor that finds the correct sentence, deletes the error, and adds the correct sentence, but doesn't change any other sentences.

How Does CRISPR-Cas9 Work?

The CRISPR-Cas9 system works in four main steps:

Scientists determine the gene for a desired trait. The purpose of the guide RNA (gRNA) is to target that particular DNA sequence. The Cas9 is then targeted to the target location and cuts the DNA there. In DNA repair, researchers can cut, transcribe, and splice in pieces of DNA to get

the desired trait. This precision method allows for efficient and targeted editing of genes, which is more precise than many previous genetic engineering methods.

Applications of CRISPR-Cas9 in Aquaculture

1. **Disease Resistance:**

Disease outbreaks are still one of the most limiting factors in aquaculture. The researchers are using the CRISPR-Cas9 system to edit genes related to the immune system so that the fish can better withstand bacterial, viral and parasitic infections. These enhancements may help to lower death rates and antibiotic use and increase farm profitability.

2. **Faster Growth**

The growth rate of fish is the key to the economic success of aquaculture. The changes in growth-related gene function can make fish mature faster without any growth deformity, enabling them to reach market size faster.

3. **Improved Feed Efficiency**

Feed production costs are nearly 50-70% of aquaculture production costs. CRISPR-Cas9 can enhance the metabolism of nutrients and feed conversion efficiency, making fish more efficient at using their feed in production and lowering production costs.

4. **Climate Resilience**

Water temperature fluctuations, salinity and environmental stress have increased due to climate change. Scientists are identifying genes that can withstand stress and create fish that can survive in varying environmental conditions.

5. **Reproductive Control**

Farmed fish can also interbreed with wild fish, and so lead to biodiversity issues. Gene editing can create sterile fish, which helps to minimise ecological risks and facilitate program management.

6. **Improved Product Quality**

Muscle development and nutritional composition genes are also being investigated to enhance flesh quality, fillet yield and consumer acceptance.

Current Research in Aquaculture

Several economically important aquatic species are currently being studied using CRISPR-Cas9 technology.

- Nile tilapia – reproductive control and growth improvement

- Atlantic salmon – disease resistance and growth performance
- Common carp – enhanced immune function
- Channel catfish – bacterial disease resistance
- Pacific oyster – improved stress tolerance
- Whiteleg shrimp – viral disease resistance
- Zebrafish – model organism for gene function studies

These studies demonstrate the expanding role of genome editing in aquatic animal improvement.

Advantages

- Precise genome editing
- Faster than conventional breeding
- Improved disease resistance
- Better feed conversion efficiency
- Reduced dependence on antibiotics
- Enhanced productivity
- Supports sustainable aquaculture
- Potential to improve food security

Challenges

Although CRISPR-Cas9 is a promising technology, several challenges remain.

- Off-target genetic modifications
- Ethical concerns regarding gene editing
- Public acceptance of gene-edited foods
- Regulatory restrictions in different countries
- High research costs
- Requirement for skilled personnel
- Need for long-term environmental risk assessment

Responsible use and transparent regulation are essential for successful adoption.

Future Prospects

CRISPR-Cas9 technology will be a more and more integral part of sustainable aquaculture. Future research could be on producing fish with natural resistance to disease, tolerance to environmental stress and good feed conversion ratios. Gene editing can be used to improve aquaculture production and reduce environmental footprints along with selective

breeding, precision nutrition and better farm management. With the increasing understanding of science and the changes in rules, CRISPR-Cas9 could be a part of future fish breeding programs.

Conclusion

The use of CRISPR-Cas9 has revolutionised the field of biological research by offering a highly precise and efficient genome editing technique. In aquaculture, the technology presents tremendous potential for enhanced resistance to disease, growth, feed efficiency, environmental tolerance and quality of product. The ethical, ecological and regulatory considerations are important, but proper usage of CRISPR-Cas9 technology will go along with traditional breeding techniques and help develop sustainable aquaculture production. Future integration of this technology into fish production systems will be determined by continued research, public awareness and science-based regulation.

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IMPACT OF THE 2026–2027 EL NIÑO ON THE MICROENVIRONMENT OF FARMERS' FIELDS: IMPLICATIONS FOR AGRICULTURAL EXTENSION AND CLIMATE-RESILIENT AGRICULTURE

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Abstract

The 2026–2027 El Niño is expected to significantly affect global agriculture through altered rainfall patterns, rising temperatures, and increased frequency of droughts and extreme weather events. According to the World Meteorological Organization (WMO) and the National Oceanic and Atmospheric Administration (NOAA), there is an 80–82% probability of El Niño developing during May–July 2026 and a 90–96% likelihood of persisting through the 2026–2027 winter. In India, the India Meteorological Department (IMD) projects the 2026 southwest monsoon at approximately 92% of the Long Period Average (LPA), indicating below-normal rainfall. These climatic anomalies are expected to alter the microenvironment of farmers' fields by reducing soil moisture, increasing soil and canopy temperatures, changing relative humidity, and increasing evapotranspiration, thereby affecting crop growth and productivity. The study emphasizes the importance of agricultural extension services in promoting climate information, early warning systems, drought-tolerant varieties, efficient water management, conservation agriculture, and digital advisory services to strengthen farmers' adaptive capacity. Adoption of these climate-resilient strategies can reduce production risks and enhance the sustainability of agricultural livelihoods under future El Niño conditions.

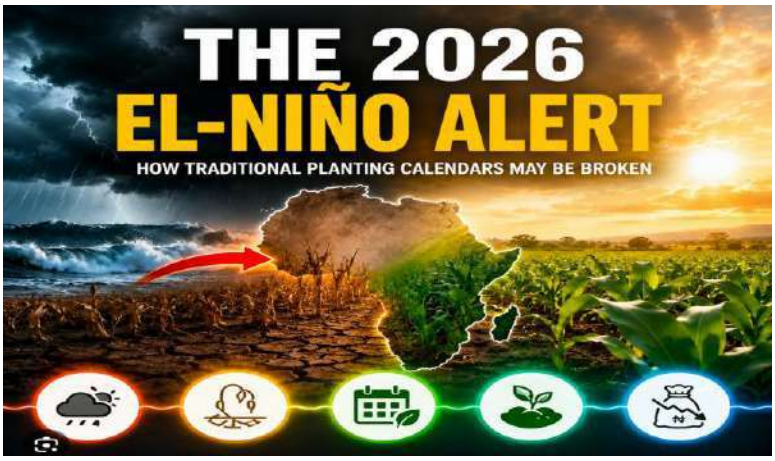
Keywords: El Niño (2026–2027), ENSO, microenvironment, agricultural extension, climate-resilient agriculture, soil moisture, crop productivity, climate adaptation.

Introduction

Climate variability is one of the major challenges affecting the global environmental productivity, with the ENSO being a key driver of changes in rainfall, temperature, and extreme weather events. The 2026-2027 El-Nino projected to develop a high probability of heat stress, increasing the risk of drought, water scarcity in many agricultural fields. In India, the India Meteorological Department (IMD) projects the 2026 southwest monsoon at approximately 92% of the Long Period Average (LPA), indicating below-normal rainfall that could adversely affect rainfed farming systems.

El Niño-induced climatic variability directly alters the microenvironment of farmers' fields, including soil moisture, soil temperature, relative humidity, evapotranspiration, and crop canopy conditions. These changes influence crop growth, water-use efficiency, nutrient availability, and the incidence of pests and diseases, ultimately affecting agricultural productivity and farm resilience. Although numerous studies have examined the influence of El Niño on rainfall and crop yields, limited attention has been given to its effects on the field-level microenvironment and the role of agricultural extension in supporting climate adaptation.

Therefore, this study reviews the potential impacts of the 2026–2027 El Niño on the microenvironment of farmers' fields and discusses its implications for agricultural extension and climate-resilient farming. The findings aim to support evidence-based decision-making for researchers, extension professionals, policymakers, and farming communities to improve agricultural sustainability under future climate challenges .



The Objectives of the study

1. To characterize the key micro environmental changes in farmers fields.
2. To examine how these micro – environment changes affect crop performance, input use, and livelihood risks for smallholder farmers.
3. To evaluate the adequacy and responsiveness of agricultural extension approaches in helping farmers in managing El – Nino related climate risks.
4. To propose extension strategies and policy recommendations.

4. Field level micro-environment changes under El Nino

Example: In the kharif season of 2026 , a small farmer in drought prone Maharashtra waits for the usual mid-june monsoon showers to sow soybean. This year, the rain arrive late and in small, scattered bursts. Days are hot and nights are warm. On his fields, the topsoil is dry and powdery, and when he presses his hand into the soil, he feels heat and almost no moisture.

5. Extension and climate- resilience response in the example

In upcoming months July-August , he receives mobile messages that El-Nino is likely and that monsoon may be delayed , so he plans for short duration ,drought tolerant soybean or even millets instead of long duration varieties. By adjusting sowing dates, crop choices, and micro-environment management (mulching, water-harvesting, diversified crops) he reduces the impact of the 2026-2027 El – Nino on his field and livelihood , even though the larger climate remains unfavorable. Digital tools (mobile advisories, apps, social media) are key for delivering timely climate -informed devices at scale.

Conservation agriculture, mulching , contour bunding,agroforestry and water-harvesting all help stabilize soil moisture, reduce heat , and control erosion.Stress tolerant and short-duration varieties, diversified cropping and mixed livestock systems spread risk and buffer income. These practices work best when backed by supportive institutions, credit, insurance, and climate smart extension.

Conclusion

El Nino is now a recurring, structural risk, so extension must prioritize long term resilience rather than one off disappear response. The core one are to embed climate information in everyday advisory work , support farmer with resilient practices, and link digital climate services

, on ground extension and policy support. Together these can help smallholders adapt their fields and livelihoods to repeated El – Nino and broader climate change.

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DIGITAL TWIN TECHNOLOGY FOR INTEGRATED WATER RESOURCE AND AQUATIC ECOSYSTEM MANAGEMENT

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Abstract

The increasing pressure on freshwater and coastal ecosystems due to rapid urbanization, industrial development, agricultural intensification, climate change, and population growth has necessitated the adoption of innovative digital technologies for sustainable water resource management. Digital Twin Technology (DTT), originally developed in the manufacturing and aerospace industries, has recently emerged as a transformative tool for environmental monitoring and decision-making. A digital twin is a dynamic virtual representation of a physical system that continuously receives real-time information from sensors, remote sensing platforms, Internet of Things (IoT) devices, and other monitoring networks. This real-time synchronization enables simulation, prediction, optimization, and proactive management of complex aquatic systems. In integrated water resource management (IWRM), digital twins facilitate improved water allocation, flood forecasting, reservoir operation, groundwater management, and water quality monitoring. Similarly, in aquatic ecosystem management, they assist in habitat restoration, biodiversity conservation, pollution control, climate adaptation, and ecosystem health assessment. The integration of Artificial Intelligence (AI), Geographic Information Systems (GIS), Remote Sensing (RS), cloud computing, and machine learning further enhances the predictive capability of digital twins. Despite challenges related to data quality, infrastructure requirements, computational complexity, cybersecurity, and implementation costs, Digital Twin Technology offers significant opportunities for sustainable and adaptive management of aquatic

environments. As countries increasingly embrace smart environmental governance, digital twins are expected to become an essential component of future water management strategies

Keywords: Digital Twin, Internet of Things, Artificial Intelligence, Remote Sensing, GIS, Smart Water Management.

Introduction

Water is one of the most valuable natural resources, supporting human survival, agriculture, industries, energy production, and the functioning of diverse aquatic ecosystems. However, freshwater resources constitute less than 3% of the Earth's total water, with only a small proportion readily available for human use. Rapid population growth, urbanization, industrialization, agricultural expansion, and climate change have placed unprecedented pressure on these limited water resources. At the same time, aquatic ecosystems such as rivers, lakes, reservoirs, wetlands, estuaries, mangroves, and coastal waters are increasingly threatened by pollution, eutrophication, habitat degradation, invasive species, and hydrological alterations. These challenges have highlighted the need for innovative technologies that enable continuous monitoring, accurate prediction, and sustainable management of water resources and aquatic ecosystems (United Nations, 2023; UNESCO, 2024).

Conventional water resource management mainly depends on periodic field surveys, historical datasets, and static hydrological models. Although these approaches have contributed significantly to water planning and management, they often fail to capture the dynamic nature of environmental systems or provide timely information during extreme events such as floods, droughts, pollution incidents, and harmful algal blooms. The concept of **Integrated Water Resources Management (IWRM)** addresses these limitations by promoting the coordinated management of water, land, and associated natural resources to achieve environmental sustainability, economic development, and social equity. Successful implementation of IWRM requires real-time environmental monitoring, predictive modelling, and rapid decision-making, which have accelerated the adoption of advanced digital technologies (Global Water Partnership, 2020).

Among these innovations, **Digital Twin Technology (DTT)** has emerged as a powerful tool for environmental management. A digital twin is a dynamic virtual representation of a physical system that continuously receives real-time information from sensors, Internet of Things (IoT) devices, remote sensing platforms, and monitoring networks. By integrating these data

with hydrological, hydraulic, and ecological models, digital twins can simulate current conditions, predict future scenarios, and evaluate management strategies before they are implemented. The incorporation of Artificial Intelligence (AI), Machine Learning (ML), Geographic Information Systems (GIS), cloud computing, and remote sensing further enhances the predictive accuracy and decision-support capabilities of digital twins, making them highly suitable for managing complex water systems (Tao et al., 2019; Fuller et al., 2020; Qi et al., 2021).

Digital Twin Technology is increasingly being applied to reservoir operation, flood forecasting, groundwater management, irrigation planning, water quality assessment, and aquatic ecosystem conservation. It enables continuous monitoring of ecosystem health, early detection of pollution and harmful algal blooms, assessment of climate change impacts, and evaluation of restoration strategies under different environmental scenarios. Although challenges such as high implementation costs, data integration, cybersecurity, and technical expertise remain, ongoing advancements in digital infrastructure and smart environmental technologies are expected to accelerate its adoption. Consequently, Digital Twin Technology represents a transformative approach toward proactive, data-driven, and sustainable management of water resources and aquatic ecosystems, contributing significantly to global water security and the achievement of the United Nations Sustainable Development Goals (European Commission, 2022; UNESCO, 2024).

Concept of Digital Twin Technology

Digital Twin Technology (DTT) is a digital representation of a physical object, system, or process that continuously updates itself using real-time data collected through sensors, Internet of Things (IoT) devices, satellite observations, and monitoring networks. Unlike conventional simulation models, digital twins maintain a dynamic connection with their physical counterparts, enabling continuous monitoring, predictive analysis, and optimization of system performance. The concept was first introduced in manufacturing and aerospace engineering but has rapidly expanded into healthcare, smart cities, agriculture, and environmental management. By integrating real-time observations with advanced computational models, digital twins support informed decision-making and proactive management of complex systems (Grieves & Vickers, 2017; Fuller et al., 2020).

In water resource and aquatic ecosystem management, digital twins create virtual models of rivers, reservoirs, lakes, estuaries, wetlands, and coastal ecosystems. These models continuously receive information on hydrological, meteorological, and water quality parameters, allowing managers to simulate different environmental scenarios, predict future conditions, and evaluate management strategies before implementing them in the real world. This predictive capability improves resource utilization, reduces environmental risks, and supports sustainable ecosystem management (Tao et al., 2019).

Components and Architecture of Digital Twin Systems

A Digital Twin system consists of several interconnected components that enable continuous interaction between the physical environment and its virtual counterpart. The physical layer includes sensors, monitoring stations, drones, autonomous vehicles, and satellite systems that collect real-time environmental data such as water level, temperature, dissolved oxygen, turbidity, salinity, nutrient concentration, and meteorological variables. These observations are transmitted through communication networks such as wireless sensor networks, 5G, or cloud platforms to centralized databases for processing (Qi et al., 2021).

The virtual layer integrates hydrological models, hydraulic simulations, ecological models, and Geographic Information Systems (GIS), Artificial Intelligence (AI), and Machine Learning (ML) algorithms to replicate the physical system digitally. Cloud computing provides the computational infrastructure required for data storage, visualization, predictive simulations, and decision support. Feedback mechanisms continuously synchronize the virtual model with the physical system, enabling adaptive management and real-time optimization. This integrated architecture forms the foundation of intelligent environmental monitoring and smart water management systems (Jones et al., 2020; Fuller et al., 2020).

Applications in Integrated Water Resource Management

Digital Twin Technology has become an important tool for Integrated Water Resource Management (IWRM) by enabling real-time monitoring, simulation, and optimization of water resources. It assists in reservoir operation, flood forecasting, drought assessment, groundwater management, irrigation scheduling, urban drainage planning, and watershed conservation. By integrating real-time hydrological data with predictive models, digital twins enable managers to evaluate multiple water allocation scenarios and optimize water distribution while maintaining

ecological flow requirements. This improves water-use efficiency, minimizes resource conflicts, and enhances climate resilience (Global Water Partnership, 2020; UNESCO, 2024).

Digital twins also support water quality management by continuously monitoring parameters such as pH, dissolved oxygen, nutrients, turbidity, and contaminants. Early detection of pollution events allows authorities to respond rapidly before environmental damage becomes severe. Furthermore, climate change simulations incorporated within digital twins enable planners to evaluate long-term adaptation strategies for floods, droughts, and changing rainfall patterns, thereby strengthening sustainable water governance (European Commission, 2022).

Applications in Aquatic Ecosystem Management

Aquatic ecosystems are dynamic environments that require continuous monitoring to maintain ecological integrity. Digital Twin Technology enables researchers and environmental managers to develop virtual representations of lakes, rivers, estuaries, mangroves, coral reefs, and coastal ecosystems by integrating field observations, remote sensing data, hydrodynamic models, and biological monitoring. These digital ecosystems provide real-time information on habitat conditions, biodiversity, nutrient cycling, sediment transport, and ecosystem productivity, thereby supporting science-based conservation planning (UNESCO, 2024).

Digital twins also facilitate early detection of harmful algal blooms, hypoxia, invasive species, fish mortality, habitat degradation, and pollution hotspots. By simulating ecosystem responses under different environmental conditions, managers can evaluate restoration measures, pollution control strategies, and habitat improvement programs before implementation. This predictive capability enhances ecosystem resilience while reducing the uncertainty associated with conventional environmental management approaches (Tao et al., 2019; Fuller et al., 2020).

Role of Artificial Intelligence, IoT, GIS and Remote Sensing

Artificial Intelligence (AI), Internet of Things (IoT), Geographic Information Systems (GIS), and Remote Sensing (RS) are key enabling technologies that significantly enhance the capabilities of Digital Twin systems. IoT-based sensors continuously collect environmental data from water bodies, while AI and Machine Learning algorithms analyze these large datasets to identify patterns, detect anomalies, predict future conditions, and recommend optimal management actions. These intelligent analytical capabilities improve forecasting accuracy for floods, droughts, pollution events, and ecosystem changes (Qi et al., 2021).

GIS provides spatial analysis and visualization by integrating hydrological, ecological, and socio-economic information into a unified platform. Remote sensing technologies using satellite imagery and drones supply large-scale observations of land use, vegetation cover, water quality, chlorophyll concentration, sediment dynamics, and coastal changes. Together, these technologies enable comprehensive monitoring and real-time decision support, making Digital Twin Technology an effective platform for sustainable water and ecosystem management (European Commission, 2022).

Benefits and Opportunities

Digital Twin Technology offers numerous benefits for integrated water resource and aquatic ecosystem management. Real-time monitoring improves situational awareness, while predictive simulations enable proactive decision-making instead of reactive responses. Digital twins reduce operational costs by optimizing infrastructure performance, minimizing water losses, improving reservoir operation, and reducing maintenance requirements. The technology also enhances disaster preparedness by providing early warnings for floods, droughts, pollution incidents, and ecosystem disturbances, thereby protecting both human communities and natural ecosystems (Fuller et al., 2020).

The technology further supports sustainable development through efficient resource utilization, ecosystem conservation, climate adaptation, and stakeholder participation. Its ability to integrate multidisciplinary datasets facilitates collaboration among engineers, hydrologists, ecologists, policymakers, and local communities. As smart environmental monitoring systems continue to expand worldwide, digital twins are expected to become a cornerstone of future environmental governance and sustainable water management (United Nations, 2023).

Challenges and Limitations

Despite its significant advantages, Digital Twin Technology faces several technical and institutional challenges. Developing accurate digital twins requires extensive sensor networks, high-quality datasets, reliable communication infrastructure, cloud computing resources, and advanced modelling expertise. Data inconsistencies, sensor failures, model uncertainties, interoperability issues, and cybersecurity risks may affect system reliability and reduce prediction accuracy. Additionally, the high initial investment and maintenance costs can limit implementation, particularly in developing countries (Jones et al., 2020).

Institutional barriers also exist, including limited technical capacity, inadequate data-sharing policies, lack of standardized protocols, and insufficient interdisciplinary collaboration. Addressing these challenges requires investment in digital infrastructure, skilled personnel, international cooperation, and supportive government policies. Continuous research and technological innovation will be essential to improve the scalability and affordability of Digital Twin systems for environmental applications (Qi et al., 2021).

Future Perspectives

The future of Digital Twin Technology is closely linked with advances in Artificial Intelligence, cloud computing, edge computing, big data analytics, 5G communication, and autonomous monitoring systems. Future digital twins are expected to provide highly accurate real-time simulations of entire river basins, coastal zones, and marine ecosystems, enabling adaptive management under changing climatic conditions. Integration with climate models will further improve long-term planning for water security, biodiversity conservation, and disaster risk reduction (European Commission, 2022).

Emerging technologies such as blockchain for secure data management, quantum computing for complex environmental simulations, and citizen science through mobile applications are expected to further strengthen digital twin platforms. As governments increasingly adopt smart environmental policies, Digital Twin Technology will play a crucial role in achieving sustainable water management and fulfilling global commitments under the United Nations Sustainable Development Goals (UNESCO, 2024).

Conclusion

Digital Twin Technology represents a transformative advancement in integrated water resource and aquatic ecosystem management by combining real-time monitoring, predictive modelling, and intelligent decision support within a unified digital platform. Through the integration of IoT, Artificial Intelligence, GIS, Remote Sensing, and cloud computing, digital twins enable accurate simulation of environmental processes, optimize resource utilization, improve ecosystem conservation, and strengthen resilience against climate change. These capabilities significantly enhance the efficiency of water management while supporting evidence-based environmental governance (Tao et al., 2019; Fuller et al., 2020).

Although challenges related to infrastructure, data quality, cybersecurity, and implementation costs remain, continued technological development and policy support are

expected to accelerate the adoption of digital twins across environmental sectors. As digital transformation becomes increasingly important for sustainable development, Digital Twin Technology has the potential to revolutionize the management of freshwater, estuarine, and marine ecosystems, ensuring long-term water security and ecological sustainability for future generations.

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LOT BASED MONITORING OF MARINE ENGINEERING PERFORMANCE AND SAFETY

Article ID: AG-VO6-I07-129

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Abstract

The Internet of Things (IoT) has emerged as a transformative technology in marine engineering, significantly improving the monitoring and management of marine engine performance and operational safety. By integrating advanced sensors, communication technologies, and data analytics, IoT-enabled systems continuously collect and transmit critical engine parameters, including temperature, pressure, fuel consumption, vibration levels, and engine speed. This real-time data enables early identification of abnormal operating conditions, supports predictive fault detection, and facilitates timely preventive maintenance. The implementation of IoT-based monitoring systems enhances fuel efficiency, reduces maintenance and operating costs, minimizes unexpected engine failures, and improves the overall reliability and safety of marine vessels. These technologies are widely applicable across fishing vessels, commercial shipping fleets, and offshore platforms, supporting the transition toward intelligent, connected, and sustainable maritime operations. Looking ahead, the integration of artificial intelligence (AI) with IoT is expected to further strengthen the capabilities of marine monitoring systems by enabling advanced predictive analytics, autonomous decision-making, and optimized engine performance.

Introduction

Marine engines play a vital role in ensuring the safe and efficient operation of vessels. Their reliable performance is essential for maintaining navigational safety, optimizing fuel consumption, and supporting uninterrupted maritime activities. Any unexpected engine malfunction during operation can result in significant financial losses, increased maintenance expenses, operational delays, and potential risks to the crew, cargo, and marine environment. Traditional maintenance practices, which primarily rely on scheduled inspections and routine servicing, are often unable to detect the early stages of developing faults such as excessive vibration, overheating, lubrication deficiencies, or abnormal pressure variations.

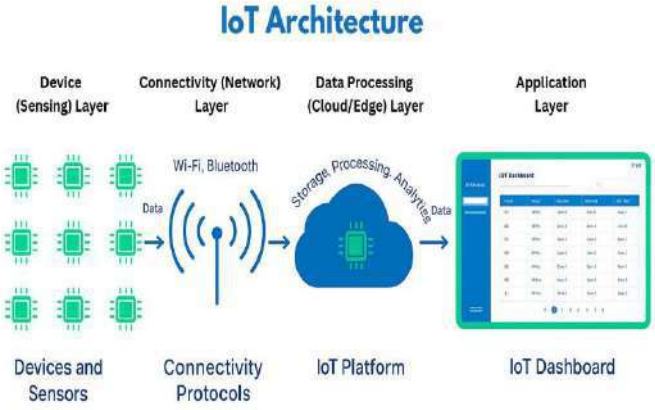
The Internet of Things (IoT) offers a modern and intelligent approach to addressing these challenges through continuous monitoring of marine engine performance. By integrating smart sensors, wireless communication technologies, and cloud-based data analytics, IoT-enabled systems continuously acquire and transmit critical engine operating parameters in real time. This enables the timely identification of abnormal operating conditions, allowing maintenance personnel to take corrective action before minor issues develop into major failures. In addition to improving the reliability of marine engines, IoT-based monitoring systems enhance fuel efficiency, reduce maintenance costs, minimize unexpected downtime, and improve the overall safety and operational performance of marine vessels. These capabilities contribute to more effective asset management and support sustainable maritime operations by optimizing engine performance and reducing unnecessary resource consumption. Furthermore, the integration of IoT with artificial intelligence (AI), machine learning, and advanced predictive analytics is expected to drive the next generation of smart marine monitoring systems, enabling autonomous diagnostics, intelligent maintenance planning, and more efficient, resilient, and environmentally sustainable marine transportation.

Concept of IoT in Marine Engine Monitoring

The Internet of Things (IoT) refers to a network of interconnected devices that collect, exchange, and analyze data through the internet. In marine engineering, IoT systems use multiple sensors installed on engines and machinery to collect real-time information about engine conditions.

The collected data is transmitted through wireless communication systems to onboard monitoring units or cloud-based platforms, where advanced software analyzes the engine

performance and provides alerts whenever abnormal conditions occur.



Picture: Real-Time loT Dashboard for Smart Device Monitoring

Source: https://codestoresolutions.com

Basic components of IoT-based engine monitoring include:

- Sensors and data acquisition devices
- Microcontrollers and processing units
- Communication networks
- Cloud data storage systems
- Data analytics and monitoring software
- User interface dashboards

Working Principle of IoT-Based Marine Engine Monitoring System

The IoT-based monitoring system operates through continuous data acquisition, transmission, processing, and analysis.

Step i: Data Collection

Sensors installed in different parts of the marine engine measure important operating parameters such as:

Engine temperature, Lubricating oil pressure, Cooling water temperature, Fuel consumption rate, Engine speed (RPM), Vibration levels, Exhaust gas temperature, Emission levels

Step ii: Data Transmission

The collected information is transferred through communication technologies such as: Wi-Fi, Bluetooth, Satellite communication, Cellular networks, Marine communication systems

Step iii: Data Processing and Analysis

The received data is analyzed using cloud platforms and artificial intelligence algorithms. The system identifies abnormal patterns and predicts possible engine failures.

Step iv: Alert and Decision Making

When unusual conditions are detected, the system sends warnings to engineers through displays, mobile applications, or control rooms, allowing preventive action before major damage occurs.

4) Sensors Used in Marine Engine Monitoring

Modern IoT-based monitoring systems use different types of sensors:

i) Temperature Sensors

Temperature sensors monitor engine coolant temperature, cylinder temperature, and exhaust gas temperature. Excessive temperature indicates overheating, cooling system failure, or lubrication problems.

ii) Pressure Sensors

Pressure sensors measure lubricating oil pressure, fuel pressure, and cylinder pressure. Abnormal pressure values help identify mechanical problems.

iii) Vibration Sensors

Vibration monitoring helps detect problems in engine components such as bearings, shafts, and rotating machinery. Increased vibration levels may indicate component misalignment, imbalance or mechanical wear.

iv) Fuel Monitoring Sensors

These sensors measure fuel consumption and help improve fuel efficiency by optimizing engine operation.

iv) Emission Sensors

Emission monitoring sensors measure exhaust gases and help maintain environmental standards by reducing harmful emissions.

Parameters Monitored by IoT Systems

IoT-based marine engine monitoring provides continuous information on:

a) Engine RPM and power output
b) Fuel consumption
c) Engine load conditions

d) Lubrication system performance
e) Cooling system efficiency
f) Exhaust temperature
g) Carbon emission levels
h) Mechanical vibrations
i) Operating hours
j) Maintenance requirements

This information helps engineers understand engine health and improve vessel performance.

Role of IoT in Predictive Maintenance

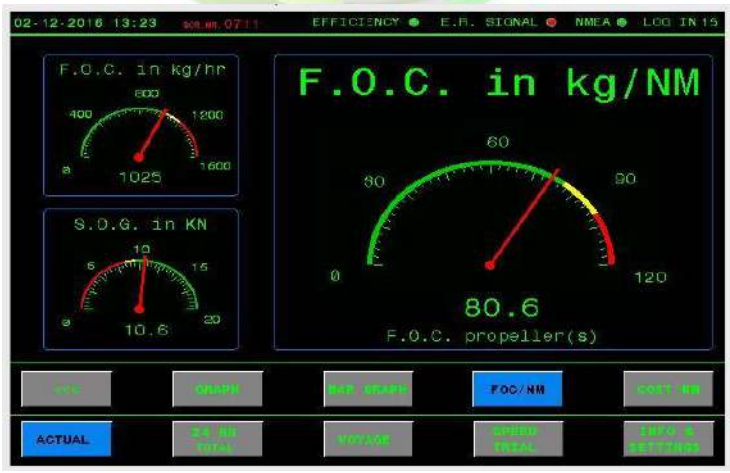
One of the major advantages of IoT technology is predictive maintenance. Traditional maintenance follows fixed schedules, whereas IoT systems predict maintenance requirements based on actual engine conditions.

By analyzing historical and real-time data, the system can identify early warning signs such as: Excessive vibration, Abnormal temperature rise, Reduced fuel efficiency, Lubrication problems, Component deterioration.

Predictive maintenance reduces unexpected engine failures, minimizes repair costs, and increases engine lifespan.

Improving Fuel Efficiency through IoT

Fuel is one of the largest operating expenses in marine transportation. IoT monitoring systems help reduce fuel consumption by analyzing engine performance and operating conditions.



Picture: Fuel optimization and vessel performance monitoring

Source: https://eefting-energy.nl/media/

Benefits includes:

A. Optimized engine speed control
B. Identification of fuel wastage
C. Improved voyage planning
D. Better load management
E. Reduced operational costs.

For fishing vessels, improved fuel efficiency directly increases profitability by reducing fishing trip expenses.

Enhancing Marine Safety Using IoT

Safety is a major concern in marine operations. Engine failure at sea can lead to vessel accidents, financial losses, and risks to human life.

IoT-based safety monitoring provides:

1. Early detection of engine problems
2. Automatic emergency alerts
3. Remote engine monitoring
4. Reduced risk of machinery failure
5. Improved decision-making during emergencies

Real-time monitoring allows operators to take corrective action before a critical situation develops.

Applications of IoT-Based Marine Engine Monitoring

i) Fishing Vessels

IoT systems help fishermen monitor engine health, fuel usage, and operational efficiency during long fishing voyages.

ii) Commercial Ships

Large vessels use IoT technology for engine optimization, reducing fuel consumption and improving reliability.

iii) Offshore Platforms

IoT monitoring supports safe operation of heavy machinery used in offshore industries.

iv) Naval Vessels

Advanced monitoring systems improve mission reliability and equipment readiness.

Challenges and Limitations

Although IoT provides many benefits, some challenges remain:

High initial installation cost, Requirement for reliable communication networks, Cybersecurity risks, Need for skilled technical personnel, Data storage and management issues, Maintenance of sensors in harsh marine environments.

Future developments in artificial intelligence and advanced communication systems will help overcome these challenges.

Future Scope of IoT in Marine Engineering

The future of marine engineering will involve smarter and more autonomous vessels. Integration of IoT with artificial intelligence, machine learning, and digital twin technology will enable advanced engine simulation and automatic fault prediction.

Future IoT systems may provide:

Autonomous engine control, AI-based failure prediction, Remote vessel operation, Smart fuel management, Carbon emission reduction, fully connected and autonomous smart ships.

Conclusion

IoT-based monitoring systems have significantly transformed the assessment of marine engine performance and operational safety, marking an important advancement in modern marine engineering. Through the integration of intelligent sensors, reliable communication networks, and advanced data analytics, these systems enable continuous real-time monitoring of critical engine parameters, allowing operators to evaluate engine health and performance more effectively. This proactive approach facilitates the early detection of potential faults, improves maintenance planning, and enhances the overall reliability of marine fishing vessels. The adoption of IoT technology also contributes to improved fuel efficiency, reduced maintenance costs, minimized unplanned equipment failures, and enhanced operational safety. By supporting condition-based and predictive maintenance strategies, IoT helps extend engine service life while reducing environmental impact and operational downtime. As the maritime industry continues its transition toward digital and smart technologies, IoT is expected to play a central role in the development of intelligent, efficient, and sustainable marine transportation systems, ultimately improving the safety, reliability, and performance of future vessels.

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EMPOWERING FARMERS THROUGH DIGITAL AGRICULTURE

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Abstract

Digital agriculture is transforming the agricultural sector by integrating modern digital technologies with traditional farming practices. The use of technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Geographic Information Systems (GIS), Global Positioning Systems (GPS), drones, remote sensing, mobile applications, cloud computing, and big data analytics enables farmers to make informed decisions based on real-time information. These innovations improve crop productivity, optimize the use of natural resources, reduce production costs, and increase farm income. In India, government initiatives such as the Digital Agriculture Mission, AgriStack, e-NAM, PM-KISAN, and the Soil Health Card Scheme have accelerated the adoption of digital technologies among farmers. Digital agriculture not only supports sustainable agricultural development but also strengthens food security, enhances climate resilience, and improves market access. Although challenges such as limited digital literacy, inadequate infrastructure, and the high cost of advanced technologies still exist, continuous technological advancements and policy support are creating new opportunities for farmers.

Key words: Digital Agriculture, Smart farming, Digital technologies, Artificial intelligence, Farmer empowerment

Introduction

Agriculture is one of the most important sectors of the Indian economy and serves as the primary source of livelihood for millions of people. It plays a vital role in ensuring food security, generating employment, and contributing to national economic growth. However, agriculture is increasingly affected by challenges such as climate change, declining soil fertility, water scarcity, pest and disease outbreaks, labour shortages, and unstable market prices. These problems often reduce crop productivity and limit farmers' incomes.

The rapid development of digital technologies has opened new opportunities to address these challenges. Digital agriculture refers to the application of information and communication technologies, artificial intelligence, sensors, drones, satellite systems, mobile applications, and data analytics in agricultural production and management. These technologies enable farmers to make timely and scientific decisions regarding crop selection, irrigation, nutrient management, pest control, harvesting, and marketing. By using accurate and real-time information, farmers can reduce production risks, improve efficiency, and increase profitability



Digital agriculture also strengthens agricultural extension services by delivering weather forecasts, market information, and technical advice directly to farmers through digital platforms. As agriculture moves towards sustainability and climate resilience, digital technologies have become essential tools for improving farm productivity, conserving natural resources, and enhancing the quality of life of farming communities

Concept of Digital Agriculture

Digital agriculture is the integration of advanced digital technologies into farming practices to improve agricultural productivity, efficiency, and sustainability. It involves the use of digital tools such as Artificial Intelligence (AI), the Internet of Things (IoT), Geographic Information Systems (GIS), Global Positioning Systems (GPS), drones, remote sensing, mobile applications, cloud computing, and big data analytics. These technologies enable farmers to collect, analyse, and use real-time information for making scientific decisions throughout the crop production cycle. Digital agriculture reduces uncertainty in farming and helps maximize production while minimizing the use of natural resources.

Importance of Digital Agriculture in Empowering Farmers

Digital agriculture empowers farmers by providing timely access to information on weather forecasts, soil fertility, irrigation scheduling, pest and disease management, and market prices. It enables farmers to make informed decisions instead of relying solely on traditional knowledge. Digital technologies reduce production costs, improve crop quality, increase yields, and provide direct market access. They also strengthen farmers' financial inclusion through digital banking, online payments, crop insurance, and government benefit transfers. As a result, farmers become more productive, self-reliant, and economically secure.

Artificial Intelligence (AI) in Agriculture

Artificial Intelligence uses computer algorithms to analyse agricultural data and provide intelligent recommendations. AI-powered systems can identify crop diseases from images, predict pest outbreaks, estimate crop yields, recommend fertilizers, and forecast weather conditions. AI improves decision-making by analysing large volumes of data quickly and accurately. It also supports automated farm machinery, precision farming, and early warning systems for natural disasters, thereby increasing productivity and reducing crop losses.

Internet of Things (IoT) in Smart Farming

The Internet of Things connects agricultural equipment, sensors, and devices through the internet. Soil moisture sensors, temperature sensors, humidity sensors, weather stations, and smart irrigation systems continuously monitor field conditions. The collected information is transmitted to farmers through smartphones or cloud platforms. IoT helps in efficient irrigation, water conservation, early disease detection, livestock monitoring, and greenhouse management. It reduces labour requirements and enables continuous monitoring of farm conditions.



Precision Agriculture

Precision agriculture is a scientific farming approach that applies agricultural inputs only where and when they are needed. Technologies such as GPS, GIS, drones, remote sensing, and variable-rate technology improve the accuracy of farming operations. Farmers can precisely manage irrigation, fertilizer application, pesticide spraying, and harvesting. This reduces production costs, improves soil fertility, conserves water, minimizes environmental pollution, and increases crop productivity.

Remote Sensing and GIS Applications

Remote sensing collects agricultural information using satellites and drones without direct contact with the field. It helps monitor crop growth, detect nutrient deficiencies, assess drought and flood damage, and estimate crop yields. Geographic Information Systems (GIS) analyse and display geographical data related to soil, water, climate, and land use. GIS supports soil mapping, irrigation planning, watershed management, pest surveillance, and crop suitability analysis. Together, these technologies improve agricultural planning and resource management.

Drone Technology in Agriculture

Agricultural drones are unmanned aerial vehicles used for crop monitoring, aerial imaging, pesticide spraying, fertilizer application, and crop damage assessment. High-resolution images captured by drones help identify pest infestations, nutrient deficiencies, water stress, and disease symptoms at an early stage. Drone spraying ensures uniform chemical application, reduces labour costs, minimizes farmers' exposure to pesticides, and increases operational efficiency.



Mobile Applications and Digital Advisory Services

Smartphone applications provide farmers with instant access to agricultural information. Mobile apps such as Kisan Suvidha, Meghdoot, Pusa Krishi, AgriMarket, and PM-KISAN offer weather forecasts, crop management practices, fertilizer recommendations, pest and disease diagnosis, market prices, and government scheme information. These digital advisory services improve farmers' knowledge and enable timely farm management decisions.

Digital Agricultural Marketing

Digital marketing platforms connect farmers directly with buyers, reducing the role of intermediaries. The National Agriculture Market (e-NAM) provides an online trading platform where farmers can compare prices and sell produce transparently. Digital payment systems, online banking, and Farmer Producer Organizations (FPOs) further improve market access and financial inclusion. Better market connectivity increases farmers' bargaining power and ensures fair prices for agricultural produce.

Government Initiatives for Digital Agriculture

The Government of India has launched several programmes to promote digital agriculture. The Digital Agriculture Mission encourages the use of AI, IoT, drones, GIS, and cloud computing. AgriStack creates a digital database of farmers to improve service delivery. PM-KISAN provides direct financial assistance through digital transfers, while the Soil Health Card Scheme promotes balanced fertilizer use based on scientific soil analysis. e-NAM improves agricultural marketing, and Meghdoot provides weather-based advisory services.

Benefits of Digital Agriculture

Digital agriculture increases crop productivity, improves input-use efficiency, conserves water, reduces fertilizer and pesticide consumption, enhances soil health, lowers production costs, and increases farm income. It strengthens food security, promotes climate-smart agriculture, improves environmental sustainability, and creates employment opportunities in agri-tech sectors. Farmers also gain better access to financial services, insurance, government schemes, and national markets.

Challenges of Digital Agriculture

Although digital agriculture offers many benefits, several challenges limit its adoption. Poor internet connectivity, inadequate digital literacy, high technology costs, small landholdings, limited technical support, and lack of awareness prevent many farmers from using digital tools effectively. Strengthening rural infrastructure, improving digital education, providing affordable technologies, and expanding agricultural extension services are essential for overcoming these barriers.

Future Scope of Digital Agriculture

The future of digital agriculture is highly promising. Emerging technologies such as robotics, blockchain, machine learning, autonomous tractors, smart irrigation systems, climate forecasting models, and advanced data analytics will further improve agricultural productivity and sustainability. Increased government support, private-sector investment, and digital innovation will empower farmers to produce more food with fewer resources while protecting the environment and ensuring long-term agricultural development.

Conclusion

Digital agriculture has become an essential component of modern farming by integrating advanced technologies with agricultural practices. It enables farmers to make informed decisions, improve productivity, optimize resource utilization, reduce production costs, and increase profitability. Technologies such as Artificial Intelligence, the Internet of Things, drones, GIS, GPS, remote sensing, and mobile advisory services have significantly improved farm management and agricultural sustainability. Government initiatives are further encouraging the adoption of these technologies across the country. Although challenges related to infrastructure, digital literacy, and affordability remain, continued investment in digital technologies and farmer education will strengthen agricultural development. Empowering farmers through digital

agriculture is vital for ensuring food security, increasing rural prosperity, protecting natural resources, and achieving sustainable agricultural growth.

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SUSTAINABLE MANAGEMENT OF PADDY DISEASES WITHOUT CHEMICAL FUNGICIDES

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Abstract

Rice (Oryza sativa L.) is the primary staple food for more than half of the world's population, making sustainable rice production essential for global food security. Rice diseases such as blast, sheath blight, bacterial leaf blight, brown spot, sheath rot, and false smut cause significant yield and quality losses each year. Conventional disease management relies heavily on chemical fungicides; however, their excessive use has resulted in fungicide resistance, environmental contamination, loss of beneficial microorganisms, and concerns regarding food safety. Sustainable disease management provides an environmentally friendly alternative by integrating resistant cultivars, cultural practices, biological control agents, botanical extracts, improved soil health, balanced nutrient management, precision agriculture, and disease forecasting systems. Recent advances in microbiome research, nanotechnology, RNA interference (RNAi), and artificial intelligence have further strengthened sustainable disease management strategies. This review summarizes current knowledge on eco-friendly approaches for managing major paddy diseases while highlighting future research opportunities for reducing chemical fungicide dependence and promoting resilient rice production systems.

Keywords: Rice, Paddy diseases, Sustainable agriculture, Biological control, Integrated Disease Management, Plant pathology, Eco-friendly disease control

1.Introduction

Rice is cultivated on over 165 million hectares worldwide and supplies approximately 20% of the global dietary energy intake. Increasing disease pressure due to climate change, intensive cultivation, and pathogen evolution threatens sustainable rice production. Chemical fungicides have been widely adopted to manage these diseases, but repeated application has led to resistant pathogen populations, environmental pollution, and adverse effects on human and ecosystem health.



Growing concerns over sustainable agriculture have shifted research toward integrated disease management (IDM), emphasizing prevention rather than cure. Sustainable disease management combines host resistance, biological control, crop management, and ecological approaches to reduce disease incidence while maintaining productivity.

2.Impact of chemical pesticides on their environment and health

Chemical pesticides have significantly improved agricultural productivity by protecting crops from pests and diseases; however, their excessive and indiscriminate use has serious environmental and human health consequences. Pesticides contaminate soil, water, and air through runoff, leaching, and spray drift, reducing soil fertility, harming beneficial microorganisms, pollinators, aquatic organisms, birds, and other non-target species, while also contributing to biodiversity loss and pest resistance. Persistent pesticide residues can accumulate in the food chain through bioaccumulation and biomagnification, posing long-term ecological risks. Human exposure to pesticides through occupational handling, contaminated food, water, or the environment may cause acute effects such as skin irritation, nausea, dizziness, and respiratory problems, as well as chronic health issues including neurological disorders, endocrine disruption,

reproductive problems, and an increased risk of certain cancers. Therefore, adopting sustainable alternatives such as integrated pest management (IPM), biological control, resistant crop varieties, and botanical pesticides is essential to reduce pesticide dependence and protect environmental and public health.



3.Major diseases in rice

- Spindle-shaped lesions with gray or white centers and brown margins develop on rice leaves, leading to drying of affected tissues."
- "Oval to irregular greenish-gray lesions with brown margins develop on leaf sheaths, enlarging and coalescing to cause blighting."
- Small circular to oval dark brown spots with gray centers and reddish-brown margins develop on leaves, reducing photosynthetic area."
- Individual rice grains are transformed into velvety green spore balls that later become orange to black at maturity."
- "Water-soaked yellow streaks begin at the leaf tip or margins, enlarge into wavy lesions, and cause complete leaf blight and drying."

Major disease	**Casual organism**	**Sustainable management practices**
Rice blast	Magnaporthe oryzae	Resistant varieties, disease-free seed, balanced nitrogen

		application, wider plant spacing, alternate wetting and drying, seed treatment with Trichoderma harzianum or Pseudomonas fluorescens, field sanitation.
Sheath blight	Rhizoctonia solani	Optimum plant spacing, avoid excess nitrogen, incorporation of organic matter, application of Trichoderma spp. and Bacillus subtilis, proper drainage, removal of infected debris.
Bacterial leaf blight	Xanthomonas oryzae pv. oryzae	Resistant varieties, certified seed, balanced fertilization with adequate potassium, proper irrigation, field sanitation, biological control using Pseudomonas fluorescens.
Brown spot	Bipolaris oryzae	Healthy seed, seed treatment with beneficial microbes, balanced nutrition (especially potassium and silicon), proper water management, crop residue management.
Sheath rot	Sarocladium oryzae	Disease-free seed, optimum plant density, biological control using Trichoderma spp., field sanitation, avoid excessive nitrogen, maintain good crop aeration.
False smut	Ustilaginoidea virens	Resistant cultivars where available, balanced nitrogen

		fertilization, field sanitation, proper irrigation, removal of infected panicles, crop rotation.

4. Sustainable management practices for rice

Host Plant Resistance

Use disease-resistant rice varieties developed through conventional breeding, marker-assisted selection, and modern biotechnology to reduce disease incidence.

Healthy Seed and Seed Treatment

Use certified disease-free seeds and treat them with beneficial microorganisms such as Trichoderma harzianum, Pseudomonas fluorescens, or Bacillus subtilis. Hot-water seed treatment can reduce seed-borne pathogens.

Cultural Practices

- Timely planting
- Optimum spacing
- Balanced fertilization
- Alternate wetting and drying
- Field sanitation
- Removal of infected crop residues
- Crop rotation where feasible

Biological Control

Beneficial microorganisms suppress pathogens through competition, antibiosis, mycoparasitism, and induced systemic resistance. Common agents include:

Trichoderma spp.

Pseudomonas fluorescens

Bacillus subtilis

Streptomyces spp.

Botanical Products

Natural plant products such as neem extract, garlic extract, turmeric extract, pongamia oil, and essential oils can suppress disease-causing pathogens with minimal environmental impact.

Soil Health Management

Apply farmyard manure, compost, green manure, and biofertilizers to improve soil microbial diversity and naturally suppress soil-borne pathogens.

Nutrient Management

Balanced nitrogen, phosphorus, and potassium fertilization, along with adequate silicon and micronutrients, improves plant vigor and enhances resistance to diseases.

Disease Surveillance and Forecasting

Regular field scouting, weather-based disease prediction models, and digital tools enable early detection and timely intervention**.**

5. Future Perspectives

The future of sustainable paddy disease management lies in integrating advanced technologies with eco-friendly agricultural practices to reduce dependence on chemical fungicides. Greater emphasis should be placed on developing disease-resistant rice varieties through molecular breeding, marker-assisted selection, and genome-editing technologies such as CRISPR. Research on beneficial plant microbiomes, microbial consortia, and improved biological control agents is expected to enhance disease suppression under field conditions. Precision agriculture, artificial intelligence (AI), remote sensing, drones, and weather-based disease forecasting systems will enable early disease detection and timely management. Nanotechnology-based biopesticides and natural plant-derived formulations offer promising alternatives with improved efficacy and reduced environmental impact. In addition, strengthening farmer education, expanding access to quality biocontrol products, and promoting supportive government policies will be essential for the widespread adoption of sustainable disease management practices. These advances will contribute to environmentally safe, climate-resilient, and economically sustainable rice production while ensuring long-term food security.

Conclusion

Sustainable management of paddy diseases without chemical fungicides relies on integrating resistant varieties, biological control agents, cultural practices, and balanced nutrient management. These eco-friendly approaches reduce environmental pollution, protect human health, and ensure long-term, resilient rice production while minimizing dependence on synthetic fungicides.

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PROSOBANE: *PROSOPIS* AS A BIOHERBICIDE

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Abstract

*Neltuma juliflor*a formerly *Prosopis juliflora* is a shrub or small tree in the family Fabaceae, a kind of mesquite. *N. juliflora* has become an invasive weed in several countries where it was introduced. It is hard and expensive to remove as the plants can regenerate from the roots.

Allelopathic plants are ecologically important as they are key players in disturbing and re-shaping the natural biodiversity of plants growing close to them. due to the presence of efficient bioactive secondary metabolites in this plant, it could be exploited for its use as an efficient bio-herbicide. For instance, L-tryptophan, syringing, and (-)- lariciersinol isolated from P. juliflora were used to inhibit the growth of weeds. Similarly, phenolics isolated from P. juliflora showed inhibition against weed plants. These allelochemicals are known to have a similar mode of action as studied in the synthetic herbicides, thereby having the ability to develop novel herbicides by fusing efficient allelochemicals and modes of action from the herbicides.

KEY WORDS: bioherbicide, chemo sterilant, autotoxicity.

Introduction

A significant reduction in the percentage of germination compared with the germination in natural forest soil indicated the presence of allelochemicals or secondary plant metabolites in the soil taken from a region with P. juliflora. Taking into consideration the vast applications of

allelopathic plants, they can also be used as biological herbicides instead of synthetic ones. Bioherbicide use of its extracts from leaf, root and seeds utilizes the vast availability of raw material and reduces it's spread and decreases the synthetic herbicide use. it can also be used as a biopesticide.



"TURNING AN INVADER INTO A SAVIOUR"

AIM

To convert the invasive *Prosopis juliflora* into an eco-friendly bioherbicide that combats weeds sustainably while restoring ecosystems.

OBJECTIVE

To develop an ecofriendly by harnessing the natural allelochemicals of *Prosopis juliflora*, transforming this invasive plant into a sustainable tool for weed control, while promoting zero waste utilization of its biomass and supporting ecosystem restoration.

PRINCIPLE

"Harnessing *Prosopis*' own defence chemistry (allelopathy) to control weed sustainably turning an invasive species into an ecofriendly solution."

ALLELOCHEMICALS WITH HERBICIDAL PROPERTY

Its extracts were used to test the impact of allelochemicals on the germination of the seeds as well as the growth of rice. P. juliflora is composed of different allelochemicals, such as derivatives of phenolic compounds, alkaloids, and water-soluble compounds. Some of the allelochemicals are juliflorine, julifloricine, juliprosopine, mesuitol, syringin, L-tryptophan, (-)-lariciresinol, and juliprosopinal. Almost all parts of the plant produce metabolites with allelopathic effects

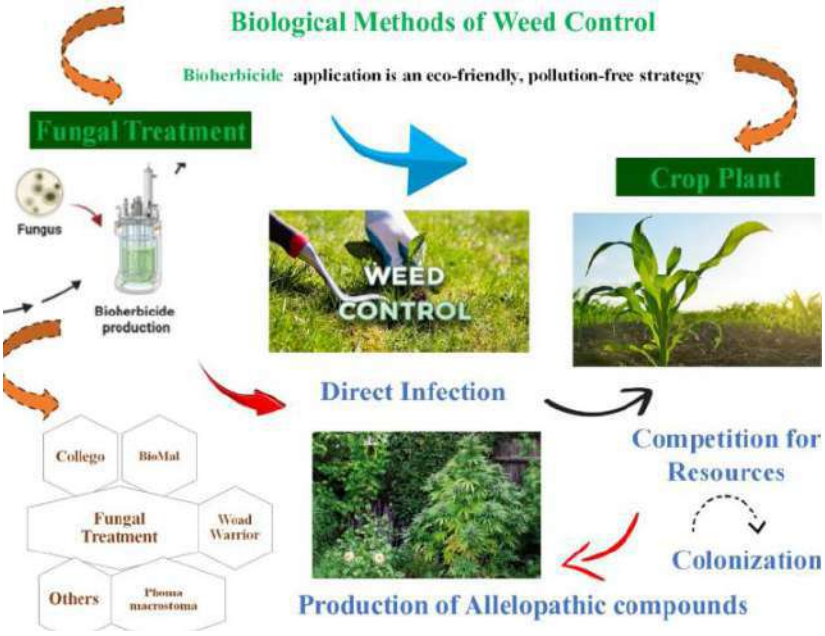
For instance, none of the metabolites have the same composition, nor do they have concentrations that are similar; they differ from species to species. Due to this variation in the

complexity of metabolites, these types of plants could be used for different purposes in agriculture.

Due to the presence of efficient bioactive secondary metabolites in this plant, it could be exploited for its use as an efficient bio-herbicide. For instance, L-tryptophan, syringing, and (-)-lariciersinol isolated from P. juliflora were used to inhibit the growth of weeds. Similarly, phenolics isolated from P. juliflora showed inhibition against weed plants. These allelochemicals are known to have a similar mode of action as studied in the synthetic herbicides, thereby having the ability to develop novel herbicides by fusing efficient allelochemicals and modes of action from the herbicides.

Two-year field experiments were once conducted to investigate the phytotoxicity of mesquite on weed control and yield of wheat in 2013-14 and 2014-15. Mesquite aqueous extracts were prepared with 10, 20, 30 and 40% concentration of leaves, stems and roots and were compared with tap water(control).

These experiments were laid out in a completely randomized block design with four replications. All parameters (weed density, fresh weed biomass, chlorophyll content, leaf area index, leaf area duration crop growth rate, plant height, assimilation rate and number of tillers) were reduced, among different concentrations, 40 % of all three plant parts of mesquite subsequently affected the wheat. It contains many phytotoxic substances which can negatively affect growth and yield of field crops also.



MODE OF ACTION

In one research, it was found that the seed germination along with the radicle length of wheat was negatively affected when compared with the control . In another study, extracts of leaves, flowers, and fruits inhibited the seed germination and seedlings growth of *Zea mays, Triticum aestivum, and Albizia lebbeck*. Furthermore, P. juliflora is also reported to significantly reduce the seed germination of *Bauhinia racemosa, Drypetes sepiaria, Flueggea leucopyrus, Salvadora persica, Ziziphus mauritiana, Hordeum vulgare,* and *Medicago sativa*. In the same experiment, the seeds were allowed to germinate in soil from a place where the allelopathic plant *P. juliflora* was present.

AUTOTOXICITY

P. juliflora can also be toxic to itself (autotoxicity). It is reported that roots, shoots, and fruit extracts of *P. juliflora* are involved in the autotoxicity process at higher concentrations . Other researchers concluded that the autotoxicity of *P. juliflora* is very little or does not exist because of the higher growth rate of seedlings of the same species under the canopy of *P. juliflora*. The contradictory results could be justified by different environmental factors that might affect the biological and chemical properties of the bioactive compounds.

The allelochemicals not only inhibit or decline the growth of other plant species but also their own. This auto-toxic property of *P. juliflora* was observed in experimental work to a certain extent.

CHARACTERISTICS OF CHEMICALS

It is reported that the allelochemical L-tryptophan degrades quickly in the soil; hence, it is less effective. Similarly, another research confirms the degradation process of allelochemicals in the soil and reports that these inhibitors of plant growth can stay active in the soil for only up to two months. Since it degrades early it doesn't pollute the environment and can be used as a pre-emergence herbicide as it suppresses the radicle growth and suppresses weed development.

Here, it is important to mention that since the accumulation of the allelochemicals in the soil is a continuous process, it cannot be concluded which type of leachate, either soil or leaf, would be more effective in terms of its allelopathic impact. It is mentioned that the leaf leachate of *P. juliflora* showed neutral to negative effects on the growth of roots of certain plants. Halophytes, being of severe socio-economic importance, might face severe threat by the presence of invasive *P. juliflora*.

OTHER APPLICATIONS

Certain laboratory experiments have proved the worth of these allelochemicals by inhibiting certain pathogens like Escherichia coli, Micrococcus luteus, and Pseudomonas aeruginosa. In our laboratory, we used the water-soluble leaf ethanolic extracts of *P. juliflora* (PJ-WS-LE) against post-harvest pathogens of mango fruits and inhibited the growth of *Alternaria alternata*, *Colletotrichum gloeosporioides*, *Botrytis cinerea*, *Bacillus subtilis*, *Staphylococcus aureus*, and *Candida albicans*. Similarly, we used PJ-WS-LE as a potential coating agent for preserving cucumber and strawberries and extending their shelf life.

It can also be used as an insecticide as it acts as a chemo sterilant or oviposition suppressant as it contains piperidine alkaloids as it can be extracted and used. It also acts as antifeedant and growth inhibitor. Prosopis contains compounds that impede the digestive system of pests weakening the adult insects and preventing them from reaching reproductive maturity.

It also has medicinal uses and can also use in certain culinary preparations after removal of certain chemicals present in it.

Conclusion

Taking into consideration the vast applications of allelopathic plants, they can also be used as biological herbicides instead of synthetic ones. Allelochemicals being used as bioherbicides is an environment-friendly and sustainable approach as they have no residual toxic effects and are biodegradable, leading to low environmental pollution. Soon, we will explore the allelopathic nature of *P. juliflora* in terms of weed management in agriculture with the hope of utilizing the allelochemicals to protect the crops.

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CLIMATE-RESILIENT INTEGRATED WEED MANAGEMENT IN VEGETABLE CROPS: PRINCIPLES, EMERGING CHALLENGES AND SUSTAINABLE ADAPTATION STRATEGIES

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Abstract

Weeds are one of the major biological constraints limiting vegetable production worldwide, causing significant yield losses due to intense competition for water, nutrients, light, and space. Vegetable crops are particularly vulnerable to weed interference because of their slow initial growth, wider spacing, shallow root systems, and lower competitive ability. In addition, weeds act as reservoirs for insect pests, nematodes, and disease-causing pathogens, further aggravating crop losses. The changing climate, characterized by rising temperatures, elevated atmospheric carbon dioxide levels, erratic rainfall patterns, and frequent extreme weather events, is altering weed ecology, increasing the prevalence of invasive species, and reducing the effectiveness of conventional weed management practices.

Integrated Weed Management (IWM) offers a sustainable and climate-resilient approach by combining preventive, cultural, mechanical, biological, and judicious chemical control methods to maintain weed populations below economically damaging levels while minimizing environmental impacts. Practices such as crop rotation, stale seedbed preparation, cover cropping, intercropping, mulching, soil solarization, and precision herbicide application improve weed suppression and enhance crop competitiveness. Emerging technologies including artificial intelligence-based weed detection, drone-assisted herbicide spraying, and robotic weeders provide new opportunities for site-specific and environmentally sustainable weed control. Therefore, the adoption of climate-smart integrated weed management strategies is essential for improving vegetable productivity, conserving natural resources, reducing chemical dependency,

and ensuring the long-term sustainability of vegetable production systems under changing climatic conditions

Keywords: Climate resilience, weeds, integrated weed management, sustainable vegetable production.

Introduction

Weeds are unwanted plants that grow along with cultivated crops and interfere with their growth, development, and productivity. In vegetable production systems, weeds are considered one of the major biological constraints due to their vigorous competition for essential resources such as nutrients, moisture, sunlight, and growing space. Vegetable crops are generally poor competitors during the initial stages of growth because of their slow seedling establishment, wider plant spacing, shallow root systems, and delayed canopy development. Consequently, uncontrolled weed infestation can lead to severe reductions in yield, quality, and marketability of vegetable produce. The magnitude of yield losses caused by weeds in vegetable crops may range from 30 to more than 90 per cent depending upon crop species, weed intensity, duration of weed-crop competition, management practices, and environmental conditions. In addition to direct competition, weeds act as alternate hosts for several insect pests, nematodes, viruses, and other plant pathogens, thereby increasing the incidence of pest and disease problems in vegetable ecosystems.

Climate change has further intensified the challenge of weed management by altering weed distribution patterns, germination behaviour, growth dynamics, and competitive ability of many invasive and difficult-to-control species. Rising temperatures, changing rainfall patterns, and increased atmospheric carbon dioxide levels may favour the proliferation of certain weed species, making conventional management practices less effective. Effective weed management is therefore essential for achieving sustainable vegetable production, ensuring higher productivity, and maintaining crop quality. Vegetable fields usually contain a complex weed flora comprising broad-leaved weeds, grasses, and sedges. Since no single control measure can provide effective and long-term suppression of all weed species, the adoption of Integrated Weed Management (IWM) is widely recommended. IWM integrates preventive, cultural, mechanical, biological, and chemical approaches to maintain weed populations below economic threshold levels while minimizing environmental hazards and reducing excessive dependence on herbicides (Rana and Rana, 2019).

Climate Change and Weed Dynamics in Vegetable Cropping Systems

Climate change is increasingly influencing the distribution, abundance, and competitiveness of weed species in agricultural ecosystems. Rising atmospheric carbon dioxide (CO_2) concentrations, increasing temperatures, altered precipitation patterns, and the greater frequency of extreme weather events are significantly modifying weed biology and crop–weed interactions. Vegetable crops, owing to their relatively short growth duration, shallow root systems, and intensive cultivation practices, are particularly vulnerable to these changes. Elevated atmospheric CO_2 generally stimulates photosynthesis and biomass accumulation in many weed species, especially C_3 weeds such as CHENOPODIUM ALBUM, PARTHENIUM HYSTEROPHORUS, and CONVOLVULUS ARVENSIS. Enhanced growth of these weeds increases their competitive ability against vegetable crops for light, nutrients, water, and space. Although crop growth may also benefit from elevated CO_2, several studies have demonstrated that weeds often exhibit a greater growth response, thereby intensifying crop yield losses. Increasing temperatures further influence weed ecology by accelerating germination, growth, flowering, and seed production. Warmer conditions may extend the growing season of many weeds and facilitate the spread of invasive species into previously unsuitable regions, including temperate and hill ecosystems. Species such as PARTHENIUM HYSTEROPHORUS, CYPERUS ROTUNDUS, and AGERATUM CONYZOIDES have shown enhanced adaptability under changing climatic conditions, resulting in greater infestation levels and management challenges.

Changes in rainfall patterns also affect weed emergence and survival. Prolonged drought periods favour drought-tolerant weed species with deep root systems, while excessive rainfall and flooding create favourable conditions for aquatic and semi-aquatic weeds. Such shifts alter weed community composition and often reduce the effectiveness of traditional weed control practices. Climate change may also influence herbicide performance. Higher temperatures can increase herbicide volatilization and degradation, whereas irregular rainfall may affect herbicide persistence and efficacy. Furthermore, environmental stresses can modify weed physiology, potentially contributing to reduced herbicide susceptibility and the evolution of herbicide-resistant weed populations.

Consequently, climate-smart and integrated weed management strategies are becoming increasingly important. Adoption of crop diversification, conservation agriculture, precision herbicide application, mulching, cover cropping, biological weed control, and AI-

assisted weed monitoring can improve resilience and sustainability of vegetable production systems under changing climatic conditions.

Importance and Impact of Weeds in Vegetable Production Systems

Weeds are among the major biological constraints limiting vegetable production, causing significant reductions in crop yield, quality, and economic returns. Due to wider row spacing and slow initial growth, vegetable crops are highly vulnerable to weed infestation, especially during early growth stages. Weeds possess strong competitive abilities and often develop deeper and more extensive root systems, enabling them to utilize soil moisture and nutrients more efficiently than vegetable crops. Modern vegetable cultivars, although improved for yield and quality, generally exhibit reduced competitiveness against weeds due to lower vigor and limited canopy development. Weed competition for light, water, nutrients, and space adversely affects crop growth and decreases marketable yield by reducing produce size, quality, and harvest efficiency. Additionally, many weeds act as alternate hosts for insects, pathogens, viruses, and nematodes, increasing pest and disease incidence in vegetable fields (Kumar et al., 2021). .

Weed infestation also increases production costs through additional labor and management requirements while interfering with irrigation and nutrient utilization. Therefore, sustainable and integrated weed management practices are essential to minimize yield losses, improve resource-use efficiency, maintain environmental sustainability, and ensure profitable vegetable production systems (Coleman et al., 2024).

Table 1: Impact of Weed Infestation on Yield Reduction in Major Vegetable Crops

Sr. No.	Vegetable Crops	Yield Loss due to weeds (%)	References
1	Tomato	92-95	Bakht and Khan 2014
2	Okra	40-80	Patel *et al*. 2017
3	Potato	52	Singh *et al*. 2005
4	Bottle Gourd	40	Dash and Mishra 2014
5	Cabbage	45-80	Akshatha *et al*. 2018
6	Carrot	90	Singh *et al.* 2017
7	Brinjal	30-35	Syriac and Geetha 2007
8	Chilli	60-70	Khan *et al.* 2012
9	Garlic	94.8	Sanjay *et al.* 2009

10	Radish	86	Singh *et al.* 2009
11	Onion	40-80	Channapagoudar and Biradar 2007

SOURCE: CHACKO ET AL .2021

Critical Period of Crop–Weed Competition (CPWC)

The **Critical Period of Crop–Weed Competition (CPWC)** refers to the specific stage in a crop's growth cycle during which weed control is essential to prevent economically significant yield losses. During this period, weeds compete most aggressively with crops for vital resources such as nutrients, moisture, sunlight, and growing space, thereby exerting the greatest negative impact on crop growth, development, and productivity. Failure to manage weeds effectively during the CPWC can result in substantial reductions in yield, even if weeds are removed at a later stage. Conversely, weed infestation occurring before or after this critical interval generally has a relatively minor effect on final crop yield. The duration and timing of the CPWC vary depending on crop species, weed flora, environmental conditions, and crop management practices. Therefore, identifying and maintaining a weed-free environment during this period is crucial for maximizing crop productivity, enhancing resource-use efficiency, and reducing economic losses (Das, 2008).

Table 2: Critical Period of Crop–Weed Competition in Vegetable Crops

Sr. No.	Crop	Critical Period of crop competition
1	Tomato (transplanted)	First 6 weeks after planting
2	Tomato (seeded)	First 9 weeks after seeding
3	Okra	2-4 weeks after emergence
4	Cabbage	2-4 weeks after emergence
5	Cauliflower	0-30 days after sowing
6	Brinjal	20-60 days after sowing
7	Carrot	3-6 weeks after emergence
8	Turnip	15-20 days after sowing
9	Radish	25-30 days after sowing
10	Cucumber	Up to 4 weeks after seeding

11	Peas	30-60 days after planting
12	Onion	Entire growing season (highly sensitive to weed competition)
13	Chilli	30-45 days after transplanting
14	Potato	15-45 days after planting

SOURCE: CHACKO ET AL .2021

Among vegetable crops, onion is highly susceptible to weed competition and requires season-long weed management. Brinjal, pea, potato, and tomato have longer critical periods of weed competition, requiring prolonged weed control, while short-duration crops like turnip and radish need weed management for a shorter period. Effective weed control during the critical period is essential for optimum growth, yield and profitability.

Major weed flora of vegetable crops:

Weed flora in vegetable production systems is diverse and consists of broad-leaved weeds, grasses, and sedges that vary in their growth habits, life cycles, and competitive ability. The composition of weed flora changes with seasons, particularly between kharif and *Rabi* crops, due to differences in climatic conditions and cropping patterns. Accurate identification of weed species and understanding their biology and propagation methods are essential for developing effective and sustainable weed management strategies (Attri et al., 2022)

Table 3: Major Kharif season weeds

Botanical Name	Common Name	Type	Family
Trianthema portulacastrum	Patharchata, Gadhupura	Broad leaved, annual	Aizoaceae
Echinochloacolona	Barnyard Grass	Narrow leaved, annual	Graminae
Cyperus rotundus	Motha	Narrow leaved, perennial	Cyperaceae
Digeriaarvensis	Chanchali	Broad leaved, annual	Amaranthaceae
Amaranthusviridis	JangliChaulai	Broad leaved, annual	Amaranthaceae
Physalis minima	Ban Makaya	Broad leaved, annual	Solanaceae
Phyllanthusniruri	Haizardana, Jar-Amla	Broad leaved, annual	Euphorbiaceae
Commelinabenghalensis	Kanna, Kena	Broad leaved, annual	Commelinaceae
Eleusine indica	Malanpuri, Kodai	Narrow leaved, annual	Graminae

Ageratum conyzoides	Neela Phool	Broad leaved, annual	Compositae
Cynodondactylon	Bermuda, Doob Grass	Narrow leaved, perennial	Graminae
Celosia argentea	Safed Murge Ka Phool	Broad leaved, annual	Amaranthaceae
Setariaverticillata	Bristly foxtail	Grass, annual	Poaceae
Digitarissanguinalis	Crab grass	Grass, annual	Poaceae
Parthenium hsyterophorus	Congress grass	Broadleaf, annual	Asteraceae

SOURCE: (SINGH et al., 2019)

MAJOR *RABI* SEASON WEEDS IN VEGETABLE CROPS:

Botanical name	**Common name**	**Type**	**Family**
Chenopodium album	Bathu	Broad leaved, annual	Chenopodiaceae
Melilotus indica	Senji Methi	Broad leaved, annual	Papilionaceae
Lathyrus aphaca	Maturi, PipuraPipari	Broad leaved, annual	Papilionaceae
Vicia sativa	Anhtaankari	Broad leaved, annual	Papilionaceae
Convolvulus arvensis	Hirankhuri	Broad leaved, perennial	Convolvulaceae
Rumex maritimus	Panbheri	Broad leaved, annual	Polygonaceae
Cynodon dactylon	Bermuda grass, Doob grass	Narrow leaved, perennial	Graminae
Orobanche spp.	Broom rape	Broad leaved, annual	Orobanchaceae
Spergula arvensis	Bhandhania	Narrow leaved, annual	Caryophyllaceae
Euphorbia hirta	Bari Dudhi	Broad leaved, annual	Euphorbiaceae
Phalaris minor	Canary grass	Grass, annual	Poaceae
Avenaludo viciana	Wild oat	Grass, annual	Poaceae
Lolium temulentum	Darnel ryegrass	Grass, annual	Poaceae
Poa annua	Annual bluegrass	Grass, annual	Poaceae
Sonchus arvensis	Sowthisle	Broad leaf, perennial	Asteraceae
Stellaria media	Chickweed	Broadleaf, annual	Carophyllaceae
Cirsium arvense	Canada thistle	Broadleaf, perennial	Asteraceae

Cuscuta reflexa	Dodder	Broadleaf, annual	Cuscutaceae

The weed flora associated with vegetable crops comprises a wide range of annual and perennial species belonging to different botanical groups. During the ***Rabi* season**, weeds such as CHENOPODIUM ALBUM, PHALARIS MINOR, and CONVOLVULUS ARVENSIS are predominant, whereas ***kharif* season** vegetable crops are commonly infested by TRIANTHEMA PORTULACASTRUM, CYPERUS ROTUNDUS, ECHINOCHLOA COLONA, and PARTHENIUM HYSTEROPHORUS. Proper identification and timely management of these weed species are essential for minimizing crop–weed competition, improving resource-use efficiency, and maximizing vegetable productivity.

SOURCE: (SINGH et al. 2019)

			
Trifolium repen	***Polypogonmons peliensus***	***Anagallis arvensis***	***Eleusine indica***
			
Ageratum conyzoides	***Portulaca oleracea***	***Veronica persica***	***Chenopodium album***

Principles of Climate-Resilient Integrated Weed Management (CRIWM):

Climate-Resilient Integrated Weed Management (CRIWM) integrates preventive, cultural, physical, and ecological approaches to suppress weeds while conserving resources and enhancing crop resilience. It is based on three key

principles: **prevention, eradication and control**. Prevention avoids the introduction and spread of weeds, eradication aims at complete removal of weed populations from a specific area, and control reduces weed growth below economically damaging levels (rana and rana, 2019).

Preventive Measures

Prevention is the most economical and sustainable strategy for weed management. It includes the use of clean seeds, well-decomposed farmyard manure, and maintenance of weed-free irrigation channels and field boundaries to restrict the introduction and spread of weed seeds (Zimdahl, 2018).

Cultural Weed Management Practices

Crop Rotation and Diversification

Rotating vegetable crops with cereals, pulses, and other crops disrupts weed life cycles, reduces the dominance of specific weed species, and improves soil health and agro ecosystem resilience (Singh et al., 2019; Chacko et al., 2021)

Optimized Nutrient and Water Management

Weeds may consume 40–50% of available soil water. Efficient irrigation systems such as drip irrigation deliver water directly to crop roots, limiting resource availability for weeds and reducing their growth (Hussein et al., 2015). Subsurface drip irrigation in tomato has been shown to reduce weed density by up to 98% while increasing crop yield.

Planting Time and Crop Geometry

Timely sowing, optimum plant population, and narrow row spacing promote rapid canopy development and improve crop competitiveness against weeds by reducing light availability. In tomato, 40 cm row spacing resulted in lower weed density compared with wider spacing (Attri et al., 2022).

Intercropping and Cover Crops

Intercropping and the use of fast-growing cover crops such as clover, oilseed radish, and sunn hemp suppress weeds through competition for light, water, and nutrients (Attri et al., 2022). Intercropping faba bean with barley reduced weed cover and biomass by 92.7% and 76.6%, respectively (Fernández et al., 2024).

Mulching: A Climate-Smart Approach

Mulching is one of the most suitable technologies for hill vegetable cultivation. Organic mulches such as dry grasses, pine needles, crop residues and compost, along with biodegradable or plastic mulches, suppress weed emergence, conserve soil moisture and moderate soil temperature. Research conducted under mid-hill conditions of Himachal Pradesh demonstrated that the use of black polythene mulch with appropriate planting methods effectively reduced weed density and improved weed control efficiency in capsicum cultivation (Tulek et al., 2025).





Biomass mulching in capsicum & Turmeric



Plastic mulch in capsicum

SOIL SOLARIZATION

Soil solarization involves covering moist soil with transparent polyethylene during hot periods to increase soil temperature and destroy weeds, pathogens, and pests. Solarization for six weeks has reduced weed density and biomass by more than 90% while improving crop yields.

PHYSICAL AND MECHANICAL WEED CONTROL

Tillage

Tillage controls weeds by uprooting plants and burying weed seeds beyond their optimum germination depth, thereby reducing the soil weed seed bank (Labrada, 1996).

HandWeeding

Hand weeding using simple tools such as KHURPI remains effective for controlling intra-row weeds, particularly in smallholder vegetable systems, although it requires considerable labor (Mohamed and Abdalla, 2023). Overall, CRIWM combines these complementary practices to reduce dependence on herbicides, enhance resource-use efficiency, improve soil health, and build resilient vegetable production systems under changing climatic conditions.

Table 5: Examples of Crop Rotation Systems in Vegetable Production

S.No.	Crop Rotation type	Examples
1	Leafy and root vegetable	Lettuce, spinach, cole crops and Carrots, Potatoes & Radish
2	Monocot and Dicot	Cereals and Spinach& tomato
3	Family based rotation	Brassicaceae and solanaceae vegetables
4	Bulb and fruit crop	Onion& leek and chilli & capsicum
5	Poor competitors and strong competitors	Carrot, onion and Maize & potato
6	Short and long duration crops	Radish, Lettuce and Potato, Tomato

Source: Singh et al 2019

Intercropping and cover crops:

Intercropping involves growing two or more crops simultaneously in the same field (Singh et al., 2019). Cover crops with rapid growth and dense canopy development, such as clover, oilseed radish, and sunn hemp, effectively suppress weeds by competing for light, water, and nutrients (Attri et al., 2022). Fernández et al. (2024) reported that intercropping faba bean with barley reduced weed cover by 92.7% and weed biomass by 76.6%.

Table 6: Example of intercropping system in vegetable Production

Temperate region	Tropical region
Lettuce + Carrot	Maize + beans + squash
Cole crops + Leek, onion, celery and tomato	Tomato + Pigeon pea
Maize+ beans & soybean	Sugarcane + onion & tomato

Source: Singh *et al.* 2019

Chemical methods of weed control (Herbicides):

Herbicides are chemical compounds used to suppress or eliminate weeds by disrupting vital physiological and biochemical processes such as photosynthesis, enzyme activity, cell division, and protein synthesis, ultimately leading to growth inhibition or plant death (Babu et al., 2024). They offer an effective and economical approach to weed management in vegetable crops, particularly under labour scarcity. Based on the time of application, herbicides are classified as **pre-emergence** and **post-emergence** herbicides.

Pre-emergence Herbicides Used in Vegetable Crops

Pre-emergence herbicides are applied after sowing or transplanting but before weed emergence. They create a chemical barrier in the soil that prevents weed seed germination and suppresses early seedling growth.

Herbicide	**Crop (Dose, kg ha^{-1})**
Pendimethalin	Garlic (0.75–1.25), Carrot & Radish (0.75–1.87), Potato (0.75–1.5), Brinjal (1.0–1.5), Cabbage (0.75–2.0), Cauliflower (0.5–1.0), Onion (0.75–1.5), Chilli (0.75–3.0), Tomato (0.56–1.0), Peas (1.20–1.50), Okra (0.50–0.75), Turmeric (0.975)
Oxyfluorfen	Garlic (0.125–0.240), Brinjal (0.10–0.15), Cabbage (0.09–0.234), Chilli (0.10–1.25)
Metolachlor	Garlic (1.50)
Fluchloralin fb Quizalofop-ethyl	Garlic (0.95 fb 0.05)
Trifluralin	Carrot/Radish (0.9–1.5)
Alachlor	Carrot/Radish (1.25–2.5)
Isoproturon	Potato (0.94)
Metribuzin	Potato (0.25–0.75), Tomato (0.37–0.525)
Fluchloralin	Cauliflower (0.84–1.5), Onion (1.12)
Pendimethalin fb Oxyfluorfen + Quizalofop-ethyl	Onion (0.75–1.5 fb 0.12–0.85 + 0.037–0.050)

Source: Singh et al. (2019)

Post-emergence herbicides used in vegetable crops:

Post-emergence herbicides are applied after the emergence of weeds and, in many cases, following crop establishment. These herbicides constitute an essential component of integrated weed management by effectively controlling weeds that escape pre-emergence herbicide applications and mechanical control practices. Their efficacy depends on several factors, including the weed species present, the growth stage of the weeds, prevailing environmental conditions, and the selectivity and compatibility of the herbicide with the crop.

Herbicide	Crop (Dose, kg ha^{-1})
Fenoxaprop-P-ethyl	Garlic (0.075)
Quizalofop-ethyl / Quizalofop	Garlic (0.05); Brinjal (0.040); Peas (0.050)
Sethoxydim	Carrot/Radish (0.8); Cabbage (1.5)
Fluazifop-butyl	Carrot/Radish (0.75)
Oxyfluorfen + Quizalofop-ethyl	Onion (0.12–0.85 + 0.037–0.050)
Imazethapyr	Peas (0.15–1.5)

SOURCE: SINGH ET AL. 2019

Biological methods of weed control:

Biological weed management involves the use of living organisms such as insects, pathogens, grazing animals, and competitive plants to suppress weed populations. It is an eco-friendly approach that reduces reliance on chemical herbicides and provides sustainable long-term weed control. These biological agents control weeds by feeding on them, causing diseases, or competing for essential resources like light, water, nutrients, and space (Kumar and Agrawal, 2024). A successful example in India is the use of the Mexican beetle (ZYGOGRAMMA BICOLORATA) to control PARTHENIUM HYSTEROPHORUS (Congress grass). The beetle feeds on the leaves and flowers of Parthenium, reducing its growth and seed production, making it an effective biological weed control agent (Mishra *et al.*, 2021).

Integrated weed management in vegetable crops (IWM):

Integrated Weed Management (IWM) is a holistic, sustainable, and ecologically sound approach that combines multiple weed control strategies to maintain weed populations below economic threshold levels. It integrates preventive, cultural, mechanical, biological, and chemical methods based on weed ecology, crop requirements, and prevailing environmental conditions. By employing diverse weed management tactics, IWM reduces reliance on herbicides, delays the development of herbicide-resistant weed populations, minimizes environmental contamination, and promotes the long-term sustainability and profitability of vegetable production systems (Babu et al., 2024). In vegetable production systems, IWM involves the use of healthy and clean seeds, crop rotation, optimum planting geometry, mulching, timely irrigation and fertilizer management, manual or mechanical weeding, and the

judicious application of herbicides when required. The integration of these strategies helps reduce weed competition for nutrients, water, light, and space, leading to improved crop growth, higher yields, reduced dependence on herbicides, and enhanced soil and environmental health. IWM is particularly important under changing climatic conditions, as it provides a resilient and sustainable solution for effective weed management in vegetable-based farming systems.

Future Prospects of Weed Management in Vegetable Crops

Future weed management in vegetable crops will increasingly focus on sustainable, precise, and technology-driven approaches rather than sole dependence on herbicides. Innovations in precision agriculture, including GPS, GIS, remote sensing, drones, and machine vision, will enable site-specific weed detection and targeted control, reducing herbicide use, production costs, and environmental impacts. Artificial intelligence (AI), robotics, and machine learning are expected to revolutionize weed management by enabling accurate weed identification and selective removal through mechanical, laser, or precise herbicide applications. Similarly, bioherbicides, beneficial microorganisms, allelopathic plants, and cover crops will play an important role in eco-friendly weed suppression. Climate change and the rise of herbicide-resistant weeds will necessitate climate-smart and integrated weed management strategies involving crop rotation, conservation practices, herbicide stewardship, and the combination of cultural, mechanical, biological, and chemical methods. Furthermore, digital technologies such as IOT sensors, cloud-based platforms, and decision-support systems will provide real-time recommendations for effective weed control.

Overall, the future of weed management lies in integrating advanced technologies with sustainable practices to enhance weed control efficiency, reduce reliance on synthetic herbicides, protect the environment, and ensure long-term productivity and profitability of vegetable production systems.

Emerging Technologies for Climate-Smart Weed Management

Recent advances in digital agriculture offer new opportunities for sustainable weed management. Artificial intelligence (AI) and machine learning algorithms can accurately distinguish weeds from crop plants through image analysis and computer vision techniques. Drone-based weed surveillance enables rapid monitoring of large areas and facilitates site-specific herbicide application, reducing chemical consumption and environmental contamination. Robotic weeders equipped with sensors, cameras, and precision tools can mechanically remove

weeds with minimal soil disturbance. Laser-based weed control technologies are also emerging as non-chemical alternatives capable of targeting individual weeds without affecting crop plants.



The integration of Internet of Things (IoT) sensors, remote sensing technologies, Geographic Information Systems (GIS), and Decision Support Systems (DSS) can provide real-time recommendations for weed management based on weather conditions, crop stage, and weed population dynamics. These technologies are expected to play a vital role in climate-resilient vegetable production systems in the future.

Conclusion

Weeds remain one of the most serious biological constraints affecting vegetable production worldwide. Their competition for nutrients, moisture, light, and space significantly reduces crop productivity, quality, and profitability. The challenge has become more complex under changing climatic conditions, which influence weed distribution, growth behaviour, competitiveness, and response to management practices. Integrated Weed Management (IWM) offers an effective and sustainable approach by combining preventive, cultural, mechanical, biological, and chemical methods to maintain weed populations below economic threshold levels while minimizing environmental impacts. Climate-resilient weed management practices such as crop diversification, mulching, cover cropping, efficient water management, soil solarization, and precision herbicide application contribute significantly to sustainable vegetable production.

Emerging technologies including artificial intelligence, robotics, drone-assisted weed detection, precision agriculture, and decision-support systems are expected to revolutionize future weed management. The successful integration of these innovative technologies with traditional ecological knowledge will be crucial for enhancing resource-use efficiency, reducing

chemical dependence, conserving biodiversity, and ensuring long-term sustainability of vegetable production systems under climate change scenarios. Therefore, adoption of climate-resilient integrated weed management strategies is essential for improving productivity, profitability, and food security while protecting environmental health.

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MICROBIAL DEGRADATION OF PERSISTENT ORGANIC POLLUTANTS: NATURE'S HIDDEN CLEANUP CREW

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Abstract

Persistent Organic Pollutants (POPs) are among the most hazardous environmental contaminants due to their persistence, toxicity, long-range transport, and ability to accumulate in living organisms. These pollutants contaminate aquatic ecosystems, soils, sediments, and food chains, posing serious risks to biodiversity and human health. Conventional remediation techniques are often expensive and may generate secondary pollutants. Microbial degradation has emerged as an environmentally friendly and sustainable alternative, utilizing bacteria, fungi, and algae to transform or mineralize POPs into less toxic compounds. Advances in microbial biotechnology, molecular biology have significantly enhanced our understanding of microbial degradation pathways and their practical applications. This article highlights the characteristics of POPs, the mechanisms of microbial degradation, factors influencing biodegradation, applications in environmental remediation, recent technological developments and future prospects for sustainable pollution management.

Keywords: Persistent Organic Pollutants (POPs), Microbial Degradation, Bioremediation, Environmental Pollution, Aquatic Ecosystems.

Introduction

Industrialization, urbanization and intensive agricultural practices have led to the widespread release of hazardous chemicals into the environment. Among these contaminants, Persistent Organic Pollutants (POPs) are of greater concern due to their toxic, persistent, carcinogenic, hydrophobic and lipophilic nature, ability of long-range transport, long half-lives and bioaccumulation in food chain. POPs include pesticides such as DDT, industrial chemicals like polychlorinated biphenyls (PCBs) and by-products such as dioxins and furans. These compounds can disrupt endocrine functions, impair reproduction, damage the immune system and even cause cancer.

Microorganisms offer a promising natural solution for combating POP pollution. Various bacteria, fungi and genetically modified microorganisms possess metabolic pathways capable of transforming or completely degrading these toxic compounds into harmless products. Microbial degradation techniques not only have the ability to remove organic materials but also immobilize unwanted toxic substances such as POPs, hydrocarbons, acids and their derivatives for degradation. Microbial degradation has therefore become a key strategy in sustainable environmental remediation.

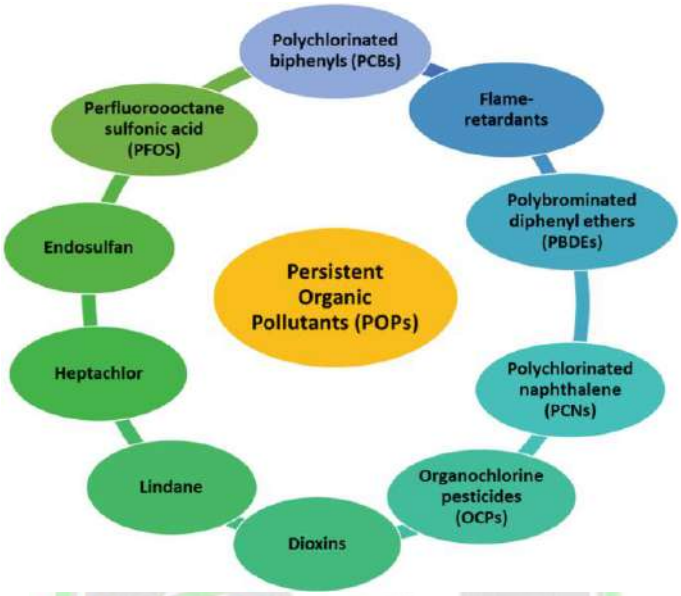
Persistent Organic Pollutants (POPs)

Persistent Organic Pollutants are synthetic organic chemicals characterized by their long environmental persistence, toxicity, bioaccumulation and ability to undergo long-range environmental transport. These compounds possess highly stable molecular structures containing chlorinated aromatic rings that resist chemical, physical and biological degradation. As a result, POPs remain in soil, water, sediments and living organisms for several years or even decades after their release into the environment.

Some of the most well-known Persistent Organic Pollutants include dichlorodiphenyltrichloroethane (DDT), aldrin, dieldrin, chlordane, heptachlor, mirex, toxaphene, hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs), dioxins and furans. These chemicals were widely used as pesticides, industrial lubricants, dielectric fluids and by-products of industrial combustion. Due to their lipophilic nature, POPs accumulate in the fatty tissues of aquatic organisms and become progressively concentrated at higher trophic levels through biomagnification. Exposure to POPs has been associated with endocrine disruption, reproductive disorders, immune suppression, neurological impairment, developmental

abnormalities and several forms of cancer. Because of these serious environmental and health consequences, the production and use of many POPs have been restricted worldwide under the Stockholm Convention on Persistent Organic Pollutants.

Source: Molecular Toxicity Mechanism of Persistent Organic Pollutants (POPs)



Intentionally And Non-Intentionally Produced POPS

The compounds which are intentionally produced in industries to meet the essential needs are called intentionally produced POPs. These intentionally produced compounds can be further divided into other subcategories including many groups of brominated and chlorinated aromatic such as polychlorinated naphthalenes (PCNs), polybrominated diphenyl ethers (PBDEs), organochlorine pesticides (OCPs), polychlorinated biphenyls (PCB) and polychlorinated dibenzo-p-dioxins/ furans (PCDD/Fs), etc.The compounds produced unintentionally/accidentally as by-products of industrial processes or activities are called non-intentionally produced POPs.

For example, polychlorinated biphenyls (PCB) as well as hexachlorobenzene (HCB) can be produced as industrial by-products and released into the environment. Other examples include the production of polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-P-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).

Microbial Degradation of Persistent Organic Pollutants

Microbial degradation is a natural biological process in which microorganisms convert toxic organic pollutants into simpler and less harmful compounds through enzymatic reactions. Many microorganisms utilize organic pollutants either as a source of carbon and energy or

transform them through co-metabolic processes without directly obtaining energy from them. During biodegradation, microorganisms produce specialized enzymes capable of breaking the strong carbon-carbon and carbon-halogen bonds that make POPs highly resistant to degradation.

The degradation process generally involves adsorption of pollutants onto microbial cells, enzymatic transformation of complex molecules, formation of intermediate metabolites and complete mineralization into carbon dioxide, water and inorganic salts. Depending on oxygen availability, microbial degradation may occur under aerobic or anaerobic conditions, each involving distinct metabolic pathways. This biological process significantly reduces pollutant toxicity while restoring environmental quality in a sustainable manner.

Bacterial Degradation of Persistent Organic Pollutants

Bacteria are among the most effective microorganisms involved in the degradation of Persistent Organic Pollutants (POPs) because of their remarkable metabolic versatility and adaptability to diverse environmental conditions. Several bacterial genera, including *Pseudomonas*, *Sphingomonas*, *Burkholderia*, *Rhodococcus*, *Bacillus*, *Arthrobacter*, and *Alcaligenes* have demonstrated the ability to degrade a wide range of chlorinated pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and other persistent organic contaminants. These bacteria produce specialized enzymes such as oxygenases, dehalogenases, hydrolases and reductases that initiate the breakdown of complex pollutant molecules by cleaving stable carbon–carbon and carbon–halogen bonds.

Under aerobic conditions, bacteria oxidize organic pollutants to form intermediate metabolites that are further mineralized into carbon dioxide, water and inorganic salts. In anaerobic environments such as sediments and groundwater, certain bacterial species perform reductive dechlorination, in which chlorine atoms are sequentially removed from chlorinated compounds, making them more susceptible to complete degradation. Owing to their rapid growth, adaptability and high degradation efficiency, bacteria are widely employed in bioremediation strategies for contaminated soils, industrial wastewater and aquatic ecosystems.

Fungal Degradation of Persistent Organic Pollutants

Fungi play a significant role in the biodegradation of Persistent Organic Pollutants due to their ability to produce powerful extracellular oxidative enzymes capable of degrading highly stable organic molecules. White-rot fungi, particularly *Phanerochaete chrysosporium*, *Trametes versicolor*, *Pleurotus ostreatus* and *Bjerkandera adusta*, are extensively studied for their

exceptional pollutant-degrading abilities.

These fungi secrete non-specific enzymes such as lignin peroxidase, manganese peroxidase, versatile peroxidase and laccase, which oxidize complex aromatic structures present in pesticides, dioxins, polychlorinated biphenyls and other POPs. Unlike many bacteria that require direct uptake of pollutants into their cells, fungal extracellular enzymes can act on contaminants present outside the fungal cell, enabling efficient degradation of high-molecular-weight compounds. Additionally, fungal hyphae can penetrate contaminated soils and sediments, increasing contact with pollutants and enhancing degradation efficiency. Their ability to tolerate harsh environmental conditions and degrade structurally diverse contaminants makes fungi valuable agents for the remediation of industrial wastes, contaminated agricultural lands and polluted aquatic environments.

Genetically Modified Microorganisms (GMMs) for POP Degradation

Recent advances in molecular biology and genetic engineering have led to the development of genetically modified microorganisms (GMMs) with enhanced capabilities for degrading Persistent Organic Pollutants. Through recombinant DNA technology and genome-editing tools such as CRISPR-Cas systems, scientists have successfully introduced or modified genes responsible for pollutant degradation, enabling microorganisms to metabolize compounds that are otherwise highly resistant to natural biodegradation. Genetically engineered strains of *Pseudomonas putida*, *Escherichia coli*, *Rhodococcus erythropolis* and *Sphingomonas* have been designed to express multiple degradation enzymes, allowing them to efficiently degrade chlorinated pesticides, polychlorinated biphenyls, dioxins and other persistent contaminants.

In addition to enhanced degradation efficiency, genetically modified microorganisms exhibit improved tolerance to toxic environments, faster metabolic rates and the ability to degrade multiple pollutants simultaneously. Despite these advantages, the environmental application of genetically modified microorganisms requires careful risk assessment and strict regulatory oversight to prevent unintended ecological consequences, such as horizontal gene transfer or disruption of native microbial communities. Nevertheless, continued advances in synthetic biology and environmental biotechnology are expected to make genetically modified microorganisms an important component of future bioremediation strategies.

Future Prospects

Despite significant advancements in microbial bioremediation, Persistent Organic

Pollutants (POPs) continue to pose a serious threat to terrestrial and aquatic ecosystems because of their persistence, toxicity and widespread distribution. Therefore, existing microbial degradation strategies must be continuously improved by addressing current limitations such as slow degradation rates, incomplete mineralization and varying environmental conditions. Recent technological innovations have opened new avenues for enhancing bioremediation efficiency. Among these, Nano bioremediation has emerged as a promising approach that combines nanotechnology with microbial processes to accelerate the removal of environmental contaminants.

Nanoparticles can enhance microbial activity, improve pollutant bioavailability and increase degradation efficiency, making remediation faster and more cost-effective Another innovative technology is the use of Microbial Fuel Cells (MFCs), which integrate microbial degradation with renewable energy generation. In MFCs, electroactive microorganisms oxidize organic pollutants while simultaneously producing electricity, offering an environmentally friendly and sustainable approach for wastewater treatment and pollutant removal. The integration of these advanced technologies with conventional microbial degradation strategies holds great promise for developing efficient, economical and sustainable solutions for managing Persistent Organic Pollutants in the future.

Conclusion

Microbial degradation has emerged as one of the most sustainable and environmentally friendly approaches for managing Persistent Organic Pollutants in contaminated aquatic ecosystems. Through their remarkable metabolic diversity, bacteria, fungi and Genetically Modified Microorganisms can transform highly toxic and persistent compounds into less harmful or completely harmless products, thereby restoring environmental quality and reducing ecological risks. Although several scientific and technological challenges remain, ongoing advances in microbial biotechnology, molecular biology, and environmental engineering continue to improve the efficiency and applicability of bioremediation strategies. As global concerns over chemical pollution and ecosystem degradation continue to grow, microbial degradation is expected to play a central role in achieving cleaner aquatic environments, sustainable fisheries and long-term environmental conservation.

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MUSCARDINE DISEASE IN SILKWORM

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Introduction

Approximately 95% of silk produced across the world is from mulberry silkworm (*Bombyx mori*) with China, India and Japan ranking as the leading producers. The mulberry silkworm is susceptible to various pathogens, that become a major challenge to cocoon production particularly in tropical regions. The major silkworm diseases that cause maximum crop loss are Grasserie (caused by viruses), Flacherie (caused by bacteria), Muscardine (caused by fungi) and Pebrine (caused by protozoa/microsporidia) causing significant larval mortality at different stages. In India, annual cocoon crop losses are estimated to range between 30-40% due to these diseases. Among the four major diseases, muscardine is considered the most lethal and destructive, as it is highly contagious and causes severe economic losses to cocoon production worldwide. This paper highlights the cause, classification, transmission and control measures for muscardine disease in silkworm.

Muscardine

The term "muscardine" is derived from the Italian word “moscardino” meaning musk or grape confit, while “calcino” refers to the white powdery growth characteristic of this disease. It is caused by many species of entomopathogenic fungus. The disease was first reported by the Italian entomologist Agostino Basi in 1763. This was the first demonstration of the germ theory of disease, the first time a microorganism was recognized as an animal pathogen. The infection primarily thrives during cold, humid, and rainy weather (temperatures below 25°C and 85%–95% relative humidity).

Major Types of Muscardine

Muscardine is categorized primarily by the color of the fungal spores (conidia) that overgrow and mummify the silkworm's body after death.

1.White Muscardine

White muscardine in silkworms occur throughout the year in all sericulture regions and its incidence is higher during rainy and winter seasons. Among the major diseases grasserie, flacherie, muscardine and microsporidiosis, white muscardine is particularly severe.

Causative Agent

White muscardine is caused by the entomopathogenic fungus *Beauveria bassiana*, also referred as mycosis. The disease mainly occurs in larval and pupal stage. The fungus infects silkworms through contamination of the body surface followed by direct penetration of the germ tube. In young larvae, the disease progresses rapidly, whereas in mature larvae, it takes a chronic course.

Transmission

Transmission primarily occurs through spores produced on the dead larvae which subsequently infect healthy worms. Infection can also spread through contaminated food, rearing appliances or direct contact between infected and healthy worms. Low temperatures (below 25 °C) and high relative humidity (90-95%) favours the spread of the disease. The pathogens may also be excreted by infected larvae, contributing to secondary infections in the rearing environment.

Symptoms



Infected larvae lose appetite, vomit and become sluggish and generally die within four to five days and in 24 hours their bodies become mummified and covered with white fungal spores. Occasionally, infected larvae manage to spin cocoons but die inside cocoon, preventing moth emergence. Major sources of infection include mummified larvae, alternate insect hosts, contaminated mulberry leaves and unclean rearing equipment.

Prevention and Management

- Strict hygiene practices, including thorough disinfection of rearing houses, appliances and surrounding areas.

- Maintaining optimal temperature, humidity and ventilation along with proper bed spacing and regular cleaning, significantly reduces disease incidence.
- Supplying nutritious mulberry leaves and reducing humidity through heaters during damp seasons are also beneficial.
- The rapid spread of the disease is attributed to its wide host range, high sporulation rate, and poor management practices. To combat this, integrated disease control technologies have been developed by CSR&TI, Mysore, which involve the use of chlorine dioxide, Anukush, and Vijetha.
- Regular application of bed disinfectants like Vijetha and Ankush, as well as the use of lime powder after each larval moult, coupled with maintenance of proper hygiene, effectively prevents the outbreak and spread of white muscardine.

2.Green Muscardine

Green muscardine is a lethal fungal disease in silkworms thrives in cool, highly humid conditions.

Causative Agent

- **Primary Pathogen:** *Metarhizium anisopliae* (commonly known as the green muscardine fungus).
- **Secondary Agent:** *Nomuraea rileyi*.

Transmission

The disease spreads via wind and through contact with pathogenic spores. The fungus thrives at temperatures below 23° C and relative humidity exceeding 80%.

Symptoms and Progression



- **Early Stages:** Larvae become sluggish, lose appetite and develop dark brown or oily specks on their body surface.
- **Mid-Stages:** Infected worms shrink, their growth is retarded and the body takes on a light yellowish-green hue.
- **Late Stages/Death:** The fungus secretes toxins that mummify the larva, making the body stiff and hard.
- **Sporulation:** Shortly after death, the fungus breaks through the insect cuticle, covering the mummified cadaver in a fuzzy, grass-to-dark-green powdery layer of spores.

Prevention and Management

- **Environmental Control:** Maintain rearing room temperatures between 24° C and 26° C with relative humidity around 70% to prevent fungal spore germination.
- **Hygiene & Disinfection:** Strictly disinfect rearing houses and equipment using chemical solutions like 2% Formaldehyde or bleaching powder before introducing silkworms.
- **Removal:** Collect diseased and dead larvae immediately and dispose of them by burning or burying them deep to prevent secondary outbreaks

3.Brown Muscardine/Aspergillosis

Brown muscardine disease (Aspergillosis) is a highly contagious fungal infection in silkworms prevalent in high-humidity and low-temperature environments.

Causal Organisms

Over 10 species of the *Aspergillus* fungus (e.g., *Aspergillus flavus* and *Aspergillus tamari*) are responsible for the disease.

Transmission

Fungal spores (conidia) spread through the air or direct contact, often entering through the silkworm's cuticle or spiracles. The disease thrives in conditions with high humidity and lower temperatures (typically < 25° C).

Symptoms and Progression

- **Early Stage:** Infected worms (especially chawki worms) show oily, brownish patches on their skin and lose their luster.
- **Advanced Stage:** The fungus grows outward and the conidial layer covers the body in a brownish or greenish-yellow fungal mat.
- **Final Stage:** The worm's body hardens and the internal tissues rot easily, potentially turning into a mummified, stiff corpse.

Management and Control

- **Environmental Regulation:** Maintain optimal temperature and humidity in the rearing house based on the larval stage to prevent the fungus from thriving. Keep the rearing bed dry and well-ventilated by splitting the bed periodically.
- **Disinfection:** Thoroughly sanitize the rearing house and all equipment with recommended antifungal agents like 2% formalin.

- **Chemical Application:** Dusting can be used as a specific measure, typically, 1–2% of Dithane M-45 mixed with slaked lime or Captaf mixed with Kaolin is dusted on the silkworm body according to schedule.
- **Containment:** Immediately remove and destroy all infected larvae and dead worms to prevent the spread of conidial spores to healthy silkworms.

4.Yellow Muscardine

Yellow muscardine is a fungal infection affecting silkworms and most prevalent during high-humidity seasons, such as rainy and winter months.

Causal organism

Yellow muscardine in silkworm is caused by entomopathogenic fungi such as *Penicillium citrinum* and *Paecilomyces variotii*, though *Isaria farinosa* is also known to cause yellow muscardine.

Transmission

Fungal spores (conidia) spread rapidly via air currents, direct contact with contaminated surfaces, dirty equipment or infected cadavers. Low temperatures and high relative humidity (above 70-80%) are the primary predisposing factors.

Symptoms and Progression

The infected silkworms mummify and become covered in a powdery coating ranging from yellow to reddish-orange depending on the specific fungal strain.

- **Initial Stages:** Larvae become sluggish, lose appetite and may vomit or display irregular growth.
- **Body Changes:** The midgut becomes opaque and pale yellow. Infected worms display oily specks or black dots on their bodies.
- **Post-Death:** The larvae's bodies stiffen, harden and mummify into a chalky texture within 24 hours.
- **Fungal Spores:** Dead worms get coated with a characteristic yellow fungal mycelium and conidial spore layer.

Prevention and Management

- **Climate Control:** Maintain recommended temperature and humidity levels in the rearing house depending on the silkworm stage to prevent fungal growth.

- **Hygiene & Disinfection:** Strictly maintain hygiene. Periodically disinfect the rearing beds and room floors using slaked lime or commercial bed disinfectants.
- **Removal:** Promptly collect and burn/destroy all diseased or dead larvae to prevent the spread of spores.
- **Bed Drying:** Split rearing beds to allow them to dry properly, as moisture favors fungal proliferation

5.Red Muscardine

Causal organism

Red muscardine is a fungal infection caused by *Isaria fumosoroseus.*

Transmission

Red muscardine typically thrives under specific conditions, particularly in rainy or foggy weather when the environment has low temperatures combined with high humidity. These conditions encourage the fungal spores to germinate and spread rapidly across rearing trays.

Symptoms and Progression

- **Initial Stages:** Larvae lose their appetite and become lethargic. The gut region may briefly turn greenish and then become translucent and reddish.
- **Physical Deformity:** The head region swells and the body becomes flaccid.
- **Mummification:** As the fungus consumes the silkworm, the body eventually hardens (mummifies) and gets covered in a layer of red, powdery fungal spores.

Management and Control

- **Environmental Control:** Ensure optimal rearing conditions by maintaining proper ventilation to reduce ambient humidity.
- **Rearing House Disinfection:** Thoroughly sanitize the rearing house and appliances before and after every crop cycle. Use recommended antifungal disinfectants like slaked lime, bleaching powder or commercial products (e.g., Jeevan Suraksha, TKO).
- **Chemical Dusting:** Lightly dust antifungal powders (such as 1-2% Dithane M-45 mixed with slaked lime or Captaf mixed with Kaolin) over the silkworm bed.
- **Remove Infected Larvae:** Promptly pick out and destroy any sick or dead larvae to prevent the fungus from spreading spores to healthy silkworm.

6.Grossy Muscardine

Grossy muscardine is a highly contagious fungal infection in silkworms and usually do not pose

a threat to Sericulture. Like other fungal mycoses (e.g., green or white muscardine), it spreads via airborne or contact-based spores and is most prevalent during periods of low temperature and high humidity.

Causal organism

Grossy muscardine in silkworms is caused by *Hirsutella necatrix* and fusariosis is caused by Fusarium species.

Symptoms and Progression

- **Blackish-brown specks:** Small oily or dark specks appear on almost every body segment of the larva.
- **Discoloration:** Infected larvae may turn reddish-brown.
- **Mummification:** As the fungus digests the insect's tissue, the larva loses its elastic properties and stiffens into a hardened mummy.
- **Synnemata:** Distinctive hair-like fungal fruiting structures often emerge from the dead cadavers.

Prevention & Management

- **Strict Disinfection:** Thoroughly sanitize the rearing house and appliances before and after each crop using recommended solutions like bleaching powder and slaked lime.
- **Environmental Control:** Maintain optimum temperatures and avoid sudden drops in temperature combined with high humidity, which are ideal predisposing conditions for fungal outbreaks.
- **Prompt Disposal:** Carefully pick up any diseased larvae and dispose of them by burning or burying them far away from your rearing plots to prevent secondary contamination.

7.Grey Muscardine

Grey muscardine is a highly contagious fungal disease in silkworms caused by entomopathogenic fungi, commonly acting as mycosis. It typically strikes during the winter and rainy seasons, thriving in conditions of low temperature (below 23°C) and high humidity (above 80%)

Causal organism

Grey muscardine is also mycoses caused by filamentous fungi are rare, but include *Isaria javanica* (formerly *Paecilomyces avanicus*)

Transmission

Grey muscardine is triggered by specific fungal spores. The conidia (spores) in the rearing house come in contact with the silkworm, germinate and penetrate the insect's body.

Symptoms and Progression

- **Initial Stages:** Larvae lose their appetite, become sluggish and inactive.
- **Progression:** Moist or oily-looking dark specks appear on the body. The larvae become flaccid, shrink, and lose their elasticity.
- **Mummification:** After death the body becomes hard, stiff and turns pale or grey. The dead larvae eventually mummify due to the fungal toxin and the growth of aerial mycelia.

Prevention & Management

- **Climate Control:** Maintain an optimum temperature (24-26°C) and humidity level (60–70%) in the rearing house to prevent fungal germination.
- **Hygiene:** Strictly clean and disinfect all rearing appliances and the rearing house using recommended disinfectants before every crop cycle.
- **Disposal:** Immediately collect and burn any dead or mummified larvae to prevent secondary outbreaks.
- **Chemical Treatment:** Dust the silkworm body with specific antifungal agents, such as 1-2% of Dithane M-45 (in slaked lime) or captaf (in Kaolin), as recommended by sericulture boards.

8.Black Muscardine

Black muscardine is a rare, highly contagious fungal disease of silkworms. The disease spreads most easily in cool temperatures, high humidity and foggy weather (typically during winter and rainy seasons).

Causal organism

Black muscardine in silkworms is caused by *Metarhizium anisopliae* and *Beauveria brongniartti*. *Metarhizium anisopliae* can cause fatal disease in over 200 species of insect.

Transmission

Fungal conidia (spores) spread by coming into contact with the silkworm's body or by consuming contaminated mulberry leaves.

Symptoms and Progression

- **Initial Stages:** Larvae become sluggish, lose their appetite, show irregular growth and develop oily or black pepper-like specks on their bodies.
- **Progression:** The fungus releases toxins inside the worm, causing it to become inactive, flaccid and eventually mummified (hardened).
- **Final Stage:** The deceased larvae turn dark green to black and may get covered in fungal spores.



Prevention and Management

- **Environmental Control:** Maintain optimal temperature and lower humidity in the rearing house. Keep the environment well-ventilated to prevent dampness.
- **Strict Hygiene:** Routinely disinfect the rearing house and appliances with appropriate chemical sterilizers (e.g., 2-4% formalin or slaked lime).
- **Bed Disinfectants:** Dust the rearing beds with fungicidal formulations like Dithane M-45 (mancozeb) or Vijetha as well as slaked lime to restrict fungal spore germination.
- **Removal of Infected Larvae:** Promptly collect and burn any dead or mummified worms to prevent the fungus from releasing more spores into the rearing environment.

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THE INDIAN SHARE MARKET- RISE AND FALL

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Abstract

The Indian share market is one of the fastest growing financial markets in the world. It plays a vital role in the country's economic development by helping companies raise capital and providing investment opportunities to millions of peoples. In mid of 2026, The Indian Stock market witnessed a decline due to a combination of domestic and global factors, including weak performance in banking sectors, raising crude oil prices, geopolitical tension, a weak Indian rupee, and cautious investor sentiment. By improving transparency, strengthening regulations, increasing investor education, and maintaining economic stability, this will help to overcome the falling of Indian Share Market.

Introduction

India's stock market has firmly established itself as one of the world's leading financial powerhouses, having crossed the historic US $5 trillion market capitalization milestone. There are two major stock exchanges in India are Bombay Stock Exchange (BSE), established in 1875, and the National Stock Exchange (NSE), established in 1992. Their benchmark indices, Sensex and Nifty 50, are considered important indicators of the performance of the Indian economy. In recent years, the Indian stock market performs rapid growth due to digital trading platforms, increased participation by retail investors, improved financial awareness, and strong regulatory

oversight by the Securities and Exchange Board of India (SEBI). This article discussed the current condition of the Indian Share Market, the major factors influencing its performance, the challenges it faces, its impact on the Indian economy, and the measures that can strengthen the market for sustainable long-term growth.

UNDERSTANDING OF INDIAN SHARE MARKET

The Indian Share Market is a centralized, regulated platform where individuals and institutions can buy and sell ownership shares in publicity listed companies. Its primary purpose is to allow companies to raise capital for business expansion without taking on debt, while offering investors the opportunity to build wealth through price appreciation and dividends.

Key Components of the Indian Share Market

- Regulatory Body: The Securities and Exchange Board of India (SEBI) regulates the market to ensure transparency, prevent fraud, and protect investors.
- Stock Exchanges: The main marketplaces where trading happens. India's to primary exchanges are the National Stock Exchange (NSE) and the Bombay Stock Exchange (BSE).
- Merket Indices: Benchmarks that track the performance of the broader market. The BSE uses the Sensex (Top 30 Companies), and the NSE uses the Nifty 50(top 50 companies).

IMPORTANCE OF STOCK MARKET

While it's important for transport and electricity networks to operate effectively, it's also critical for capital to be saved and channelled to the "most profitable investment projects" and for both households and businesses to receive assistance in dealing with financial risks and uncertainty, and the ability to spread consumption over time. Every civilization that has progressed beyond the era of mainly domestic economies includes financial markets as an essential component of its infrastructure. The financial markets, including the stock market, serve the following purposes in a country's economy.

- Raising capital for Businesses: Companies may obtain money for growth by selling shares to the investing public on the stock market.
- Mobilizing savings for Investment: Instead of being utilised for consumption or idle bank deposits, the money is mobilised and redirected to encourage commercial activity, which helps a range of economic sectors including agriculture, trade, and industry, resulting to greater productivity and better economic development.

- Facilitate Company Growth: Many companies see acquisitions as a way to grow their company by adding new products, increasing distribution channels, reducing volatility, and gaining market share. The easiest and most frequent method for a business to expand via acquisition or fusion would be through a takeover offer or merger agreement on the stock market.
- Redistribution of Wealth: When the stock market allows a wide range of people to buy shares and become part owners of successful companies, it reduces substantial wealth inequalities. Increasing stock prices and dividends give both casual & professional stock investors a stake in other people's future profits.
- Creates Investment Opportunities for Small Investors: Investment in shares, in contrast to other companies, does not need a significant initial capital investment, thus it is accessible to both large and small stock investors alike. Consequently, the stock market offers small investors with an additional revenue stream.
- Government Raise Capital for Development Projects: To fund large infrastructure projects like sewage as well as water treatment plants or housing estates, the government or even local governments may opt to issue bonds, a different kind of security. Members of the public may purchase these bonds when they are listed on the stock market and raised in this manner. Instead of raising taxes on citizens to pay for infrastructure improvements, the government or local council may use this new source of funding.

PERFORMANCE OF THE MARKET IN 2026

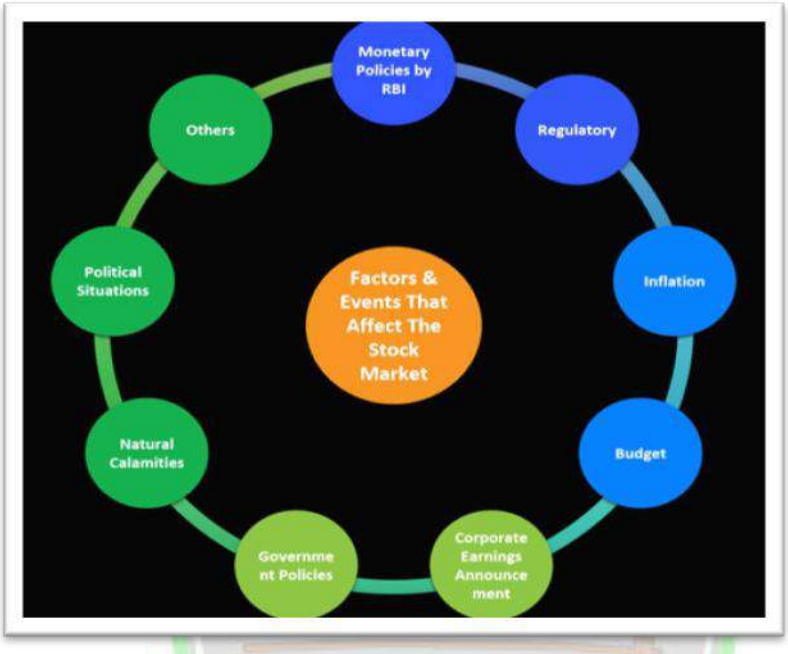
As of 2026, The Indian share market is experiencing a fall of benchmark indices facing minor corrections, while broader markets and specific sectors show resilience. The BSE Sensex is trading near the 77,709mark, and the Nifty 50 is hovering around 24,238. While large-cap indices have seen a dip due to sell-offs in major banking stocks, mid-cap and small -cap segments are outperforming.

WHY DID THE MARKET FALL?

Several factors contributed to today's market decline.

The declines in the Indian share market are usually not caused by a single factor, but by the interactions of economic, political, corporate, and global developments. Rising crude oil prices, weak corporate earnings, foreign investor selling, geopolitical tensions, inflation, higher interest rates, and global economic uncertainty are among the major reasons behind the recent

weakness. Despite these short-term fluctuations, the Indian stock market has historically demonstrated resilience. Investors who focus on strong fundamentals, maintain diversified portfolios, and adopt a long-term investment approach are generally better positioned to withstand periods of market volatility.



Weak performance of banking stocks:

Private banking stocks such as HDFC Bank, Axis Bank, and Kotak Mahindra Bank came under selling pressure after investors reacted to their quarterly financial results. Since banking companies have a large weight in the Sensex and Nifty indices, their decline pulled the overall market lower.

Rising Global crude oil prices:

Global crude oil prices crossed 90 US dollars per barrel because of increasing geopolitical tensions. India imports most of its crude oil requirements, so higher oil prices increase, and inflation, negatively affecting economic growth.

Geopolitical Tensions

International tensions, particularly in the Middle East, increased uncertainty among investors often reduce their exposure to risky assets such as equities, leading to market declines.

Weaking of the Indian Rupee:

The Indian rupee weakened against the US dollar due to higher oil import costs and global

uncertainty. A weaker rupee makes imports more expensive and can reduce the confidence of foreign investors.

Profit Booking

After recent gains, many investors chose to book profits by selling shares. Profit booking is anormal part of stock market behaviour and often causes temporary declines in stock indices.

Sector specific problems:

IT sector may suffer due to reduced global demand. Automobile sector may experience weak sales. Real estate may decline because of higher interest rates. Pharmaceutical companies may face regulatory issues.

Inflation:

Inflation refers to the continuous increase in the prices of goods and services. High inflation due to reduces consumers purchasing power, increases business operating costs, lowers company profits, and decreases consumer demand.

SOLUTIONS

- Control inflation
- Reduced dependence on Imported Crude Oil
- Attract Foreign Investment
- Improve Corporate Performance
- Strengthen SEBI Regulations
- Encourage Long-Term Investing
- Increase Financial Literacy
- Promote Domestic Investment
- Strengthen Banking and Financial Institution
- Improve global trade relation

Conclusion

The Indian Share market is currently experiencing volatility due to global and domestic challenges, these problems can be managed through sound economic policies, strong corporate governance, effective regulation, and informed investing. By controlling inflation, attracting investment, improving corporate performance, promoting renewable energy, and encouraging long-term investment, India can build a stronger and more resilient stock market. In the long run,

the Indian share market has significant growth potential because of the country's expanding economy, young population, technological advancement, and increasing investor participation.

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ELECTROHYDRODYNAMIC DRYING: A PROMISING FUTURE FOR FOOD PRESERVATION

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Abstract

Electrohydrodynamic (EHD) drying is an emerging nonthermal drying technology that uses a high-voltage electric field to generate ionic wind. It enhances drying at ambient or low temperatures and offers an alternative to conventional heat-based drying methods to preserve food. This drying method maintains the nutritional integrity, colour, taste, texture, and bioactive constituents of heat-sensitive foods while effectively reducing energy requirements. This article outlines the operational principle of EHD drying, its advantages, limitations and future potential for industrial applications and challenges of large-scale implementation. It also emphasizes the increasing interest in hybrid drying systems that integrate EHD with other advanced technologies to enhance drying efficiency and product quality. With the growing focus on sustainable and energy-efficient food processing, EHD drying emerges as a significant next-generation food preservation method.

Keywords: Electrohydrodynamic drying, nonthermal drying, ionic wind, energy-efficient drying, sustainable food processing.

Introduction

Drying is one of the earliest food preservation techniques. Drying extends the shelf life and improves product stability during storage by eliminating moisture from the food product and preventing microbial growth, enzymatic activity, and spoilage. In appropriate circumstances, drying preserves the nutritional value and sensory attributes of the food products. Additionally, lowering the weight and volume of the food products during drying reduces the expenses associated with packaging, transportation, storage, and processing. These benefits make drying an essential component of the food processing industry for products such as fruits, vegetables, grains, seafood, herbs, spices, and medicinal plants.

Commercially, a variety of drying techniques, such as vacuum drier, microwave drier, hot-air drier and solar driers are used. However, most of them rely on heat, causing significant energy consumption and quality deterioration. Particularly with heat-sensitive food components, overheating can result in nutritional loss, discolouration, shrinkage, texture degradation, and flavor deterioration [1]. Conventional sun drying techniques also have issues with contamination, extended drying duration, weather dependency, and inadequate process control. Although cutting-edge methods like freeze drying yield higher-quality products, they frequently come with hefty equipment and operational costs.

Researchers are investigating cutting-edge nonthermal drying technologies to increase energy efficiency while maintaining food quality in order to get around these restrictions. Electrohydrodynamic (EHD) drying is one such promising technology. EHD drying is gaining increased attention as a sustainable and energy-efficient drying method for heat-sensitive food items because of its low energy consumption and decreased thermal damage.

1.0 What is electrohydrodynamic drying?

Electrohydrodynamic (EHD) drying is an emerging nonthermal drying technology that uses a high-voltage electric field, generated by applying a potential difference in the range of 10 - 40 kV between electrodes, to enhance moisture removal from food materials. In contrast to traditional thermal drying techniques, EHD drying does not mainly rely on high temperatures for evaporation. Rather, at relatively lower temperatures, it produces a phenomenon called corona wind or ionic wind, which speeds up the removal of moisture from the food surface. Compared to many traditional drying methods, EHD drying preserves the nutritional, structural, and sensory properties of the food products more efficiently as it uses gentle drying conditions.

2.0 How does ehd drying work?

The working principle of EHD drying is based on the generation of ionic wind through corona discharge. The air molecules around a sharp electrode become ionized when a high voltage is applied to it. As they approach the grounded collecting electrode, these charged particles run into neutral air molecules. This interaction generates ionic wind, a fast-moving airflow.

The ionic wind promotes water evaporation by disturbing the thin saturated moisture layer on the food surface. As a result, moisture gets removed even at low temperatures. Since this process does not require external heating, thermal damage to the product has been reduced. **Fig 1** represents the key performance indicators of EHD. Therefore, delicate and heat-sensitive goods such as fruits, vegetables, herbs, mushrooms, and medicinal plants can be dried using EHD driers to maintain their quality during drying.

Key Advantages of EHD Drying

One of the major advantages of EHD drying is its ability to preserve food qualities, such as inherent color, flavor, aroma, texture, nutrients, and bioactive substances of food products, as drying takes place at ambient temperatures. Additionally, EHD helps to preserve the overall appearance and rehydration qualities of dried materials by reducing shrinkage and structural damage.

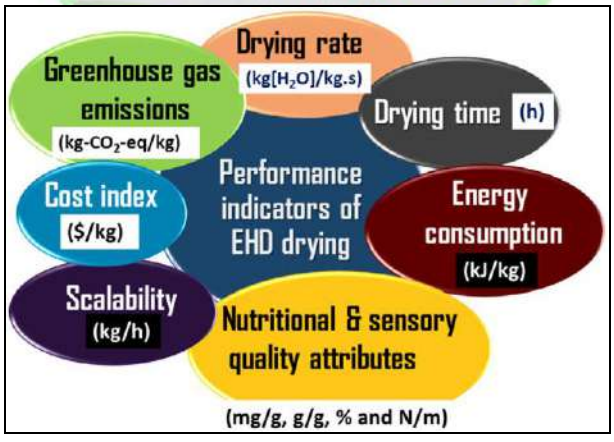


Fig 1. Performance indicators of EHD drying *(adapted from* Onwude et al. 2021)

Compared to conventional hot air driers, the EHD drier uses less energy as it primarily relies on ionic wind rather than excessive thermal heating. Additionally, it uses fewer moving mechanical components and operates with lower airflow requirements. Therefore, the process becomes more environmentally friendly and energy-efficient .

Furthermore, EHD driers can accomplish faster drying than natural drying techniques while avoiding quality issues related to high-temperature drying. Because of these advantages, EHD drying is a viable substitute for creating superior dried foods.

Current Limitations of EHD Drying

Despite its advantages, certain technical challenges still limit the widespread industrial adoption of EHD drying. The delayed removal of internal moisture in the later stages of drying is one of the major problems. Therefore, EHD drying is typically more successful for thin-layer and small-sized food materials. The need for high-voltage power sources, which necessitate appropriate insulation and operating safety measures, is another drawback. Corona discharge may also produce ozone and nitrogen oxides, requiring suitable ventilation and process control. In addition, scaling up EHD drying systems for industrial production remains challenging because maintaining a uniform electric field over large drying areas is difficult [2].

In order to increase drying efficiency and industrial feasibility, EHD drying is frequently combined with various pre-treatments such as ultrasound, blanching, pulsed electric field, etc. Additionally, it can be combined with other technologies such as hot air drying and heat pump drying.

Conclusion

Electrohydrodynamic drying is still developing toward commercial and industrial implementation. Currently, researchers are focusing on enhancing the energy efficiency, vapor transport, airflow distribution, and dryer design for large-scale applications. Due to their potential to enhance drying performance while preserving product quality, hybrid drying systems integrating EHD with other cutting-edge drying technologies attract a lot of interest [2].

Future research is expected to focus on reducing ozone generation, improving the efficiency of high-voltage systems, and developing advanced mathematical models to better understand mass transfer during EHD drying. With increasing demand for sustainable food processing and energy-efficient preservation technologies, EHD drying has strong potential to become an important next-generation drying method in the food industry.

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METHYLOBACTERIUM: A CLIMATE-SMART BIOINOCULANT FOR MITIGATING MOISTURE STRESS IN CROPS

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Abstract

Climate change-induced abiotic stresses, such as drought, salinity, heat, flooding, and temperature extremes, seriously threaten global crop productivity. This study argues that pink pigmented facultative methylotrophs (PPFMs), belonging to the genus *Methylobacterium*, are promising plant growth-promoting bacteria for climate-resilient agriculture because they enhance crop resilience through phytohormone production, improved nutrient uptake, osmoprotection, and activation of plant defense mechanisms. It also describes the major application methods, including seed treatment, seedling root dipping, soil application, foliar spraying, and their integrated use. Each method facilitates effective microbial colonization of the rhizosphere and phyllosphere, thereby improving germination, root development, photosynthetic efficiency, water-use efficiency, stress tolerance, and crop productivity. Integrated application provides synergistic benefits by ensuring continuous plant–microbe interactions throughout the crop growth cycle. Adoption of PPFM-based technologies offers an eco-friendly, sustainable, and cost-effective strategy to enhance crop performance while reducing reliance on chemical inputs, thereby supporting climate-smart agricultural production systems.

Key words: Abiotic stress, bioinoculants, PPFM, *Methylobacterium*, and PGPR.

Introduction

Global crop productivity is affected by climate-driven stresses, such as drought, floods, salinity, temperature extremes, and diseases. Low-cost biological approaches are essential for enhancing crop resilience and mitigating these threats. Beneficial microorganisms offer an effective solution because of their widespread distribution, genetic diversity, and close

association with plants. These microbes improve soil health by forming biofilms and producing exopolysaccharides. They also activate stress-response mechanisms by inducing the expression of osmoprotectants and heat shock proteins, thereby enhancing plant tolerance to drought, salinity, chilling, heat, and heavy metal toxicity. Beneficial microorganisms are widely recognized for promoting plant growth, improving nutrient availability, and suppressing plant diseases. They colonize the rhizosphere and establish beneficial interactions with plants, thus enhancing plant tolerance to abiotic and biotic stresses. Plant growth-promoting rhizobacteria (PGPR) enhance stress resilience by inducing systemic tolerance, a process that triggers physiological and biochemical changes in plants, enabling them to tolerate drought, salinity, heat, cold, and other environmental stresses while maintaining growth and productivity.

Under stress conditions, beneficial rhizobacteria produce osmoprotectants, such as proline, trehalose, glycine betaine, and ectoine, which help maintain cellular water balance and protect both microbial and plant cells. They also synthesize membrane-derived polysaccharides that preserve cell turgor under adverse conditions. Many PGPR, including *Rhizobium, Bacillus, Pseudomonas, Azospirillum, Paenibacillus, Methylobacterium, Burkholderia*, and *Enterobacter*, enhance plant tolerance to drought, salinity, heat, cold, and heavy metal toxicity. These microbes also produce phytohormones, such as indole-3-acetic acid (IAA) and gibberellins, which stimulate root growth, increase root surface area, improve nutrient uptake, and ultimately enhance plant resilience under stress conditions.

Pink Pigmented Facultative Methylotrophs

Methylobacterium, commonly known as Pink Pigmented Facultative Methylotrophs (PPFMs), are gram-negative, rod-shaped bacteria that colonize the rhizosphere, phyllosphere, and seed surfaces of many crop plants. They utilize methanol released from plant leaves as a source of carbon and energy, forming a mutually beneficial association with their host plants. In return, PPFMs produce plant growth-promoting substances, such as auxins, cytokinins, vitamin B12, and urease, which enhance plant growth, stimulate natural defense mechanisms, and improve stress tolerance. Due to these multifunctional traits, *Methylobacterium* has gained considerable attention for its applications in sustainable crop production and environmental bioremediation.

Synthesis of Cytokinins and Auxins

Methylobacterium species produce phytohormones, cytokinins, and auxins that regulate

plant growth and stress tolerance. These phytohormones stimulate cell division, root and shoot development, delay leaf senescence, and enhance overall plant vigor. Studies have shown that phylloplane-associated *Methylobacterium* species synthesize cytokinins, including zeatin and zeatin riboside, confirming their ability to promote plant growth. Thus, *Methylobacterium* improves crop performance under stress conditions and contributes to sustainable crop production.

Application Methods of PPFM

The use of PPFMs depends on selecting an appropriate application method to ensure effective colonization of the plant. As naturally occurring plant-associated bacteria, PPFMs colonize the rhizosphere, phyllosphere, and internal plant tissues, where they promote growth and enhance tolerance to abiotic stresses, such as moisture deficit. Application methods, such as seed treatment, seedling root dipping, soil application, and foliar application, facilitate the establishment of beneficial microbial populations at different stages of crop growth. Each method offers unique advantages, and their combined application often provides superior benefits for improving crop productivity and resilience under climate-induced moisture stress.

Seed Treatment

Seed treatment is one of the most effective, economical, and environmentally friendly methods for applying PPFMs to promote early crop establishment and enhance tolerance to moisture stress. For seed treatment, 10–20 mL of liquid formulation or 10–15 g of talc-based formulation per kilogram of seed is recommended. A 10% jaggery solution or rice gruel may be used as an adhesive to ensure uniform coating of the inoculant on the seed surface. The required quantity of PPFM is thoroughly mixed with the adhesive and uniformly coated onto the seeds. The treated seeds should be shade-dried for 20–30 min and sown within 24 hours to maintain maximum bacterial viability. Treated seeds should not be exposed to direct sunlight, as ultraviolet radiation and high temperatures can reduce the survival of beneficial bacteria. Seed treatment enables PPFMs to colonize the seed surface and emerging roots at the earliest stage of crop growth. This simple and cost-effective technique is suitable for a wide range of crops, including rice, maize, groundnut, cotton, pulses, millets, and various vegetable crops, making it an important component of sustainable and climate-resilient agricultural production systems.

Seedling Root Dip

Seedling root dip treatment is an effective method for establishing PPFMs on

transplanted crops, ensuring rapid colonization of the root system and improved crop establishment. For this method, 1000 ml of liquid formulation is diluted in 45–50 L of clean water, which is sufficient to treat seedlings required for approximately one hectare of transplanted crops. Healthy seedlings are carefully uprooted from the nursery, and excess soil adhering to the roots is gently washed off. The seedling roots are then immersed in the prepared PPFM suspension for 20–30 min to facilitate bacterial attachment and colonization. Immediately after treatment, the seedlings should be transplanted into the main field to maximize the survival and effectiveness of the beneficial bacteria. Early root colonization by PPFMs enhances the production of plant growth-promoting substances such as auxins and cytokinins, resulting in vigorous root growth, improved nutrient and water uptake, and better establishment under field conditions. In addition, the treatment reduces transplant shock, improves seedling vigor, enhances chlorophyll content and photosynthetic efficiency, activates natural defense mechanisms, and increases tolerance to drought, salinity, heat, and other stresses. This method is particularly suitable for transplanted crops such as rice, tomato, brinjal (eggplant), chilli, onion, cabbage, cauliflower, and other vegetable seedlings.

Soil application

PPFMs are an effective method for introducing PPFMs into the rhizosphere, where they establish beneficial associations with plant roots and enhance soil biological activity. For effective inoculation, 1-1.5 L of liquid PPFM formulation per hectare is recommended. The inoculum should be thoroughly mixed with 40-50 kg of well-decomposed farmyard manure (FYM) or compost, and 25 kg of vermicompost may be added as an optional carrier to further enhance microbial proliferation and soil fertility. The mixture should be incubated in a shaded place for 12–24 h to facilitate microbial activation and multiplication before field application. The enriched organic manure is then broadcast uniformly over the field prior to sowing or transplanting and incorporated into the top 5–10 cm of soil using a cultivator or hand hoe. Light irrigation immediately after application is recommended to maintain adequate soil moisture, thereby ensuring the rapid establishment and survival of beneficial microorganisms.

In soil application, PPFMs actively colonize the rhizosphere and stimulate plant growth through the production of phytohormones, such as auxins and cytokinins, which promote root elongation, lateral root development, and increased root biomass. They also enhance nutrient availability and uptake, improve soil microbial diversity, and stimulate biological processes

involved in nutrient cycling. In addition, PPFMs produce extracellular polysaccharides (EPS) that improve soil aggregation, enhance soil moisture retention, and create a favorable microenvironment for root growth. These physiological and microbiological interactions increase water-use efficiency, improve tolerance to drought and other abiotic stresses, and contribute to higher crop productivity. Soil application of PPFMs is therefore considered an eco-friendly and sustainable technology for improving soil health, strengthening crop resilience to climate variability, and reducing dependence on synthetic fertilizers in climate-smart agricultural production systems.

Foliar application

This method involves delivering PPFMs directly to the leaf surface, where the bacteria rapidly colonize the host plant's phyllosphere. For effective foliar application, 5–10 mL of liquid PPFM formulation should be diluted in 1 L of clean water, requiring approximately 500 L of spray solution per hectare. The total quantity of PPFM required is 1–2 L per hectare, depending on the crop canopy and growth stage. The first foliar spray is recommended at 25–30 days after sowing (DAS), followed by a second spray at the flower initiation stage, while a third spray during pod or fruit development may be applied if required, particularly under moisture-stress conditions. The PPFM formulation should be thoroughly mixed with clean water and sprayed uniformly during the early morning or late evening to minimize desiccation and maximize bacterial survival. Care should be taken to ensure complete coverage of both the upper and lower leaf surfaces, as this facilitates efficient colonization of the phyllosphere. Spraying should be avoided during periods of high temperature, intense sunlight, or rainfall, as these conditions can reduce bacterial viability and spray efficiency. Repeated applications at critical crop growth stages help maintain an active microbial population on the leaf surface, enhancing the physiological benefits throughout the crop cycle.

Once established on foliage, PPFMs utilize methanol naturally released by plant leaves as a carbon source and produce plant growth-promoting substances, including cytokinins, auxins, vitamins, and other bioactive metabolites. These compounds delay leaf senescence, maintain chlorophyll content, improve photosynthetic efficiency, enhance nutrient translocation, and stimulate biomass accumulation. Foliar application also activates antioxidant defense mechanisms, improves water-use efficiency, and enhances tolerance to drought, heat, salinity, and other abiotic stresses. As a result, treated plants exhibit improved vegetative growth,

flowering, fruit set, grain filling, crop quality, and yield. Foliar application of PPFMs has demonstrated significant benefits in cotton, sugarcane, maize, baby corn, groundnut, rice, vegetables, and a wide range of fruit crops, making it an important component of climate-resilient and sustainable crop production systems.

Integrated Application Methods

The integrated application of PPFMs combines two or more application methods to ensure continuous colonization of both the rhizosphere and phyllosphere throughout the crop growth cycle. This approach maximizes the beneficial effects of PPFMs by promoting sustained plant–microbe interactions from seed germination to crop maturity. The most effective combinations include seed treatment followed by foliar spray; seed treatment combined with soil application; seedling root dip followed by foliar spray; and soil application combined with foliar spray. Seed treatment establishes early bacterial colonization on the seed surface and emerging roots, whereas soil application enhances microbial activity in the rhizosphere, improving root growth, nutrient availability, and soil health. Foliar application enables rapid colonization of the leaf surface, maintains chlorophyll content, improves photosynthetic efficiency, and enhances physiological tolerance to moisture stress. Similarly, combining seedling root dip treatment with foliar spray ensures rapid root establishment after transplanting and sustained phyllosphere colonization during critical growth stages.

The integrated use of PPFMs provides synergistic benefits by enhancing phytohormone production, improving root architecture, increasing nutrient uptake, strengthening antioxidant defense systems, maintaining photosynthetic activity, and improving water-use efficiency. These combined effects result in greater tolerance to drought, heat, salinity, and other abiotic stresses while promoting vigorous plant growth, higher biomass accumulation, improved flowering, enhanced fruit or grain development, and increased crop yield. Furthermore, integrated application reduces dependence on synthetic growth regulators and chemical fertilizers, improves soil biological health, and supports sustainable nutrient management. Therefore, the integrated application of PPFMs represents the most effective strategy for maximizing the potential of Methylobacterium in climate-resilient, environmentally sustainable, and resource-efficient agricultural production systems.

Conclusion

The effectiveness of PPFMs depends not only on their plant growth-promoting capabilities but also on the method of their application. Seed treatment, seedling root dipping, soil application, and foliar spraying facilitate effective colonization at different stages of crop development and collectively improve germination, root growth, nutrient uptake, photosynthesis, stress tolerance, and yield. The integration of these methods offers the greatest potential for enhancing crop resilience to moisture stress and supports the development of climate-smart, sustainable, and environmentally friendly agricultural production systems.

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ZEOLITE: A SMART SOIL CONDITIONER FOR IMPROVING SOIL HEALTH AND RESOURCE-USE EFFICIENCY IN AGRICULTURE

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Abstract

Zeolites are crystalline aluminosilicate minerals that occur both synthetically and naturally. They are distinguished by their exceptional adsorption capabilities, microporous structure, and high cation exchange capacity. These properties make them suitable soil amendments in sustainable agriculture. The ability of soil to retain and release water and nutrients improves its physical, chemical, and biological properties, increasing productivity and resource efficiency. Zeolites reduce nutrient depletion caused by leaching, volatilization, and runoff, thus enhancing the efficacy of nitrogen, phosphorus, and potassium usage. Furthermore, they sequester hazardous heavy metals, reducing their bioavailability and enhancing soil vitality. Zeolites also function as media for biofertilizers and slow-release herbicides, improving microbial viability and herbicide effectiveness. Their improved water-retention ability enhances water-use efficiency, diminishes the need for irrigation, and bolsters crop resilience in environments with high moisture and salinity. Thus, zeolites help reduce environmental pollution, promote sustainable crop production, and ensure long-term agricultural sustainability.

Keywords: Zeolite, Nutrient and water use efficiency, sustainable agriculture and soil amendments

Introduction

Zeolites are naturally formed crystalline, hydrated aluminosilicate minerals with a three-dimensional framework of interlinked SiO_4 and AlO_4 tetrahedra that create micropores and channels. The replacement of Si^{4+} with Al^{3+} generates a lasting negative charge, counterbalanced by interchangeable cations, such as Na^+, K^+, Ca^{2+}, Mg^{2+}, and NH_4^+. These interchangeable cations, along with water molecules, fill the internal pore spaces and can be easily swapped with

adjacent ions, endowing zeolites with significant cation exchange capacity (CEC), adsorption, molecular sieving, and ion-exchange characteristics. Their distinctive porous architecture facilitates the reversible uptake and release of water, frequently surpassing 30% of their dry mass, without compromising the crystalline structure, rendering zeolites exceptionally efficient for water and nutrient retention. Initially delineated by Axel Fredrik Cronstedt in 1756, natural zeolites are generated via the hydrothermal transformation of volcanic ash and rocks in alkaline environments. To date, approximately 50 natural and over 150 synthetic varieties of zeolite have been recognized. Among natural zeolites, clinoptilolite, mordenite, chabazite, and analcime are predominantly utilized in agriculture owing to their prevalence, affordability, and advantageous physicochemical characteristics. Conversely, synthetic zeolites exhibit higher purity, consistent structure, regulated pore design, and improved thermal and chemical resilience, resulting in enhanced adsorption and ion-exchange capabilities. This chapter examines the physicochemical characteristics and diverse applications of zeolites in agriculture, emphasizing their contributions to enhancing soil quality, optimizing nutrient and water efficiency, controlling weeds, and immobilizing heavy metals, thus promoting environmental sustainability and climate resilience.

Soil enhancements

Zeolites enhance soil characteristics by augmenting moisture retention, facilitating hydraulic conductivity, and boosting yields in acidified soils. The use of zeolite reduces soil bulk density by enhancing soil porosity and promoting soil aggregation, especially in sandy substrates. These enhancements promote soil aeration, facilitate water infiltration, stimulate root development, and improve the overall physical quality of the soil. Zeolite also alters soil hydraulic conductivity by enhancing the pore structure and moisture retention. In sandy soils, the application of 1% zeolite reduced saturated hydraulic conductivity from 0.317 to 0.117 cm min^{-1}, thereby hindering rapid water movement, while in loamy soils, it increased slightly due to enhanced pore connectivity. These modifications improve soil moisture retention, water allocation, and overall hydraulic efficiency. Zeolite markedly enhances soil infiltration, water retention, and moisture levels, concurrently diminishing runoff, drainage losses, and sediment movement. The enhanced moisture retention is due to zeolite's elevated porosity and adsorption capability, which also increases the accessibility of exchangeable nutrients, such as Ca^{2+} and K^{+}. Consequently, zeolite improves soil physical properties and reduces nutrient depletion via leaching. Furthermore, these enhancements promote beneficial soil microorganisms, such as

bacteria, fungi, and actinomycetes, thereby improving soil biological activity, nutrient cycling, and long-term soil fertility.

Heavy metal containment and soil restoration

Soil contamination with heavy metals, including lead, cadmium, zinc, nickel, manganese, chromium, copper, and iron, poses a significant issue in agriculture, primarily resulting from industrial operations and the overapplication of fertilizers. The solubility of heavy metals in soil is influenced by pH levels, with lower pH correlating to an increased risk of their incorporation into a trophic chain. Their bioavailability is linked to levels in the soil solution. Due to their elevated cation-exchange capacity and ability to attract positively charged ions, zeolites are extensively utilized for the sequestration of cationic contaminants, including heavy metals like Cd, Pb, Cr, Zn, and Cu. The use of natural zeolite (20 g kg^{-1}) enhances soil pH, cation exchange capacity, organic matter levels, and soil structure, concurrently diminishing the bioavailability of lead. In soils contaminated with lead (2000 mg kg^{-1}), zeolite reduced lead absorption by 49% in roots and 30% in shoots of certain crops, illustrating its efficacy in immobilizing heavy metals and improving soil quality.

Nutrient Utilisation Efficiency (NUE)

Enhancing nutrient use efficiency (NUE) is a primary goal of sustainable agriculture, as a considerable amount of applied fertilizers is lost via ammonia volatilization, nitrate leaching, denitrification, runoff, and soil fixation, leading to poor fertilizer recovery by crops and considerable environmental harm. Agricultural plants globally absorb only 30–50% of the applied nitrogen (N), 10–25% of the phosphorus (P), and 35–60% of the potassium (K). This underscores the necessity for innovations that improve nutrient retention and synchronize nutrient release. In this context, zeolites provide an effective method for improving nutrient retention and utilization efficiency. Natural zeolites, especially clinoptilolite, have garnered significant interest as versatile soil enhancers owing to their elevated cation exchange capacity (100–300 cmol (+)/kg), extensive specific surface area, microporous crystalline structure, and remarkable adsorption-desorption characteristics. The negatively charged aluminosilicate structure selectively captures nutrient cations, such as NH_4^+, K^+, Ca^{2+}, Mg^{2+}, and various micronutrients, thus diminishing nutrient mobility while ensuring their accessibility in the rhizosphere. Through reversible ion exchange, zeolites act as gradual nutrient reservoirs, aligning nutrient availability with crop requirements and improving fertilizer recovery efficiency. Among

vital nutrients, nitrogen exhibits the least recovery efficiency owing to its vulnerability to volatilization, leaching, and gaseous losses.

Zeolite selectively adsorbs ammonium (NH_4^+) at its exchange sites, thus diminishing ammonia volatilization and postponing nitrification, which in turn reduces nitrate (NO_3^-) leaching. This regulated retention and incremental release of ammonium extend nitrogen availability throughout crop development, leading to notable improvements in nitrogen utilization efficiency and reduced fertilizer wastage. Conversely, zeolite improves potassium utilization efficiency (KUE) by holding exchangeable K^+ in its porous framework, thus reducing potassium leaching, especially in sandy and coarse-textured soils. Phosphorus is not directly absorbed via cation exchange; however, zeolite improves phosphorus use efficiency (PUE) indirectly by improving soil moisture retention, stabilizing soil pH, boosting microbial activity, encouraging root growth, and minimizing phosphorus fixation, which ultimately increases phosphorus availability to plants. The incorporation of zeolite with mineral fertilizers markedly improves nutrient efficiency in various agricultural systems. The primary agricultural advantages encompass:

- ✓ Improved efficiencies in the utilization of nitrogen, phosphorus, potassium, and micronutrients
- ✓ Minimizing nutrient depletion via leaching, volatilization, runoff, and fixation.
- ✓ Enhanced alignment between nutrient availability and crop nutrient requirements
- ✓ Enhanced nutrient absorption, root development, and physiological efficiency in nutrient utilization
- ✓ Enhanced agricultural yield and superior product quality with diminished fertilizer usage
- ✓ Improved soil nutrient retention and sustained soil fertility
- ✓ Minimized nitrate pollution in aquifers and diminished risks of eutrophication
- ✓ Reduced emissions of ammonia (NH_3) and nitrous oxide (N_2O), aiding in climate change alleviation

Zeolite enhances the agricultural efficacy of organic nutrient sources, such as farmyard manure, poultry manure, compost, vermicompost, and digestates, by adsorbing ammonium produced during the mineralization of organic matter and reducing nitrogen losses. Moreover, its elevated porosity and ability to retain moisture render zeolite an outstanding medium for biofertilizers, enhancing microbial viability, longevity, and rhizosphere establishment. In

addition, zeolite functions as a regulated-release herbicide medium, supporting herbicide effectiveness.

Controlled-release herbicide

Zeolites play a significant role in weed control, functioning as an effective transporter and regulated-release medium for herbicides. Its extensive surface area, microporous crystalline configuration, and exceptional ion-exchange capability facilitate the adsorption and sustained release of herbicide molecules, ensuring effective concentrations in the soil and on weed leaves for an extended duration. This regulated-release system extends the longevity of the herbicide, increases absorption by intended weeds, and boosts the effectiveness of weed management. Thus, zeolite-infused slow-release herbicide formulations reduce the need for frequent applications, curtail herbicide losses via leaching, volatilization, and surface runoff, and lower the total amount of herbicides required. Zeolites provide an eco-friendly and sustainable method for integrated weed management by enhancing herbicide efficacy while minimizing environmental pollution and production expenses.

Water Use Efficiency (WUE)

Water deficiency significantly hampers agricultural output, especially in arid, semiarid, and rain-fed areas. Zeolites have proven to be potent soil enhancers for improving water-use efficiency during periods of moisture scarcity owing to their significant porosity, extensive internal surface area, and remarkable water-adsorption capabilities. Their three-dimensional microporous architecture can sequester and hold significant volumes of water, which are progressively discharged into the rhizosphere as soil moisture diminishes, thus preserving water accessibility during dry periods. This ability renders zeolites particularly significant in contexts where water preservation is essential. Zeolites enhance the physical characteristics of soil by augmenting water retention, infiltration, aggregate stability, and porosity, while diminishing bulk density and evaporation losses. These enhancements increase soil moisture retention and extend water accessibility for plant roots, leading to reduced irrigation requirements and increased drought resilience.

In sandy soils, characterized by rapid drainage and minimal water retention that hinder agricultural yield, zeolites markedly enhance soil moisture availability and reduce deep percolation losses. In addition to retaining soil moisture, zeolites promote root growth, nutrient absorption, photosynthetic efficiency, and stomatal control, allowing plants to sustain their

elevated physiological functions during periods of water scarcity. Enhanced coordination of water and nutrient accessibility elevates transpiration efficiency and biomass yield per unit of water. Numerous studies have reported enhanced crop development, elevated yields, and improved water-use efficiency after zeolites were applied to drought-affected cereals, vegetables, legumes, and horticultural crops. As a result, zeolites serve as natural water reservoirs in the soil, maintaining soil moisture, reducing drought-related stress, enhancing irrigation efficiency, and increasing crop resilience under variable climatic conditions. These attributes render zeolites crucial for climate-conscious and sustainable water management in agricultural applications.

Crop management practices

Zeolites have been used in various field crops, such as rice, maize, wheat, potato, soybean, and other upland varieties, to enhance crop yield, nutrient and water utilization efficiency, and soil vitality across different soil classifications. Their distinctive physicochemical characteristics augment nutrient retention, maximize fertilizer efficiency, and enhance soil moisture accessibility while preserving soil integrity and ecological sustainability. The simultaneous use of 1.5 kg m^{-2} zeolite and 75% N ha^{-1} resulted in the maximum yield of transplanted rice, realizing a 14.9% enhancement compared to nitrogen fertilization alone. Zeolite has demonstrated considerable promise in enhancing maize yield and nutrient utilization efficiency. The utilization of clinoptilolite zeolite (CZ) at a rate of 60 g kg^{-1} soil, or in conjunction with 75% of the advised fertilizer dosage, resulted in cob yield, dry matter generation, and nutrient absorption similar to that of the complete fertilizer recommendation. These advantages stem from the elevated cation exchange capacity and clinoptilolite's strong attraction of NH_4^+ and K^+, which mitigate nutrient depletion via leaching, volatilization, and nitrification, thereby enhancing nitrogen utilization efficiency. Furthermore, zeolite utilization can reduce fertilizer needs by up to 25% and sustain residual benefits for 2–3 years, thereby reducing production costs and environmental contamination. The introduction of zeolite to French beans in alkaline and saline soils markedly enhanced nutrient absorption, water-use efficiency, and overall crop yield. These enhancements are ascribed to the liberation of Ca^{2+}, which diminishes the Na^+/Ca^{2+} ratio, mitigates sodium toxicity, augments soil structure, and increases nutrient accessibility, consequently fostering superior crop performance in saline environments.

Conclusion

The application of zeolites in agriculture is increasing owing to their diverse functions in enhancing soil characteristics, optimizing nutrient utilization, and conserving water. Zeolites promote climate-resilient and sustainable agricultural methods by improving soil moisture retention, decreasing fertilizer wastage, sequestering heavy metals, and lessening environmental contamination. Their application supports sustainable resource utilization, enhances agricultural yield, and helps preserve soil and groundwater. Therefore, zeolites have become an essential resource for fostering robust and ecologically sound agricultural practices.

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SELECTIVE BREEDING OF HIGH-PERFORMANCE AQUACULTURE SPECIES

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Abstract

The "Blue Revolution" in the aquaculture industry is mostly driven by selective breeding, which is examined in this article. Modern breeding efforts have effectively created high-performance lines with cumulative, long-lasting increases in growth rates, disease resistance, and feed efficiency by taking advantage of the quick maturation and high fecundity of aquatic species. The essay illustrates the enormous productivity gains that can be attained in a matter of generations with examples such as GIFT Tilapia, Jayanti Rohu, and Amrit Catla. To ensure a sustainable global seafood supply without correspondingly raising resource demands, it also tackles important issues like inbreeding, ecological risks from escaped fish, and fair seed access for smallholder farmers.

Key words: Selective breeding, Aquaculture, Genetic improvement, Disease resistance, Blue Revolution

Introduction

Selective breeding is the unglamorous process that has contributed more to the productivity, resilience, and affordability of farmed fish, shrimp, and other aquatic species than nearly any other single intervention. The same idea that transformed wolves into Labradors and wild teosinte into corn is now applied to organisms that live entirely underwater. Aquaculture recently overtook wild capture fisheries as the world's primary source of seafood, and it is projected to keep growing as ocean catches plateau. But growth in tonnage alone is not enough; farms need animals that thrive in crowded ponds and cages, resist the diseases that spread easily in such conditions, and convert every rupee of feed into flesh as efficiently as possible.

That is precisely the job selective breeding was built to do.

Selective breeding

Selective breeding is simple and choose the best-performing parents in each generation, mate them, and let their offspring form the next generation. Over time, the traits you selected for faster growth, better disease resistance, tolerance to cold water, a plumper fillet accumulate in the population. Unlike a one-time technological fix, genetic gain is cumulative and permanent. A fish that grows 15 percent faster than its parents passes that advantage on, generation after generation, at no extra cost to the farmer beyond buying improved seed.

The science behind this rests on a concept breeders call the 'breeding value', an estimate of how much of an individual's performance is due to its genes rather than its environment. Modern breeding programmes use pedigree records, growth data from tagged fish reared together, and increasingly, DNA information to calculate these values with precision. The animals with the highest estimated breeding values become the parents of the next generation, and the cycle repeats.

EXAMPLES OF SELECTIVE BREEDING PROGRAMS OF THE WORLD

1) GIFT Tilapia

The WorldFish Center's GIFT (Genetically Improved Farmed Tilapia) initiative produced a tilapia strain with faster growth, greater survival rates, and improved disease resistance (Eknath et al., 1993; Hallerman et al., 2021). The WorldFish Center has also been successfully used with Nile tilapia and other tilapia species in Egypt, Ghana, and Malawi, as well as with other fish species such as carp.

Improved traits: Growth rate, body form, and disease resistance, has resulted in enhanced tilapia strains for aquaculture.

2) Salmon

In Chile, selective breeding of coho salmon led to a 13–15-day shorter spawning season after four generations. Atlantic salmon have been selectively bred for improved growth, survival, and disease resistance, making them a valuable species in the aquaculture business (Embody and Hayford, 1925; Donaldson and Olson, 1957). Selective breeding has produced all female salmon populations, which can benefit aquaculture due to their greater and faster growth rates compared to males.

Improved traits: Early spawning, improved growth, disease resistance and sex reversal.

3) Jayanti rohu

The Indian Council of Agricultural Research Central Institute of Freshwater Aquaculture (ICAR-CIFA) and the Institute for Aquaculture Research (AKVAFORSK), Norway, began selective breeding of rohu in India in 1992.

Improve traits: Genetic improvement of Jayanti Rohu with 17% higher growth efficiency per generation has been reported (Mahapatha et al., 2016). Completed 13 generations of selective breeding. It shows an additional trait of disease resistant towards *Aeromonas hydrophila*.

4) GI Scampi

The ICAR-Central Institute of Freshwater Aquaculture (ICAR-CIFA) has made significant advancements in freshwater prawn research, leading to the creation of CIFA-GI SCAMPI®—a genetically enhanced strain of *Macrobrachium rosenbergii.* Beginning in 2007, ICAR-CIFA partnered with WorldFish, Malaysia, to launch a structured selective breeding program aimed at producing a faster-growing scampi variety. This improved strain has demonstrated a cumulative growth gain of 7.2% over 16 generations. Improved traits: Growth rate and disease resistance.

5) Amrit Catla

CIFA has launched a genetically modified Catla called AMRIT CATLA, a Selective breeding program which began from 2010.

Improved traits: A 35% cumulative gain by 3rd generation for improved aquaculture productivity. Better feed efficiency, higher survival rates and better disease resistance.

Breeder's Dream of Shrimp and Fish

Aquatic species offer breeders advantages that terrestrial livestock simply cannot match. A single female fish can release thousands, sometimes millions, of eggs in one spawning. Compare that to a dairy cow, which produces only one or two calves at a time. Combined with early sexual maturity in many farmed species, this fecundity means breeders can apply far more intense selection pressure and see results far sooner. Where it takes roughly six years to produce a new generation of cattle, a new generation of tilapia can be produced in about a year. This is one reason genetic improvement programmes for fish, once they got started in the 1980s, quickly began delivering gains that took terrestrial agriculture many decades to achieve. Because a single female fish lays thousands of eggs and matures in months rather than years, aquaculture can compress into a single career what livestock breeding took centuries to accomplish

Need for Selective Breeding

Early breeding programmes almost always started with growth rate, for the simple reason that it is easy to measure and has an immediate, visible payoff for farmers. But as programmes mature, breeders typically expand their focus to a wider basket of traits, including:

- **Disease resistance**: reducing losses from bacterial, viral, and parasitic outbreaks, often the single biggest source of farm economic loss.
- **Feed conversion efficiency**: getting more flesh from every kilogram of feed, which matters enormously given that feed is typically the largest cost in fish and shrimp farming.
- **Environmental tolerance**: cold tolerance, low-oxygen tolerance, and salinity tolerance, which widen the range of environments where a species can be farmed.
- **Product quality**: fillet yield, flesh colour and texture, and reduced intermuscular bones, all of which affect market price.
- **Reproductive traits:** later or controlled maturation, so that energy goes into growth rather than into eggs or milt before harvest.

Selecting for several traits at once is harder than selecting for one, because traits do not always move in the same direction. A fish bred hard for growth may become more vulnerable to disease, for instance. Modern breeding programmes manage this using selection indices, mathematical formulas that weigh multiple traits according to their economic importance, allowing breeders to make balanced genetic progress across the whole basket rather than over-optimising for any single trait.

The Challenges

Selective breeding is powerful, but it is not without risks, and any honest account of the field has to consider them.

1) **Inbreeding and Genetic Diversity**

Intense selection for a narrow set of traits can shrink the effective size of a breeding population, increasing the risk of inbreeding. Inbred populations tend to show reduced fertility, slower growth, and weaker immune function, the opposite of what breeding programmes are trying to achieve. Reputable programmes counter this by maintaining large numbers of unrelated families, carefully rotating mating schemes, and monitoring genetic diversity using molecular markers. Still, the risk never disappears entirely and requires constant vigilance.

2) Escapes and Wild Populations

Farmed fish, especially fast-growing salmon, sometimes escape from cages into the wild, where they can interbreed with wild populations and dilute locally adapted genetics that took thousands of years to evolve. This is a genuine ecological concern in salmon-farming regions and one reason regulators increasingly require containment standards and, in some cases, sterile or all-female stocks.

3) Access and Equity

Breeding programmes are long, expensive undertakings, often running for a decade or more before delivering a commercially released strain. That reality tends to concentrate genetic improvement in the hands of a small number of well-resourced public institutions or private companies, raising real questions about whether smallholder farmers, who make up the bulk of aquaculture in countries like India, get fair and affordable access to improved seed, or whether gains stay concentrated among larger, better-connected operators.

India's Road Ahead

The long-term benefits of public breeding initiatives that dedicate themselves to multi-generational improvement are demonstrated by India's success with Jayanti Rohu. However, the majority of aquaculture in India continues to use inferior or mixed-quality seed. Although fundamental breeding and conservation capability is provided by ICAR agencies (CIFA, CIBA, and NBFGR), it is still necessary to establish sustained breeding programs to include catla, other major carps, and brackishwater species. Millions of farmers would see long-term, cost-free increases in productivity with each new species included in a tough, multi-generation program, just as Jayanti Rohu has.

The Invisible Engine of the Blue Revolution

It is easy to overlook selective breeding precisely because its results look so ordinary: a slightly bigger fish in the harvest net, a slightly lower mortality rate after a disease outbreak, a slightly better feed bill at the end of the season. But multiply those small, unglamorous improvements across millions of ponds, cages, and tanks worldwide, compounding generation after generation, and you get something extraordinary. An aquaculture sector that has grown fast enough to overtake wild fisheries as humanity's main source of seafood, without needing proportionally more water, land, or feed to do it.

Conclusion

Selective breeding serves as the foundational engine of the global "Blue Revolution," offering cumulative and permanent genetic advancements that have enabled aquaculture to sustainably surpass wild fisheries as humanity's primary seafood source. Established programs, including those for GIFT Tilapia, Jayanti Rohu, and Amrit Catla, have quickly produced lines with higher growth, increased disease resistance, and improved feed efficiency by taking advantage of the quick maturation and high fecundity of aquatic species. The industry must actively address intrinsic obstacles, such as the potential for inbreeding, the ecological concerns of farmed fish escaping into wild populations, and the need to guarantee smallholder farmers equitable access to seed, even though this technology has enormous promise. In the end, maintaining these crucial advancements and feeding an expanding population without requiring a corresponding increase in land, water, or feed resources will require the ongoing expansion of sustained, multigenerational public breeding programs, especially in developing aquaculture sectors like India.

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ROLE OF ARTIFICIAL INTELLIGENCE IN FOOD PROCESSING

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Introduction

Artificial Intelligence (AI) has emerged as one of the most transformative technologies of the twenty-first century, revolutionizing numerous industries, including food processing and manufacturing. AI refers to the capability of computer systems to simulate human intelligence by performing tasks such as learning, reasoning, decision-making, problem-solving, pattern recognition, and language understanding. Unlike conventional automation systems that execute predefined instructions, AI systems possess the ability to learn from historical data, identify complex patterns, and continuously improve their performance without explicit reprogramming. This adaptive capability enables food processing industries to achieve greater precision, efficiency, consistency, and sustainability throughout the production chain.

The global food industry is currently facing several unprecedented challenges, including rapid population growth, increasing consumer demand for high-quality and safe food, changing dietary preferences, labor shortages, climate change, and the need to minimize food losses and environmental impacts. Traditional food processing methods often rely on manual inspection, operator experience, and fixed process parameters, which may lead to inconsistencies in product quality, increased operational costs, and limited production efficiency. Consequently, the adoption of AI-driven technologies has become essential for developing intelligent manufacturing systems capable of responding dynamically to changing production conditions while maintaining consistent product quality and safety.

The concept of Industry 4.0 has accelerated the integration of AI with advanced technologies such as the Internet of Things (IoT), cloud computing, robotics, cyber-physical systems, digital twins, and big data analytics. Smart sensors installed throughout food processing lines continuously collect information related to temperature, pressure, moisture content, pH, microbial growth, equipment performance, and product characteristics. AI algorithms analyze these large datasets in real time to detect abnormalities, optimize process parameters, predict equipment failures, and support autonomous decision-making. As a result, food manufacturers can reduce production costs, minimize waste, improve energy efficiency, enhance food safety, and increase consumer satisfaction.

Artificial Intelligence has found applications across virtually every stage of food processing, including raw material inspection, sorting, grading, peeling, cutting, mixing, fermentation, thermal processing, drying, packaging, storage, transportation, and distribution. Modern AI systems are capable of identifying defective products using computer vision, predicting shelf life using machine learning models, optimizing processing conditions using artificial neural networks, and managing supply chains through predictive analytics. These technologies not only increase operational efficiency but also support sustainable food production by reducing energy consumption, minimizing raw material losses, and improving resource utilization.

The increasing demand for minimally processed foods with superior nutritional quality has further expanded the role of AI in emerging non-thermal processing technologies such as high-pressure processing (HPP), pulsed electric fields (PEF), cold plasma, ultrasound, and radio frequency heating. AI-based predictive models assist researchers in optimizing process variables, reducing experimental trials, and maintaining product quality while ensuring microbial safety. Consequently, AI has become an indispensable tool for both industrial food manufacturing and academic research.

Fundamentals of Artificial Intelligence

Artificial Intelligence encompasses a broad range of computational techniques that enable machines to mimic human cognitive abilities. Machine Learning (ML), a major branch of AI, allows computer systems to learn relationships from historical datasets and make predictions without explicit programming. In food processing, machine learning models are trained using

experimental data to predict product quality, optimize processing conditions, estimate shelf life, and classify food materials based on physicochemical characteristics.

Deep Learning, an advanced subset of machine learning, utilizes multilayer artificial neural networks capable of extracting complex features from large datasets. Deep learning algorithms have demonstrated remarkable success in image recognition, object detection, defect classification, and quality inspection. Convolutional Neural Networks (CNNs), for example, are extensively employed for automated grading of fruits, vegetables, meat, seafood, and cereal grains based on visual characteristics. These systems can detect bruises, cracks, discoloration, fungal infection, and foreign materials with high accuracy, significantly outperforming traditional manual inspection methods.

Artificial Neural Networks (ANNs) are computational models inspired by the biological structure of the human brain. ANNs consist of interconnected processing units called neurons that learn nonlinear relationships between input variables and output responses. Food engineers frequently employ ANN models for predicting drying kinetics, microbial inactivation, texture changes, moisture migration, and nutrient degradation during processing. Compared with conventional regression models, ANNs can effectively model complex nonlinear interactions that commonly occur during food processing operations.

Computer Vision represents another important AI technology that enables machines to interpret visual information acquired through cameras and imaging sensors. High-resolution digital images captured during food processing are analyzed using AI algorithms to evaluate product appearance, color, texture, shape, size, and surface defects. Computer vision systems eliminate subjectivity associated with manual inspection while providing rapid, objective, and reproducible quality assessment. Consequently, these technologies have become essential components of modern automated food grading and sorting systems.

Natural Language Processing (NLP) enables AI systems to understand, analyze, and generate human language. Within the food industry, NLP is increasingly applied to analyze customer reviews, identify emerging consumer preferences, monitor social media sentiment, summarize scientific literature, and support automated documentation for quality management systems. These capabilities assist manufacturers in improving product development and market responsiveness.

Fuzzy logic systems are particularly useful for modeling uncertain and imprecise conditions frequently encountered in food processing operations. Since food materials exhibit considerable biological variability, precise mathematical descriptions are often difficult to establish. Fuzzy logic provides flexible decision-making by incorporating linguistic rules similar to human reasoning. Applications include fermentation control, drying optimization, and intelligent temperature regulation.

Expert systems represent another branch of AI that utilizes accumulated expert knowledge to support decision-making during food processing. These systems assist operators in troubleshooting equipment problems, selecting processing parameters, diagnosing product defects, and maintaining consistent production quality. More recently, reinforcement learning has gained attention for its ability to continuously optimize industrial processes through trial-and-error learning, enabling autonomous control of complex food manufacturing systems.

AI Technologies Supporting Food Processing

The successful implementation of Artificial Intelligence in food processing relies on its integration with several complementary digital technologies that collectively enable intelligent manufacturing. Among these, the Internet of Things (IoT) forms the backbone of modern smart food factories by connecting sensors, processing equipment, storage facilities, and distribution systems through wireless communication networks. IoT devices continuously monitor processing variables such as temperature, humidity, pressure, gas composition, pH, moisture content, vibration, and equipment performance. These real-time data streams are transmitted to cloud-based AI platforms, where sophisticated algorithms analyze the information and generate actionable recommendations for process optimization.

Cloud computing has significantly enhanced the scalability and accessibility of AI applications by providing centralized storage and high-performance computing resources. Food processing industries can securely store large volumes of production data, perform advanced analytics, and deploy machine learning models without investing in expensive local computing infrastructure. Cloud-based AI platforms also facilitate collaboration among researchers, manufacturers, and quality assurance personnel by enabling remote monitoring and real-time access to production data.

Big data analytics plays an increasingly important role in extracting meaningful information from the enormous quantities of structured and unstructured data generated during

food production. Modern processing plants produce data from production equipment, laboratory analyses, sensor networks, customer feedback, market trends, and supply chain operations. AI algorithms analyze these diverse datasets to identify hidden relationships, predict future trends, optimize resource utilization, and support strategic decision-making. The ability to convert raw data into valuable knowledge represents one of the greatest advantages of AI-driven food manufacturing.

Digital twins have recently emerged as powerful tools for intelligent food processing. A digital twin is a virtual replica of a physical processing system that continuously receives real-time operational data from sensors installed on actual equipment. By simulating various processing scenarios, digital twins enable engineers to optimize production parameters, predict system behavior, identify bottlenecks, and evaluate process modifications without interrupting commercial production. This technology substantially reduces development time, experimental costs, and operational risks while improving overall manufacturing efficiency.

Robotics integrated with Artificial Intelligence has revolutionized automation in food processing industries. AI-powered robotic systems perform repetitive tasks such as sorting, grading, cutting, peeling, packaging, palletizing, and material handling with exceptional precision and speed. Advanced robotic systems equipped with computer vision can recognize different food products, adapt to variations in size and shape, and perform delicate handling operations without damaging the products. Such automation enhances workplace hygiene by minimizing direct human contact with food products while simultaneously increasing production capacity and consistency.

Applications of Artificial Intelligence in Food Processing

Artificial Intelligence has become an indispensable technology in the modern food processing industry, enabling manufacturers to improve product quality, operational efficiency, food safety, and sustainability. AI systems integrate machine learning algorithms, computer vision, robotics, sensor technologies, and predictive analytics to automate complex manufacturing processes and support real-time decision-making. Unlike traditional automation, AI continuously learns from production data, allowing processing systems to adapt to variations in raw materials and processing conditions. Consequently, AI has been adopted across the entire food value chain, from raw material inspection to product distribution.

One of the most widespread applications of AI in food processing is quality inspection and grading. Traditionally, food quality assessment relied on manual inspection, which is labor-intensive, subjective, and prone to human error. AI-powered computer vision systems equipped with high-resolution cameras and deep learning algorithms can rapidly inspect food products based on size, shape, color, texture, surface defects, and foreign matter. Convolutional Neural Networks (CNNs) have demonstrated exceptional performance in detecting bruises, cracks, fungal infections, discoloration, insect damage, and mechanical injuries in fruits and vegetables. Similar technologies are used for grading cereal grains according to size and color, evaluating meat marbling and freshness, identifying fish species, and detecting shell defects in eggs. Automated grading systems improve inspection accuracy, ensure product uniformity, increase processing speed, and reduce labor costs.

AI also plays a vital role in process optimization by continuously analyzing data collected from processing equipment and environmental sensors. Food processing operations such as drying, pasteurization, sterilization, extrusion, evaporation, freezing, and fermentation involve numerous interdependent variables that significantly influence final product quality. Machine learning models can predict the effects of temperature, pressure, processing time, moisture content, airflow, and heating rate on product characteristics such as texture, color, nutritional value, microbial inactivation, and sensory quality. Artificial Neural Networks (ANNs), Support Vector Machines (SVMs), Random Forest models, and deep learning algorithms are widely employed to determine optimal processing conditions that maximize product quality while minimizing energy consumption and production costs. These predictive models reduce experimental trials, shorten process development time, and facilitate intelligent process control.

Food safety is another critical area where Artificial Intelligence has made significant contributions. AI systems continuously monitor critical control points throughout food production using data generated by sensors, laboratory analyses, and imaging systems. Computer vision technologies detect foreign materials such as metal fragments, plastic particles, glass pieces, insects, and other contaminants during production. Machine learning algorithms identify microbial contamination by analyzing spectral imaging data, electronic nose signals, hyperspectral images, and biosensor outputs. AI also supports Hazard Analysis and Critical Control Point (HACCP) systems by automatically identifying deviations from critical processing parameters and generating real-time alerts for corrective actions. Such intelligent monitoring

systems improve regulatory compliance, reduce the likelihood of foodborne illnesses, minimize product recalls, and enhance consumer confidence.

Artificial Intelligence has revolutionized shelf-life prediction by replacing conventional empirical methods with predictive mathematical models capable of analyzing multiple quality attributes simultaneously. Traditional shelf-life determination requires lengthy storage experiments under various environmental conditions, making product development time-consuming and expensive. AI models utilize physicochemical parameters such as pH, moisture content, water activity, color, texture, microbial load, antioxidant activity, vitamin retention, and storage temperature to predict product deterioration over time. Machine learning algorithms establish complex relationships among these variables and accurately estimate remaining shelf life under different storage conditions. Such predictive systems assist manufacturers in optimizing packaging materials, storage conditions, transportation logistics, and inventory management while reducing food waste and economic losses.

Robotics integrated with Artificial Intelligence has transformed food manufacturing by automating repetitive and labor-intensive operations. AI-powered robotic systems perform sorting, cutting, peeling, slicing, deboning, packaging, palletizing, and material handling with remarkable speed and precision. Unlike conventional industrial robots that follow fixed programming, intelligent robots equipped with computer vision and deep learning algorithms can recognize different food products, adapt to variations in shape and size, and adjust their operations accordingly. Collaborative robots, commonly known as cobots, safely work alongside human operators in food processing plants, improving workplace productivity while maintaining high standards of hygiene and occupational safety.

Artificial Intelligence has also become an essential component of modern food supply chain management. Food supply chains involve numerous interconnected activities, including procurement, transportation, storage, inventory management, distribution, and retail operations. Machine learning algorithms analyze historical sales data, weather conditions, market trends, seasonal demand, consumer preferences, and transportation routes to optimize supply chain operations. AI-driven forecasting models accurately predict product demand, enabling manufacturers to reduce overproduction, minimize inventory costs, and improve product availability. Furthermore, AI enhances cold chain management by continuously monitoring

storage temperature, humidity, and transportation conditions, thereby preventing spoilage and maintaining product quality throughout distribution.

Smart packaging technologies have further expanded the application of AI in food processing. Intelligent packaging systems incorporate biosensors, RFID tags, gas sensors, color indicators, and wireless communication devices capable of monitoring product freshness in real time. AI algorithms interpret data generated by these smart sensors to assess product quality, detect spoilage, predict shelf life, and recommend appropriate storage conditions. Consumers, retailers, and manufacturers can access real-time product information through cloud-based platforms, improving traceability, reducing food waste, and enhancing food safety.

Another important application of Artificial Intelligence involves reducing food losses and improving resource utilization throughout food processing operations. Machine learning models optimize energy consumption by regulating heating systems, refrigeration equipment, drying operations, and process scheduling according to production requirements. AI also minimizes raw material losses by identifying optimal cutting patterns, improving sorting accuracy, and maximizing extraction efficiency during processing. Predictive analytics further supports waste valorization by identifying economically viable opportunities for converting agricultural by-products into functional ingredients, animal feed, biofuels, biodegradable packaging materials, and nutraceutical compounds. These intelligent resource management strategies contribute significantly to sustainable food manufacturing and environmental conservation.

Non – thermal Processing

The rapid advancement of emerging food processing technologies has created new opportunities for integrating Artificial Intelligence into advanced preservation methods. Novel non-thermal processing technologies such as radio frequency heating, cold plasma, high-pressure processing, pulsed electric fields, and power ultrasound require precise control of multiple operating parameters to achieve microbial safety while preserving nutritional and sensory quality. Artificial Intelligence provides powerful predictive and optimization tools capable of analyzing complex interactions among processing variables and product characteristics, thereby accelerating technology development and industrial implementation.

Radio frequency (RF) heating has emerged as an efficient volumetric heating technology for pasteurization, sterilization, drying, thawing, and insect disinfestation of food products. However, the effectiveness of RF processing depends on several interrelated variables, including

electrode gap, frequency, power input, conveyor speed, dielectric properties, product geometry, and moisture content. Machine learning algorithms and Artificial Neural Networks can predict temperature distribution, heating uniformity, microbial inactivation, enzyme inactivation, and quality changes under different processing conditions. AI-driven optimization significantly reduces the number of experimental trials required for process development while improving product quality and process efficiency. In the case of tender palmyrah endosperm, AI models can optimize RF processing parameters to maximize shelf life while preserving color, texture, nutritional quality, and sensory attributes.

Cold plasma technology has gained considerable attention as a non-thermal preservation method capable of inactivating microorganisms without significantly affecting food quality. The effectiveness of cold plasma treatment depends on applied voltage, treatment duration, gas composition, gas flow rate, feed rate, electrode configuration, and product characteristics. AI algorithms can analyze experimental data to determine optimal treatment conditions that maximize microbial reduction while minimizing undesirable changes in color, antioxidant activity, vitamin content, and flavor. Predictive models also facilitate large-scale industrial implementation by reducing process optimization time and improving treatment consistency. For highly perishable products such as palmyrah neera, AI-assisted optimization of cold plasma processing can significantly enhance shelf life while maintaining nutritional and sensory quality.

High-pressure processing (HPP) is widely used for preserving fruit juices, meat products, seafood, dairy products, and ready-to-eat foods. AI assists HPP by predicting microbial inactivation, enzyme stability, texture modification, and nutrient retention under different combinations of pressure, holding time, temperature, and product composition. Machine learning models also optimize packaging materials and storage conditions for HPP-treated products, contributing to improved product quality and extended shelf life.

Pulsed electric field (PEF) technology utilizes short-duration high-voltage pulses to inactivate microorganisms while preserving heat-sensitive nutrients. Artificial Intelligence predicts cell membrane permeabilization, enzyme inactivation, electrical conductivity changes, and quality retention under varying electric field strengths and pulse durations. These predictive models enable manufacturers to determine optimal processing conditions for different food matrices while reducing energy consumption.

Ultrasound processing has become increasingly important for extraction, emulsification, homogenization, crystallization, drying, and microbial inactivation. AI algorithms analyze cavitation intensity, ultrasonic frequency, treatment time, and power density to optimize extraction efficiency and product quality. Machine learning also predicts bioactive compound recovery and structural modifications in food materials, enabling researchers to improve extraction processes with minimal experimental effort.

Several multinational food companies have successfully implemented Artificial Intelligence across their production systems. Nestlé employs AI for demand forecasting, predictive maintenance, quality monitoring, and consumer preference analysis. PepsiCo utilizes machine learning for flavor optimization, production planning, and packaging quality control. Unilever integrates AI into product development, ingredient selection, and manufacturing optimization, while Bühler incorporates AI into grain sorting, milling, and digital food processing solutions. These industrial case studies demonstrate the significant economic and operational benefits of AI adoption in commercial food manufacturing.

The implementation of Artificial Intelligence offers numerous advantages for the food industry. AI improves product consistency, enhances food safety, reduces production costs, minimizes processing time, increases energy efficiency, optimizes resource utilization, reduces labor dependency, enhances traceability, improves predictive maintenance, and supports sustainable manufacturing. Intelligent decision-making also enables manufacturers to respond rapidly to changing market demands while ensuring regulatory compliance and consumer satisfaction.

Despite its remarkable potential, several challenges remain in implementing AI within food processing industries. High initial investment costs, limited availability of high-quality datasets, integration difficulties with legacy processing equipment, cybersecurity concerns, shortage of skilled personnel, algorithm interpretability, and regulatory uncertainties continue to hinder widespread adoption. Additionally, biological variability in food materials presents unique challenges for developing universally applicable AI models. Continued collaboration among food scientists, engineers, computer scientists, and policymakers will be essential for addressing these limitations.

The future of Artificial Intelligence in food processing is closely aligned with the transition toward Industry 5.0, which emphasizes collaboration between humans and intelligent

machines. Emerging technologies such as digital twins, edge AI, explainable AI (XAI), generative AI, autonomous robotic systems, blockchain-enabled traceability, and personalized nutrition are expected to redefine the future of food manufacturing. AI-driven digital twins will enable virtual simulation of entire food processing plants, while explainable AI will improve transparency and regulatory acceptance of automated decision-making systems. Integration of AI with precision agriculture, smart packaging, and intelligent logistics will create highly interconnected food production systems capable of delivering safer, healthier, and more sustainable food products.

Conclusion

Artificial Intelligence has fundamentally transformed the food processing industry by introducing intelligent automation, predictive analytics, and real-time decision-making into manufacturing operations. Its applications extend across quality inspection, process optimization, food safety monitoring, shelf-life prediction, robotics, smart packaging, supply chain management, and waste reduction. Furthermore, AI has become an essential tool for optimizing emerging non-thermal technologies such as radio frequency heating, cold plasma, high-pressure processing, pulsed electric fields, and ultrasound. Although challenges related to data quality, infrastructure, cost, and regulatory compliance remain, ongoing advances in machine learning, deep learning, robotics, and sensor technologies will continue to accelerate AI adoption. In the coming years, Artificial Intelligence is expected to play a pivotal role in developing intelligent, sustainable, resilient, and consumer-oriented food processing systems that meet the increasing global demand for safe, nutritious, and high-quality food.

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BIODEGRADABLE FISHING NETS: A SUSTAINABLE SOLUTION FOR CLEANER OCEANS AND RESPONSIBLE FISHERIES

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Abstract

Fishing is one of the most important sectors supporting food security, employment, and economic development worldwide. However, the widespread use of conventional plastic fishing nets has created serious environmental challenges. Lost, abandoned, or discarded fishing nets, commonly known as "ghost nets," continue to trap marine organisms for many years, causing biodiversity loss and contributing significantly to marine plastic pollution. These synthetic nets are made from materials such as nylon, polyethylene, and polypropylene, which persist in the environment for several decades before degrading. Biodegradable fishing nets have emerged as an environmentally friendly alternative that can reduce ghost fishing, minimize plastic waste, and promote sustainable fisheries. These nets are manufactured from biodegradable polymers that gradually decompose through the action of microorganisms after their useful life, thereby reducing long-term environmental impacts. Although biodegradable nets have certain limitations such as higher production costs and slightly lower durability, continuous technological advancements are improving their performance. The adoption of biodegradable fishing nets represents an important step toward responsible fishing practices, healthier marine ecosystems, and a circular blue economy.

Introduction

The world's oceans provide food, livelihoods, and ecological services that are essential for human survival. Fishing plays a vital role in meeting the growing demand for seafood and supporting millions of fishing communities across the globe. Modern fishing operations largely depend on synthetic fishing gear because of its high strength, durability, flexibility, and relatively low cost. Materials such as nylon, polyethylene (PE), and polypropylene (PP) have become the preferred choice for manufacturing fishing nets.

Despite their advantages, synthetic fishing nets pose a significant environmental threat when they are lost or abandoned at sea. Every year, thousands of tonnes of fishing gear enter marine ecosystems due to storms, accidents, illegal dumping, or operational losses. These discarded nets continue to catch fish, crustaceans, turtles, seabirds, and marine mammals for many years, a phenomenon known as ghost fishing. In addition, synthetic nets gradually break down into microplastics, which contaminate marine food webs and threaten both aquatic organisms and human health.

Growing awareness of marine plastic pollution has encouraged researchers, governments, and the fishing industry to search for environmentally sustainable alternatives. Among these innovations, biodegradable fishing nets have attracted considerable attention because they are designed to decompose naturally after disposal or accidental loss. These nets provide a practical solution to reduce the environmental footprint of fisheries while maintaining fishing efficiency. As countries move toward sustainable fisheries management, biodegradable fishing nets are expected to become an important component of eco-friendly fishing practices.

Biodegradable Fishing Nets

Biodegradable fishing nets are fishing gears manufactured from biodegradable polymers that can be broken down naturally by microorganisms such as bacteria and fungi into harmless substances including carbon dioxide, water, methane (under anaerobic conditions), and biomass. Unlike conventional plastic nets, biodegradable nets do not remain in the marine environment for several decades. Instead, they gradually degrade under suitable environmental conditions, significantly reducing the persistence of ghost nets in aquatic ecosystems.

The degradation process depends on environmental factors such as temperature, oxygen availability, salinity, microbial activity, and sunlight exposure. While degradation is slower in

cold marine environments compared to composting conditions, biodegradable nets still decompose much faster than traditional synthetic fishing nets.



Fig1.1: Biodegradable fishing gear must improve to help address the environmental and economic impacts of ghost fishing, a new study concludes. Photo courtesy of the University of Portsmouth. **Source: https://www.globalseafood.org**

Materials Used in Biodegradable Fishing Nets

Several biodegradable polymers are currently used in the manufacture of fishing nets. One of the most widely studied materials is Polybutylene Succinate (PBS), which possesses excellent mechanical strength and flexibility while being biodegradable. Polybutylene Adipate Terephthalate (PBAT) is another biodegradable polymer known for its elasticity and toughness. Polylactic Acid (PLA), produced from renewable agricultural resources such as corn starch and sugarcane, is also used in biodegradable fishing products, although its marine degradation rate is relatively slower. Polyhydroxyalkanoates (PHA), synthesized naturally by microorganisms, have attracted considerable attention because they degrade efficiently in marine environments without leaving harmful residues.

Researchers are also investigating bio-based natural fibers, starch blends, cellulose, and chitosan composites to improve the biodegradability, strength, and cost-effectiveness of fishing gear. Continuous material innovation aims to produce biodegradable nets with performance characteristics comparable to conventional synthetic nets.

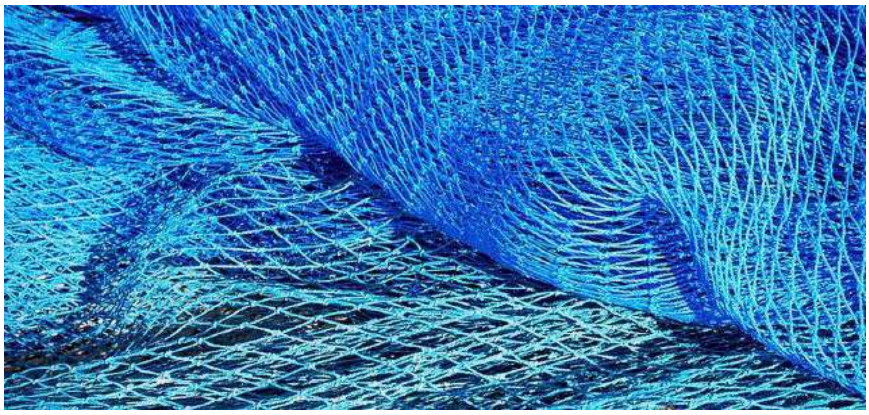


Fig:1.2 Biodegradable Fishing Nets

Source: https://www.gaiabiomaterials.com

Environmental Importance

One of the greatest environmental benefits of biodegradable fishing nets is the reduction of ghost fishing. When conventional nets are lost in the ocean, they continue trapping fish, crabs, lobsters, turtles, seals, dolphins, and seabirds for many years. This causes unnecessary mortality of marine organisms and disturbs ecological balance. Since biodegradable nets gradually lose their structural integrity after prolonged exposure, their fishing ability declines naturally, thereby reducing ghost fishing.

Biodegradable nets also help reduce marine plastic pollution. Conventional plastic fishing gear contributes significantly to floating plastic debris and microplastic contamination. As these plastics fragment into tiny particles, they are consumed by plankton, fish, shellfish, and eventually humans through seafood consumption. By decomposing into environmentally safe products, biodegradable fishing nets reduce long-term plastic accumulation in marine ecosystems.

The adoption of biodegradable fishing gear also supports international efforts to achieve sustainable fisheries management, marine biodiversity conservation, and cleaner oceans.

Advantages of Biodegradable Fishing Nets

Biodegradable fishing nets offer numerous environmental and social benefits. They significantly reduce marine plastic pollution by preventing the long-term accumulation of synthetic plastics in aquatic environments. They minimize ghost fishing by naturally degrading after being lost, thereby protecting fish stocks and endangered marine species. Their use contributes to healthier marine ecosystems and promotes responsible fishing practices.

These nets also support sustainable fisheries by reducing ecological damage while maintaining harvesting efficiency. Their development encourages innovation in green materials and contributes to the transition toward a circular economy. As governments implement stricter regulations on plastic pollution, biodegradable nets may become increasingly important in meeting environmental standards.

Furthermore, biodegradable fishing nets improve the environmental image of fisheries, increase consumer confidence in sustainably harvested seafood, and contribute to achieving the United Nations Sustainable Development Goals, particularly SDG 12 (Responsible Consumption and Production) and SDG 14 (Life Below Water).

Challenges and Limitations

Despite their advantages, biodegradable fishing nets still face several challenges that limit widespread adoption. Their manufacturing cost remains higher than that of conventional plastic nets, making them less affordable for small-scale fishers. In some fishing operations, biodegradable nets may exhibit slightly lower tensile strength, abrasion resistance, and service life compared to nylon nets.

The degradation rate varies depending on environmental conditions, and complete decomposition may still require several months or years in cold marine waters. Fishers may also hesitate to adopt biodegradable gear due to concerns about durability, fishing efficiency, and replacement costs. In addition, limited commercial availability and lack of awareness remain barriers in many developing countries.

Ongoing research is focused on improving the mechanical properties, durability, biodegradation rate, and cost-effectiveness of biodegradable fishing materials to encourage wider commercial adoption.

Recent Developments

Recent scientific research has demonstrated promising results for biodegradable fishing nets, particularly those manufactured from Polybutylene Succinate (PBS). Field trials conducted in several countries, including South Korea and Norway, have shown that biodegradable gillnets can achieve catch efficiencies comparable to conventional nylon nets while significantly reducing long-term environmental impacts.

Researchers are also developing biodegradable coatings, nanocomposite materials, and reinforced bio-polymers that improve strength without compromising biodegradability.

Governments and international organizations are increasingly supporting pilot projects, financial incentives, and regulations encouraging the adoption of environmentally friendly fishing gear. With increasing public concern regarding marine plastic pollution, biodegradable fishing nets are expected to play a major role in future sustainable fisheries and marine conservation programs.

Future Prospects

The future of biodegradable fishing nets appears highly promising as research continues to improve material performance and reduce production costs. Advances in polymer science, biotechnology, and material engineering are expected to produce fishing nets that combine excellent durability with rapid biodegradation after loss or disposal. Greater investment in large-scale manufacturing will likely reduce market prices and increase accessibility for commercial and artisanal fishers.

Government subsidies, awareness programs, and supportive fisheries policies can further accelerate adoption. Integration of biodegradable fishing gear into national fisheries management plans will help reduce marine pollution while promoting sustainable harvesting of aquatic resources. As global attention shifts toward environmental conservation and circular economy principles, biodegradable fishing nets are expected to become an essential component of responsible fisheries.

Conclusion

Biodegradable fishing nets represent one of the most promising innovations for reducing the environmental impacts of modern fisheries. By addressing the persistent problem of ghost fishing and marine plastic pollution, these eco-friendly fishing gears contribute significantly to marine biodiversity conservation and sustainable fisheries management. Although challenges related to cost, durability, and large-scale adoption still exist, continuous scientific research and technological advancements are steadily improving their performance. Supportive government policies, industry participation, and increased awareness among fishers will be crucial for encouraging widespread use. The transition from conventional plastic fishing gear to biodegradable alternatives is not merely a technological advancement but an essential step toward protecting marine ecosystems for future generations. Adopting biodegradable fishing nets today will help ensure cleaner oceans, healthier fish populations, and a more sustainable blue economy tomorrow.

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BIOFORTIFIED VEGETABLES: FIGHTING HIDDEN HUNGER

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Introduction

Millions of people around the world consume enough food to satisfy their hunger, yet many suffer from a silent form of malnutrition known as **hidden hunger**. Hidden hunger occurs when the body lacks essential vitamins and minerals despite adequate calorie intake. Deficiencies of vitamin A, iron, zinc, iodine, and folate can lead to weakened immunity, poor growth, impaired cognitive development, anaemia, and increased susceptibility to diseases. Biofortification has emerged as one of the most sustainable and cost-effective solutions to combat hidden hunger. Unlike conventional fortification, where nutrients are added during food processing, biofortification enhances the nutritional quality of crops during their development through plant breeding, biotechnology, or improved agronomic practices. Vegetables, being naturally rich in vitamins, minerals, and antioxidants, are ideal candidates for biofortification.

What Are Biofortified Vegetables?

Biofortified vegetables are varieties that have been developed to contain higher concentrations of essential nutrients without compromising yield, quality, or consumer acceptance. Plant breeders identify nutrient-rich parent lines and develop improved varieties through conventional breeding or modern biotechnological approaches. The objective is simple: **to provide better nutrition through everyday diets**, especially for populations with limited access to dietary supplements or fortified foods.

Why Is Biofortification Important?

Micronutrient deficiencies remain a major public health concern in many developing countries. Poor dietary diversity, poverty, and limited access to nutritious foods contribute to hidden hunger. Biofortified vegetables offer several advantages:

- Improve nutritional status naturally.
- Reduce micronutrient deficiencies.
- Strengthen immunity and overall health.
- Enhance child growth and cognitive development.
- Support pregnant and lactating women.
- Provide a sustainable and affordable nutrition intervention.

Because vegetables are consumed regularly, increasing their nutrient content can have a significant impact on public health.

VITAMIN A (B-CAROTENE)

Vitamin A is an essential micronutrient required for healthy vision, immune function, reproduction, and normal growth and development. In biofortified vegetables, vitamin A is mainly present as **β-carotene**, a provitamin that is converted into active vitamin A in the human body. Adequate intake of vitamin A helps prevent night blindness, xerophthalmia (dry eyes), and other vision-related disorders while strengthening the immune system and protecting against infections. It also supports healthy skin, cell differentiation, and antioxidant activity by neutralizing harmful free radicals. Biofortification aims to increase β-carotene levels in vegetables to combat vitamin A deficiency, which is a major public health concern in many developing countries. **Orange carrot, orange-fleshed sweet potato, pumpkin, and orange-fleshed squash** are important biofortified vegetable sources rich in β-carotene.

IRON (FE)

Iron is an essential mineral that plays a crucial role in the formation of hemoglobin, the oxygen-carrying protein in red blood cells, and myoglobin, which stores oxygen in muscles. It is also involved in energy metabolism, enzyme activity, cognitive development, and immune function. Iron deficiency is the leading cause of nutritional anemia worldwide, especially among women, children, and pregnant mothers, resulting in fatigue, weakness, reduced work capacity, and impaired learning ability. Biofortification increases the iron content of vegetables to improve dietary iron intake and reduce the prevalence of anemia and hidden hunger. Iron-rich biofortified

vegetables such as **spinach, amaranthus, iron-enriched beans, and other leafy vegetables** contribute significantly to improving nutritional status and overall health.

ZINC (ZN)

Zinc is an essential trace mineral required for the proper functioning of more than 300 enzymes involved in metabolism, protein synthesis, DNA synthesis, cell division, and growth. It plays a vital role in maintaining a healthy immune system, promoting wound healing, supporting reproductive health, and ensuring normal physical and mental development. Zinc deficiency can lead to stunted growth, impaired immunity, delayed wound healing, hair loss, skin disorders, and loss of appetite, particularly among children. Biofortification enhances the zinc concentration in vegetables, providing an effective and sustainable approach to improving zinc intake in populations dependent on plant-based diets. **Zinc-enriched beans, spinach, peas, and green leafy vegetables** are important dietary sources of this micronutrient.

VITAMIN C (ASCORBIC ACID)

Vitamin C, also known as ascorbic acid, is a water-soluble vitamin and a powerful natural antioxidant that protects body cells from oxidative damage caused by free radicals. It plays an important role in collagen synthesis, wound healing, healthy skin, blood vessel integrity, and immune function. One of its most significant nutritional benefits is enhancing the absorption of non-haeme iron from plant foods, thereby reducing the risk of iron deficiency anaemia. Vitamin C deficiency results in scurvy, characterized by bleeding gums, delayed wound healing, and weakened immunity. Biofortified vegetables with increased vitamin C content improve overall nutritional quality and provide better health benefits. **Tomato, bell pepper (capsicum), broccoli, cabbage, and leafy vegetables** are excellent sources of vitamin C.

FOLATE (VITAMIN B_9)

Folate, also known as vitamin B_9, is an essential water-soluble vitamin required for DNA and RNA synthesis, cell division, protein metabolism, and the formation of healthy red blood cells. It is particularly important during pregnancy because it supports foetal growth and helps prevent neural tube defects such as spina bifida. Folate also contributes to brain development, cognitive function, and overall growth. Deficiency of folate can cause megaloblastic anaemia, fatigue, poor growth, and congenital abnormalities in newborns. Biofortification of vegetables with folate is an effective strategy to improve maternal and child nutrition and reduce

micronutrient deficiencies. **Spinach, broccoli, asparagus, amaranthus, and other green leafy vegetables** are important biofortified sources of folate.

Examples of Nutrient-Rich Vegetables

- **Carrot** – Rich in β-carotene (pro-vitamin A)
- **Sweet potato** – Excellent source of vitamin A
- **Tomato** – High in lycopene and vitamin C
- **Spinach** – Rich in iron, folate, calcium, and antioxidants
- **Broccoli** – High in vitamins C and K and folate
- **Red and yellow capsicum** – Rich in vitamin C and carotenoids
- **Purple cabbage and purple carrot** – Rich in anthocyanins
- **Beetroot** – Contains folate and natural antioxidants

Role of Plant Breeding

Plant breeders play a crucial role in developing biofortified vegetables by:

- Identifying nutrient-rich germplasm.
- Crossing superior parents.
- Selecting nutrient-dense offspring.
- Combining high nutritional quality with superior yield and disease resistance.
- Evaluating varieties under different environmental conditions.

Modern breeding techniques such as marker-assisted selection, genomic selection, and genome editing (CRISPR/Cas9) are accelerating the development of nutrient-rich vegetable varieties.

Benefits to Farmers

Biofortified vegetables benefit farmers by:

- Producing premium-quality crops.
- Increasing market demand.
- Improving consumer confidence.
- Enhancing farm income.
- Supporting climate-resilient agriculture.

Many biofortified varieties are also bred for higher productivity and improved resistance to pests and diseases.

Benefits to Consumers

Consumers gain multiple health advantages:

- Better nutritional intake through regular meals.
- Improved immunity and overall well-being.
- Reduced risk of micronutrient deficiencies.
- Better growth and development in children.
- Healthier pregnancies through adequate vitamin and mineral intake.

Unlike dietary supplements, biofortified vegetables provide nutrients through fresh, natural foods that are already part of daily diets.

Challenges

Despite their potential, biofortified vegetables face several challenges:

- Limited public awareness.
- Slow adoption among farmers.
- Need for stronger seed distribution systems.
- Consumer preference for appearance over nutritional value.
- Requirement for nutrition education and awareness campaigns.

Addressing these challenges requires collaboration among researchers, governments, extension agencies, seed companies, and consumers.

Future Prospects

The future of biofortified vegetables is promising. Advances in genomics, precision breeding, artificial intelligence, and biotechnology are enabling the rapid development of nutrient-rich varieties. As concerns about malnutrition, food security, and climate change continue to grow, biofortified vegetables will become increasingly important in creating healthier and more sustainable food systems.

Conclusion

Biofortified vegetables represent a powerful strategy to combat hidden hunger by delivering essential vitamins and minerals through everyday diets. They bridge the gap between agriculture and nutrition, offering benefits to farmers, consumers, and society alike. By integrating advanced plant breeding with sustainable agricultural practices, biofortification has the potential to improve public health, strengthen food security, and build a healthier future for generations to come.

"Every nutrient-rich vegetable grown today is an investment in a healthier tomorrow."

Volume: 06 Issue No: 07

MARINE POLYSACCHARIDE HYDROGEL: FROM SUSTAINABLE RESOURCES TO INNOVATIONS

Article ID: AG-VO6-I07-144

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Abstract

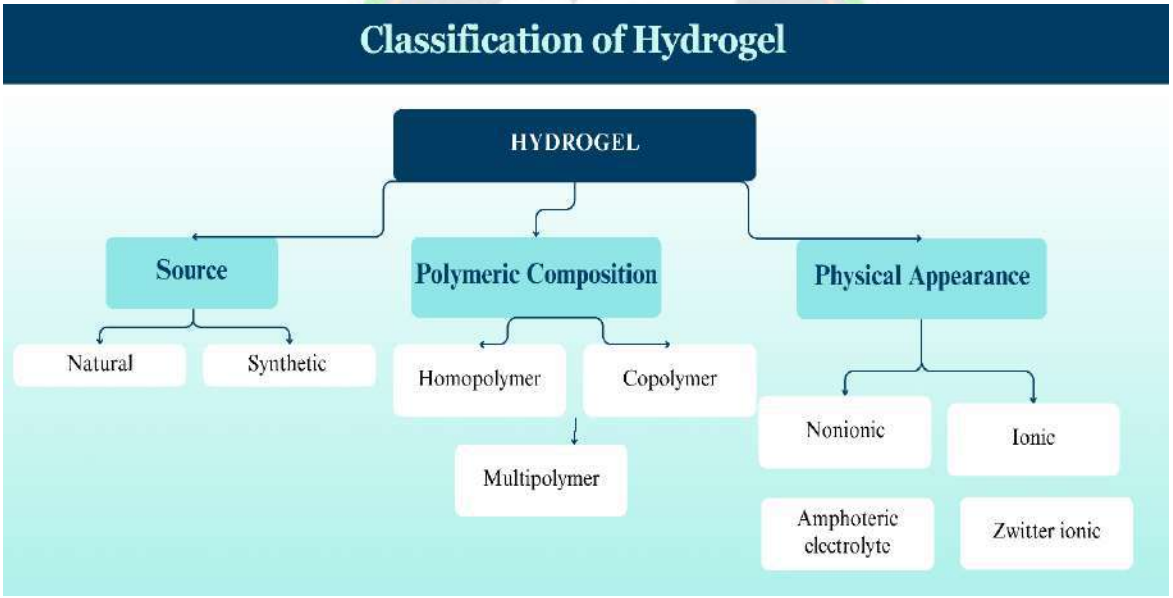
Marine polysaccharide hydrogel is a three-dimensional structure of hydrophilic natural polymer material (i.e., alginate, carrageenan, chitosan and agarose). It traps water molecules within its structure and exhibits a soft consistency and porosity. These biomaterials have greater biocompatibility, biodegradability, and bioactivity, lower toxicity, and reduced immunogenicity. Sources of marine polysaccharides include various seaweed species and the shells of shrimp, crabs, and lobsters. They have attracted greater attention for their polymerisation and gelling properties. Marine polysaccharide-based hydrogels are widely used in biomedical applications, tissue engineering, drug delivery, and biosensors.

Keywords: Marine polysaccharide hydrogel, Alginate, Carrageenan, Chitosan, Biomedical engineering, Drug delivery system

Introduction

A hydrogel is a hydrophilic polymeric material that entraps water molecules without dissolving the structure. The polymeric network forms a three-dimensional structure composed of one or more monomers, with hydrophilic functionality serving as the backbone. The hydrogel has a high water content, a soft consistency, and porosity that closely resembles living tissues; it also has high structural durability. Hydrogels are also defined as “reversible” or “physical” gels, and they will be stabilised in both charged and non-charged conditions. The hydrogel (synthetic poly-2-hydroxyethyl methacrylate (PHEMA)) was first developed by Wichterle and Lim in 1960

and used as a biomaterial in eye enucleation fillers and contact lenses. After that, in 1990, hydrogels were used for tissue engineering specifically for the eye and wound healing. Later, different types of hydrogels were used in various applications, such as soft robotics, wastewater treatment, environmental monitoring, and biomedical engineering (Implantable, injectable, and sprayable materials for repairing organs and tissues). In recent years, hydrogels have gained more attention for 3D cell cultures, drug delivery, and advanced tissue engineering. Notably, marine hydrogels are natural hydrogels developed from cellulose, chitosan, collagen, alginate, agarose, hyaluronic acid, fibrin and gelatin. These natural hydrogels exhibit greater biocompatibility, biodegradability, and bioactivity, and are also low in toxicity and immunogenicity. Therefore, marine hydrogels serve as an excellent food source to meet nutritive and functional product requirements. This chapter provides insights into the hydrogel classification, sources, crosslinking, properties and various applications of marine polysaccharide hydrogels.



Marine polysaccharide hydrogel

Marine-derived polysaccharide hydrogels act as promising alternatives to synthetic polymers, and marine polysaccharides contain numerous bioactive compounds. The list of polysaccharides present in marine organisms is as follows:

1. Alginate



Seaweed (*Laminaria sp, Macrocystis pyrifera, Sargassum sp, Turbinaria sp and Durvillaea sp*) (Image Source: Pereira and Cotas, 2020)

2. Carrageenan



Red seaweed -Eucheuma, Gigartina, Hypnea, Kappaphycus, Chondrus and Mastocarpus (Image Source: Bayu et al., 2021)

3. Chitosan



Shells of Shrimp, Crab, Lobster (Image Source: Zhang et al., 2025)

4. Agarose



Red seaweed: Gracilaria and Gelidium (Image Source: Pereira and Valado, 2025)

5. Hyaluronic acid

Salmon head and bones, sardine head, shark skin and cartilages, *Ulva sp*, bivalve and squid tissues, *Saccharina sp* and red seaweeds. This kind of marine hydrogel has inherent biocompatibility, biodegradability, bioactivity, and water-absorption capacity. Marine polysaccharides comprise the functional groups of sulfate, carboxyl, and hydroxyl. Using these marine sources, advanced hydrogels with enhanced functional properties can be developed specifically for drug delivery systems. The functional groups of polysaccharides are more effective at binding and carrying proteins, drugs, and bioactive components to specific sites.

The natural polysaccharide of brown algae, alginate, has received more attention in hydrogel development due to its copolymer (Polyanionic linear) characterisation, and it contains β-D-mannuronic acid (M-block) and α-L-guluronic acid (G-block) residues, which are linked by β-1,4-glycosidic bonds. The length of the G-block helps to determine the properties of alginate. Key properties for the alginate-based hydrogel are biocompatibility, non-toxicity, and structural

integrity (Porosity and Swelling). Carrageenan-based hydrogels are formed from linear polysaccharides composed of galactose and 3,6-anhydrogalactose residues, linked by α-1,3 and β-1,4 glycosidic bonds**.** Carrageenan may exhibit pharmaceutical properties and bioactivities, including anticancer, antimicrobial, antihyperlipidemic, and immunomodulatory functions. During gelation, potassium ions played a prominent role in carrageenan cationation, though sugars and polyols also enhanced gel formation. Chitosan-based hydrogels are cost-effective, eco-friendly, and an alternative to conventional biodegradable materials. Chitosan is a natural polymer composed of N-acetyl-D-glucosamine and β-(1→4)-linked D-glucosamine (Sepe et al., 2025).

Applications

1. Tissue engineering and wound healing

The polysaccharide hydrogel of chitosan, alginate, and carrageenan was used to heal wounds by promoting cell migration and absorbing wound exudate. Hydrogels exposed to wounds activated fibroblasts to promote healing and reduced infectious bacteria through their bioactive properties.

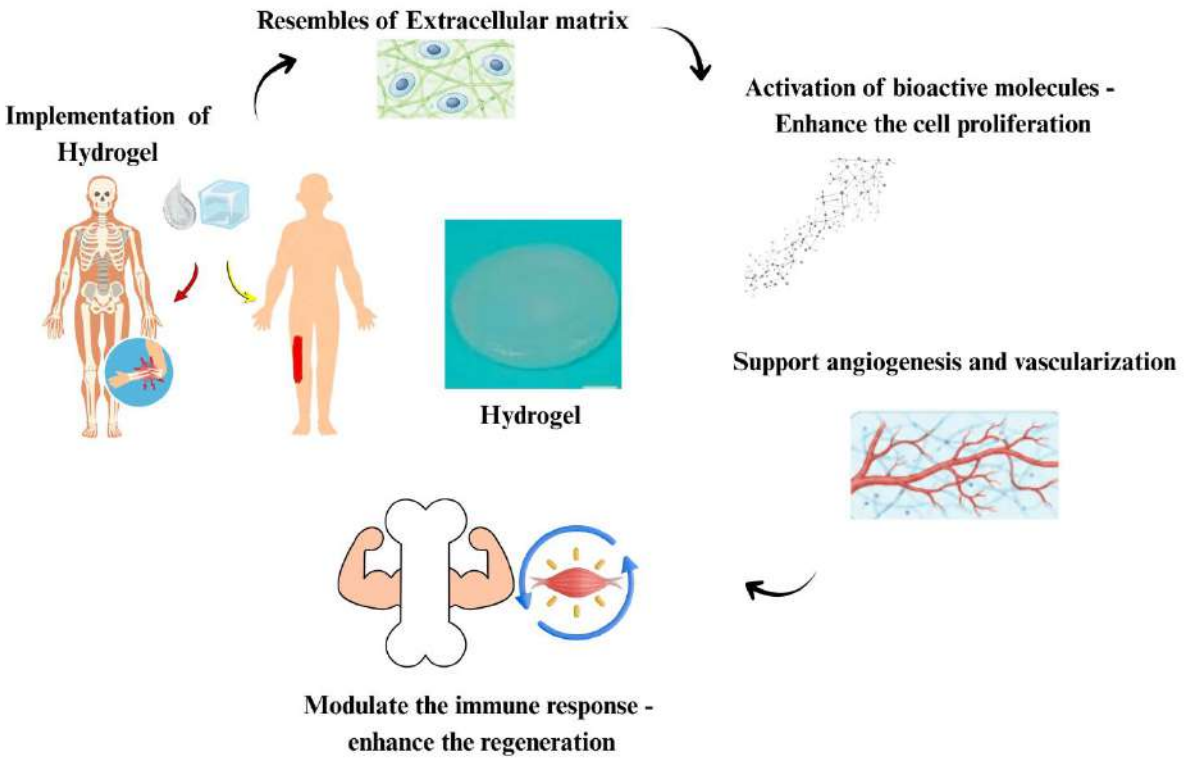


Figure 1 depicts the mechanisms of hydrogel application in tissue engineering (Rumon et al., 2024).

2. Drug carrier

Alginate-based hydrogel (AH) enhanced with ZnO and loaded with diclofenac. In oral administration, drug molecules accumulate at the target site of the infectious region. This specific hydrogel is used for targeted drug delivery. The hydrogel beads exhibited maximum drug absorption and were bioavailable in the stomach (Tan et al., 2025). Whilst alginate-based hydrogel combined with furazolidone to treat *Helicobacter pylori*. A chitosan-based hydrogel was used as an injectable adhesion carrier for a drug delivery system. This hydrogel exhibits rapid gelation, good bacteriostatic activity, high adhesion, and potential functional properties (Silva et al., 2019).

3. Biosensor

The chitosan-polyacrylic acid-sodium alginate hydrogel was used to develop a wearable and biomedical biosensor. It has a double-network hydrogel structure, with polyacrylic acid for mechanical strength and chitosan–alginate for electrostatic interactions. A well-structured wearable biosensor is used to monitor human movements and health and acts as flexible electronic skin (e-skin) (Wang et al., 2024).

Table 1 shows the developed polysaccharide-based hydrogels for biosensors

Polysaccharide Hydrogel	***Application***	***Target Compound***	***sources***
Agarose	Glucose	Glucose oxide (GOx), 3,3′,5,5′-tetramethylbenzidine (TMB)	
	cysteine	Au/Ag core – shell nanostar	
Alginate	Glucose	Glucose oxide (GOx), 3,3′,5,5′-tetramethylbenzidine (TMB)	Kim et al., 2025
	Oxalate	MnO_2/ tetramethylbenzidine	
	Cholesterol	Horseradish peroxidase, Cholesterol oxidase (COD), luminol	

Conclusion

Marine polysaccharide hydrogels are widely used in various applications due to their structural similarity to the extracellular matrix, the presence of bioactive components, and their excellent flexibility. These hydrogels offer high structural stability and are easy to customise,

biocompatible and biodegradable. Owing to these properties, it is considered a promising low-risk biomaterial for biomedical engineering applications. Consequently, marine-derived polysaccharide hydrogels have attracted significant attention across diverse fields, with growing interest in their future exploration and the development of innovative biomedical technologies.

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SOIL ENZYMES: ESSENTIAL BIOLOGICAL INDICATORS FOR SOIL QUALITY ASSESSMENT

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Introduction

Soil is one of the most valuable natural resources on Earth and serves as the foundation of terrestrial ecosystems. It supports plant growth, regulates water movement, stores and recycles nutrients, sequesters carbon, and sustains an immense diversity of living organisms. The productivity of agriculture, environmental sustainability, and global food security depend greatly on maintaining healthy and functional soils. Traditionally, soil quality has been assessed using physical and chemical properties such as texture, structure, bulk density, pH, electrical conductivity, nutrient availability, and organic matter content. Although these parameters provide important information about soil condition, they do not fully reflect the biological processes that govern soil functioning.

In recent years, soil has increasingly been recognized as a living ecosystem inhabited by diverse microorganisms, plant roots, and soil fauna that continuously drive nutrient cycling and organic matter decomposition. Among the various biological indicators of soil health, soil enzymes have gained considerable attention because they play direct roles in essential biochemical reactions. These enzymes catalyze the transformation of carbon, nitrogen, phosphorus, sulfur, and other nutrients into forms available for plant and microbial use. Since enzyme activities respond rapidly to environmental changes, management practices, and pollution, they serve as sensitive and reliable indicators of soil quality, fertility, and overall ecosystem health.

Soil as a Living Ecosystem

Soil is a living, dynamic, and non-renewable resource that supports a vast diversity of organisms and ecological processes. A single gram of fertile soil may contain billions of microorganisms, including bacteria, fungi, actinomycetes, algae, protozoa, and archaea. These microscopic organisms play a fundamental role in maintaining soil fertility and productivity through the decomposition of organic matter and the recycling of nutrients. Plant residues, animal remains, and root exudates are continuously transformed into simpler compounds, releasing essential nutrients for plant growth and contributing to humus formation.

In addition to microorganisms, soil macrofauna such as earthworms and termites significantly influence soil health. Earthworms improve soil aeration, drainage, aggregation, and nutrient availability through their burrowing and feeding activities, while termites enhance soil structure, nutrient distribution, and moisture regulation. Soil organisms also facilitate nutrient cycling, biological nitrogen fixation, weathering of minerals, and soil formation. The efficiency of these processes depends largely on soil enzymes, which act as biochemical catalysts driving decomposition, nutrient transformations, and overall ecosystem functioning.

Understanding Soil Enzymes

Soil enzymes are protein-based biological catalysts that accelerate biochemical reactions without being consumed during the process. They are produced primarily by soil microorganisms, plant roots, and soil fauna. Many enzymes become stabilized by binding to clay particles and organic matter, allowing them to remain active in the soil for extended periods. Soil enzymes play a central role in organic matter decomposition, nutrient mineralization, energy transfer, and the transformation of nutrients into forms available for plant uptake. Because their activities are closely linked to microbial metabolism and soil biological processes, they provide valuable information about soil functioning. Soil enzymes are considered excellent bioindicators due to their sensitivity to environmental changes, land management practices, and pollution. Their rapid response to changing soil conditions makes them useful tools for assessing soil health, fertility, ecosystem stability, and overall soil quality.

Major Soil Enzymes and Their Functions

Urease

Urease is one of the most important enzymes involved in the nitrogen cycle. It catalyzes the hydrolysis of urea to produce ammonium, a form readily available for plant uptake. Since

urea is among the most widely used nitrogen fertilizers globally, urease plays a crucial role in determining nitrogen-use efficiency and crop productivity. High urease activity indicates active nitrogen transformations, efficient nutrient cycling, and healthy microbial activity.

Dehydrogenase

Dehydrogenase is an intracellular enzyme associated with microbial respiration and energy production. Unlike many other soil enzymes, it occurs only within living microbial cells. Therefore, its activity directly reflects the metabolic activity of soil microorganisms. High dehydrogenase activity signifies vigorous microbial growth, active decomposition of organic matter, and efficient nutrient cycling. It is widely regarded as one of the most reliable indicators of soil biological health.

Protease

Proteases are hydrolytic enzymes responsible for breaking down proteins into peptides and amino acids. These compounds are subsequently mineralized into ammonium and nitrate, which plants can absorb. Proteases play a vital role in nitrogen cycling and organic matter decomposition. Increased protease activity reflects enhanced nitrogen recycling and active microbial populations, making it an important indicator of soil fertility.

Cellulase

Cellulase is a group of enzymes that degrade cellulose, the most abundant organic polymer found in plant residues. Through a series of enzymatic reactions, cellulase converts cellulose into glucose, which serves as an energy source for microorganisms. Because cellulose constitutes a major portion of plant biomass entering soil, cellulase activity is fundamental to carbon cycling and residue decomposition. High cellulase activity indicates active microbial communities and efficient organic matter turnover.

Hemicellulase

Hemicellulases degrade hemicellulose, another major component of plant cell walls. These enzymes release simple sugars that serve as carbon and energy sources for soil microorganisms. Together with cellulases and lignin-degrading enzymes, hemicellulases facilitate the decomposition of crop residues and forest litter. Their activity is an important indicator of carbon cycling and soil biological functioning.

Lignase

Lignase refers to a group of oxidative enzymes that catalyze the degradation of lignin, a

highly resistant component of plant tissues. Lignin decomposition is one of the most difficult processes in nature and is primarily carried out by specialized fungi and certain bacteria. Lignase enzymes contribute to carbon recycling, humus formation, and nutrient release from woody residues. Their activity is especially important for understanding long-term soil carbon dynamics and ecosystem sustainability.

Phosphatase

Phosphatases are enzymes responsible for the mineralization of organic phosphorus compounds. They release inorganic phosphate that can be absorbed by plants and microorganisms. Since phosphorus is often a limiting nutrient in agricultural soils, phosphatase activity is closely linked to soil fertility. High phosphatase activity indicates efficient phosphorus cycling and improved nutrient availability.

Arylsulfatase

Arylsulfatase plays a key role in the sulfur cycle by hydrolyzing organic sulfur compounds and releasing sulfate ions. Because most soil sulfur exists in organic forms, arylsulfatase is essential for sulfur mineralization. Its activity reflects sulfur availability, microbial activity, and organic matter content. As sulfur is necessary for protein synthesis and enzyme formation in plants, arylsulfatase contributes directly to soil fertility and crop nutrition.

β-Glucosidase

β-Glucosidase catalyzes the final step in cellulose degradation by converting cellobiose into glucose. Because it occupies a critical position in carbon cycling, β-glucosidase is considered one of the most sensitive indicators of soil organic matter dynamics. Changes in β-glucosidase activity often occur before measurable changes in soil organic carbon, making it a valuable tool for monitoring soil quality.

Nitrogenase

Nitrogenase is the enzyme responsible for biological nitrogen fixation. It converts atmospheric nitrogen into ammonia, making nitrogen available to plants and microorganisms. The activity of nitrogenase reflects the soil's natural capacity to enrich itself with nitrogen and is particularly important in sustainable agricultural systems that rely on biological rather than synthetic nitrogen inputs.

Catalase

Catalase is an important soil oxidoreductase enzyme that decomposes toxic hydrogen

peroxide into water and oxygen, protecting microorganisms and plant roots from oxidative stress. Its activity is closely linked to aerobic microbial metabolism and microbial biomass. High catalase activity indicates healthy, biologically active, and well-aerated soils with efficient organic matter decomposition.

Soil Enzymes as Indicators of Soil Quality

The concept of soil quality refers to the capacity of soil to function as a living system that sustains biological productivity, maintains environmental quality, and supports ecosystem health. Soil enzymes provide direct information about these functions because they are intimately involved in nutrient cycling and organic matter transformations.

Several characteristics make soil enzymes valuable indicators of soil quality:

- They respond rapidly to environmental changes.
- They reflect microbial abundance and functional capacity.
- They provide early warning signs of soil degradation.
- They integrate information from multiple soil processes.
- They are relatively easy and cost-effective to measure.

Generally, soils with high enzyme activities exhibit greater biological activity, improved nutrient availability, enhanced organic matter decomposition, and stronger ecosystem resilience. Consequently, enzyme assays are increasingly incorporated into soil quality evaluation programs.

Factors Influencing Soil Enzyme Activity

Soil enzyme activity is influenced by a variety of environmental and management factors. Organic matter is a major determinant of soil enzyme activity because it provides energy and nutrients for microorganisms, leading to greater enzyme production. Adequate soil moisture is essential for microbial metabolism and enzyme-substrate interactions, whereas drought or waterlogging can reduce activity. Temperature affects enzyme kinetics, with moderate temperatures promoting activity and extreme temperatures inhibiting it. Soil pH also plays a crucial role, as each enzyme functions best within a specific pH range. Plant roots stimulate enzyme production by releasing organic compounds into the rhizosphere. Agricultural practices such as compost application, biochar application, crop rotation, cover cropping, residue retention, and conservation tillage generally enhance enzyme activity, while excessive tillage, soil compaction, pollution, and misuse of pesticides may suppress soil biological processes.

Soil Enzymes and Sustainable Agriculture

Soil enzymes play a vital role in sustainable agriculture by regulating nutrient cycling, organic matter decomposition, and overall soil fertility. Agricultural practices such as organic farming, compost application, crop residue incorporation, cover cropping, crop rotation, and conservation tillage enhance microbial activity and enzyme production, thereby improving soil health and productivity. Higher enzyme activity generally reflects improved nutrient availability, active microbial communities, and better ecosystem functioning. Monitoring soil enzyme activity enables farmers and researchers to assess the effectiveness of sustainable management practices and identify strategies for maintaining soil quality. Emerging technologies such as biochar application, microbial inoculants, precision agriculture, remote sensing, artificial intelligence, and molecular biology are creating new opportunities for enhancing and monitoring soil enzyme activity. These innovations will support the development of resilient, productive, and environmentally sustainable agricultural systems capable of meeting future food and environmental challenges.

Conclusion

Soil enzymes are vital components of the soil ecosystem, driving nutrient cycling, organic matter decomposition, and overall soil biological activity. Produced primarily by microorganisms, soil enzymes regulate the essential transformations of carbon, nitrogen, phosphorus, and sulfur, thereby maintaining soil fertility and productivity. Because enzyme activities respond quickly to environmental changes and management practices, they serve as sensitive and reliable indicators of soil quality and ecosystem health. Assessing enzymes such as urease, dehydrogenase, phosphatase, cellulase, and catalase provides valuable insights into soil functioning and sustainability. Integrating soil enzyme analysis with conventional physical and chemical assessments offers a more comprehensive evaluation of soil health, supporting sustainable agriculture, environmental conservation, and long-term food security.

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NANOTECHNOLOGY APPLICATIONS IN FOOD PACKAGING: SMART INNOVATIONS FOR SAFE, FRESH, AND SUSTAINABLE FOODS

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Introduction

Food packaging is essential for protecting food from contamination, physical damage, and environmental factors during storage and transportation. However, conventional packaging has limited ability to prevent microbial spoilage, oxidation, and moisture loss, resulting in reduced shelf life and food waste. Nanotechnology offers an advanced solution by improving the strength, barrier properties, and antimicrobial performance of packaging materials. It also enables the development of active and smart packaging systems that monitor food quality and freshness. These innovations improve food safety, extend shelf life, and contribute to sustainable food packaging (BISWAS ET AL., 2022) (DUNCAN, 2011).

2.What is Nanotechnology?

Nanotechnology is the science of designing materials with dimensions between **1 and 100 nanometres (nm)**. A nanometre is one-billionth of a metre, nearly 80,000 times smaller than the width of a human hair(de Azeredo et al., 2011) . At this scale, materials exhibit unique properties such as greater strength, higher surface area, and enhanced antimicrobial activity. In food packaging, nanomaterials including silver nanoparticles, zinc oxide, nanoclays, and cellulose nanofibres improve packaging durability, reduce oxygen and moisture transfer, and control microbial growth. These properties make nanotechnology an effective tool for developing safer and more efficient food packaging systems.

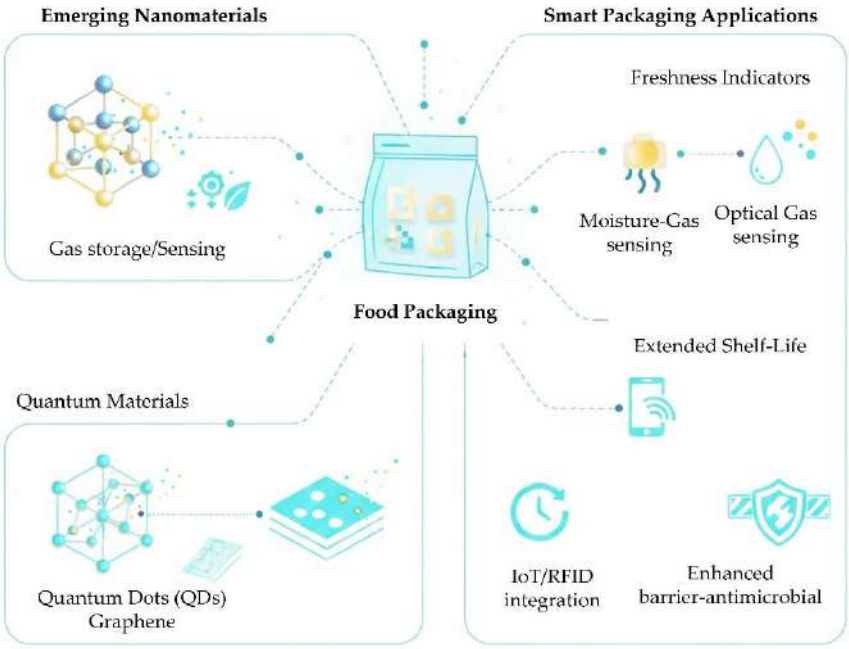


Figure 1. Nanomaterials and smart packaging functions

Need for Nanotechnology in Food Packaging

Food spoilage caused by microorganisms, oxygen, and moisture leads to significant post-harvest losses worldwide. Conventional packaging provides basic protection but cannot always maintain food quality during storage and transportation. Nanotechnology improves packaging by enhancing barrier properties, mechanical strength, and antimicrobial activity. It also supports biodegradable and smart packaging systems that monitor freshness and reduce food waste. Nearly one-third of the food produced worldwide is lost before it reaches consumers. Advanced packaging technologies such as nanotechnology can significantly reduce these losses.These improvements help deliver safer food while meeting the growing demand for sustainable packaging materials. *(Biswas et al., 2022)*

3. Types of Nanomaterials Used in Food Packaging

The most commonly used nanomaterials in food packaging include silver nanoparticles, zinc oxide, titanium dioxide, nanoclay, cellulose nanofibres, chitosan, silica, and graphene. Each material performs a specific function, such as preventing microbial growth, improving barrier properties, or enhancing packaging strength. Several nanomaterials are used to improve food packaging performance. **Silver nanoparticles** provide strong antimicrobial protection, while **zinc oxide** and **titanium dioxide nanoparticles** inhibit microbial growth and offer UV protection. **Nanoclays** improve gas and moisture barrier properties, helping maintain food

quality during storage. **Cellulose nanofibres** and **chitosan nanoparticles** strengthen biodegradable films and enhance sustainability. The choice of nanomaterial depends on the food product and the required packaging function, such as preservation, safety, or environmental protection. *(de Azeredo et al., 2011)*

Table 1. Nanomaterials and Their Functions

Nanomaterial	*Main Function*	*Food Application*
Silver nanoparticles	**Antimicrobial**	**Meat, Dairy, Seafood**
Zinc oxide nanoparticles	**Antibacterial, UV protection**	**Fruits, Vegetables**
Titanium dioxide	**Photocatalytic, Antimicrobial**	**Dairy, Packaged Foods**
Nanoclay	**Gas barrier**	**Snacks, Cereals**
Cellulose nanofibres	**Mechanical strength**	**Eco-friendly packaging**
Chitosan nanoparticles	**Antimicrobial**	**Fruits, Vegetables**
Silica nanoparticles	**Moisture control**	**Bakery Products**
Graphene	**Smart sensing**	**Intelligent Packaging**

Active Food Packaging

Active food packaging interacts with food to maintain freshness and extend shelf life. It incorporates antimicrobial nanoparticles, oxygen scavengers, moisture absorbers, and ethylene scavengers that help preserve food quality during storage. Silver and zinc oxide nanoparticles inhibit microbial growth, while oxygen absorbers reduce oxidation and maintain freshness(Duncan, 2011). Moisture-control materials also minimize fungal growth in fresh produce and bakery products. Active packaging reduces spoilage, improves food safety, and minimizes post-harvest losses throughout the supply chain

Smart Food Packaging

Smart or intelligent food packaging monitors the condition of packaged food and provides real-time information about its quality. It uses nanosensors, freshness indicators, gas sensors, and RFID technology to detect changes in temperature, humidity, pH, and microbial activity. Colour-changing indicators alert consumers to food spoilage, while smart sensors improve product traceability during transportation. These technologies increase consumer confidence and support better food quality management. *((Sharma et al., 2022)*

Antimicrobial Food Packaging

Antimicrobial packaging prevents the growth of bacteria, fungi, and other spoilage microorganisms. Nanoparticles such as silver, zinc oxide, titanium dioxide, and chitosan are incorporated into packaging films to provide continuous antimicrobial protection. These materials reduce microbial contamination, extend shelf life, and decrease the need for chemical preservatives. Antimicrobial nano-packaging is widely used for dairy products, meat, seafood, fruits, and vegetables where food safety is critical.

Nanocomposite Packaging

Nanocomposite packaging is produced by incorporating nanoparticles into polymer materials to improve their strength and barrier properties. Nanoclays, cellulose nanofibres, silica nanoparticles, and graphene reduce oxygen and moisture permeability while enhancing mechanical durability. These materials help maintain food quality and extend shelf life without increasing packaging thickness. Nanocomposite packaging is increasingly used for dairy products, beverages, meat, and processed foods because of its superior protective properties. *(de Azeredo et al., 2011)*

Biodegradable Nano-Packaging

Biodegradable nano-packaging combines renewable polymers with nanomaterials to produce environmentally friendly packaging. Materials such as polylactic acid (PLA), starch, cellulose, and chitosan are reinforced with nanoparticles to improve strength, flexibility, and barrier performance.



Figure 2 Types of nano enabled food packing systems

These biodegradable materials reduce plastic pollution while maintaining food quality and safety (López-Rubio et al., 2019). Their growing use supports sustainable food packaging and reduces dependence on petroleum-based plastics.

4. Applications of Nanotechnology in Different Food Products

Nanotechnology has wide applications in food packaging. In dairy products, antimicrobial packaging improves the shelf life of milk, cheese, and yogurt. Edible nano-coatings delay ripening and reduce moisture loss in fruits and vegetables. Meat and seafood packaging uses antimicrobial films and oxygen scavengers to control spoilage during storage. Moisture-resistant nanocomposite films help maintain the freshness and texture of bakery products (Sharma et al., 2022). These applications improve food quality, reduce post-harvest losses, and ensure safer food throughout the supply chain.

Table 2. Applications in Different Food Products

Food Product	*Nano Technology Used*	*Purpose*
Milk	**Smart indicator labels**	**Freshness monitoring**
Cheese	**Silver nanoparticles**	**Antimicrobial protection**
Yogurt	**Nanocomposite packaging**	**Shelf-life extension**
Fruits	**Edible nano-coating**	**Delay ripening**
Vegetables	**Chitosan nano-film**	**Reduce microbial growth**
Meat	**Active antimicrobial packaging**	**Pathogen control**
Seafood	**Oxygen scavengers**	**Prevent oxidation**
Bakery	**Moisture barrier films**	**Maintain texture**

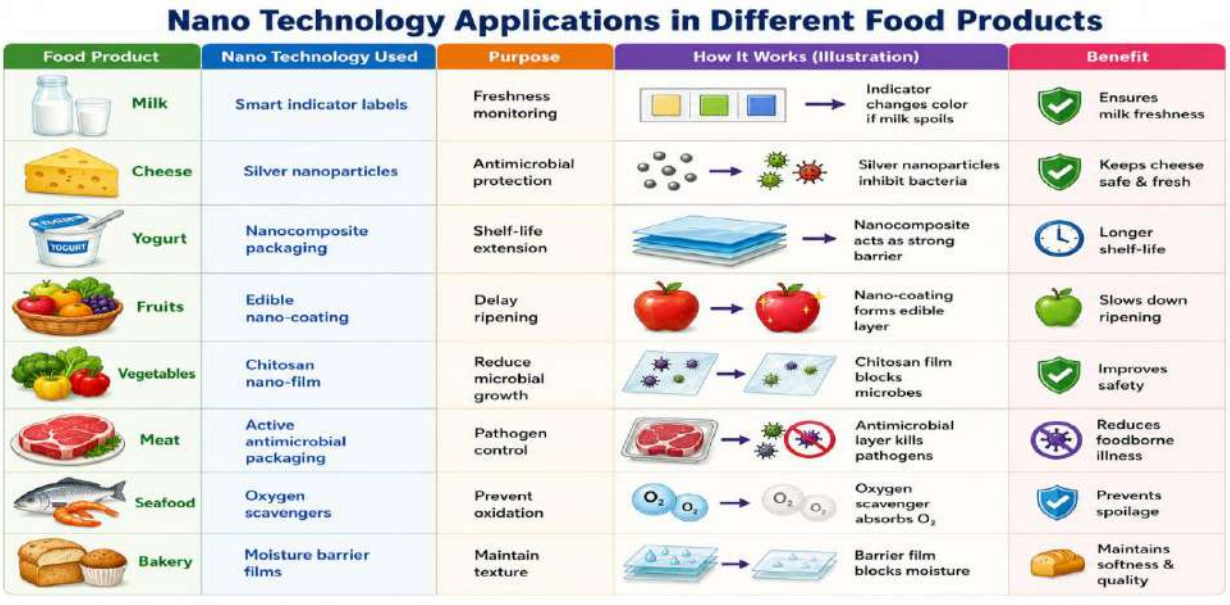


Figure 3 Nano technology applications in different food products

Advantages of Nanotechnology in Food Packaging

Nanotechnology improves food packaging by enhancing barrier properties, controlling microbial growth, and extending shelf life. Smart packaging monitors food freshness, while biodegradable nanocomposites reduce plastic waste. These innovations improve food safety, reduce spoilage, and support sustainable packaging practices. They also help manufacturers reduce post-harvest losses and deliver high-quality food products to consumers.

Challenges and Safety Issues

The use of nanotechnology in food packaging raises concerns about nanoparticle migration, long-term health effects, and environmental safety. High production costs, strict regulations, and limited consumer awareness also affect large-scale commercialization. Continuous research and proper safety assessment are necessary to ensure the responsible use of nanomaterials in food packaging.*(Duncan, 2011)*

Table 3. Advantages and Challenges

Advantages	***Challenges***
Extended shelf life	**Nanoparticle migration**
Improved food safety	**Toxicity concerns**
Better barrier properties	**High production cost**
Reduced food waste	**Regulatory approval**
Smart freshness monitoring	**Consumer acceptance**
Eco-friendly packaging	**Environmental assessment**
Lower plastic usage	**Standardization issues**
Improved product quality	**Large-scale commercialization**

5.Recent Innovations (2025–2026)

Recent developments have focused on AI-enabled smart packaging, graphene-based nanosensors, biodegradable cellulose nanofibre films, and edible nano-coatings. AI and Internet of Things (IoT) technologies are making food packaging smarter than ever before.These innovations provide real-time monitoring of food quality, detect spoilage at an early stage, and improve packaging sustainability. Self-healing packaging films and nanoencapsulated natural antimicrobial compounds are also being explored to enhance food preservation. These emerging technologies are expected to reduce food waste, improve supply chain management, and support environmentally friendly food packaging solutions in the coming years.

Table 4. Emerging Nanotechnology Innovations in Food Packaging

Innovation	Application	Benefit
AI-enabled nanosensors	Real-time monitoring	Improved food safety
Graphene biosensors	Pathogen detection	High sensitivity
Cellulose nanofibre films	Biodegradable packaging	Sustainable materials
Self-healing packaging	Film repair	Longer packaging life
Edible nano-coatings	Fruits & vegetables	Reduced food waste
Nanoencapsulated essential oils	Active packaging	Natural antimicrobial activity
RFID-enabled smart packaging	Supply chain	Improved traceability
Bioplastic nanocomposites	Eco-friendly packaging	Reduced plastic pollution

6.Future Scope

The future of food packaging lies in the integration of nanotechnology with Artificial Intelligence (AI), the Internet of Things (IoT), and biodegradable materials. Advanced nanosensors will enable continuous monitoring of food quality, while sustainable nanocomposites derived from renewable resources will reduce environmental pollution (Biswas et al., 2022) . Future packaging systems may also provide consumers with real-time information on freshness, nutritional quality, and product traceability through smart labels. Continued research and supportive regulations will help expand the commercial use of nano-enabled food packaging.

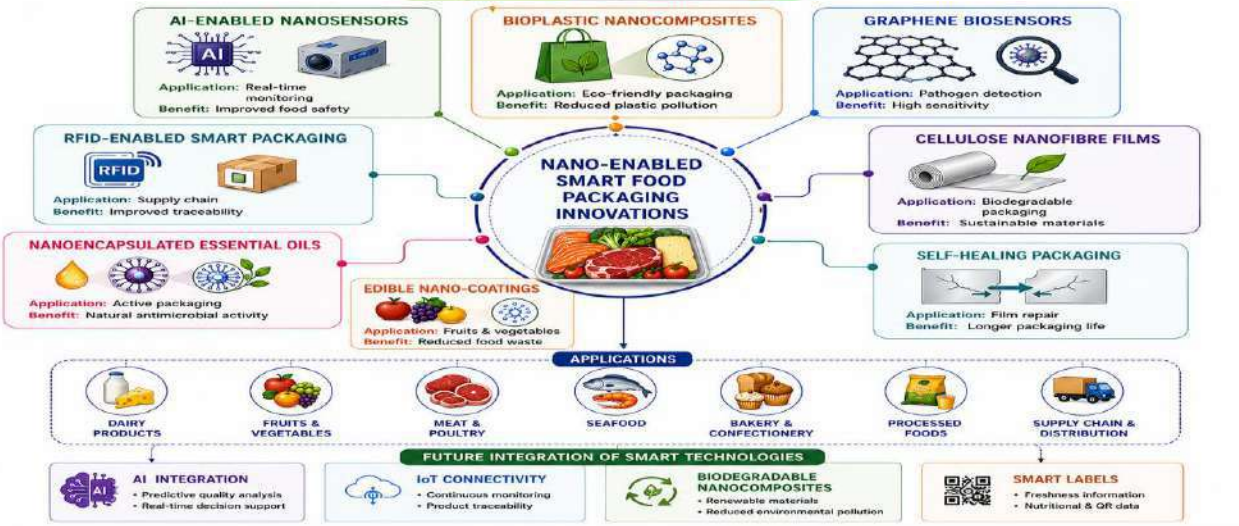


Figure 4. Future Smart Food Packaging System Using Artificial Intelligence, IoT, and Nano-Sensors

Conclusion

Nanotechnology is transforming food packaging by making it safer, smarter, and more sustainable. Through antimicrobial materials, intelligent sensors, and biodegradable nanocomposites, it helps extend shelf life, improve food quality, and reduce food waste. Although challenges related to safety, cost, and regulations remain, ongoing research continues to improve the reliability and environmental compatibility of nano-enabled packaging. With further technological advancements, nanotechnology is expected to play a key role in ensuring food safety and supporting sustainable food systems worldwide.

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SENSORS FOR FOOD STORAGE: TECHNOLOGIES AND APPLICATIONS

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Introduction

Food spoilage is a major global challenge. According to international estimates, roughly one-third of the food produced for human consumption is lost or wasted each year. Spoilage occurs at every stage of the food supply chain, from farms and warehouses to transport vehicles, retail stores, and household kitchens. Apart from economic losses, food waste also consumes valuable resources such as water, energy, and land while contributing to greenhouse gas emissions.

Traditional food storage relies on periodic inspections and fixed expiry dates, but these methods cannot always reflect the actual condition of food. Advances in sensor technology are changing this approach by enabling continuous, real-time monitoring of storage conditions. Modern sensors can detect changes in temperature, humidity, gases, microbial activity, and other indicators of food quality, helping producers, retailers, and consumers make informed decisions.

What Are Food Storage Sensors?

A sensor is a device that detects a physical, chemical, or biological change in its surroundings and converts it into information that can be measured or recorded. In food storage, sensors monitor conditions that influence food quality and safety.

Unlike conventional monitoring systems, smart sensors not only collect data but often communicate it wirelessly to computers or smartphones. When connected through the Internet of Things (IoT), they can automatically alert users if storage conditions become unsuitable. For example, if the temperature inside a refrigerated warehouse rises above the recommended level

because of a power failure, the sensor immediately sends an alert so corrective action can be taken before the food spoils.

Why Monitoring Food Storage Matters

Food is a living or chemically active material that continues to change after harvest or processing. Several environmental factors determine how quickly these changes occur.

a) Temperature

Temperature is the most critical factor in food preservation. High temperatures accelerate microbial growth, enzyme activity, and chemical reactions that cause spoilage. Even a brief interruption in refrigeration can significantly reduce the shelf life of meat, dairy products, seafood, and fresh produce.

b) Humidity and moisture content

Moisture affects both microbial growth and product quality. Excess humidity encourages mould growth and bacterial contamination, while very low humidity causes fruits and vegetables to lose water, resulting in shrivelling and reduced freshness.

c) Oxygen

Many spoilage reactions require oxygen. Oxidation causes fats to become rancid and can change the colour and flavour of foods. Monitoring oxygen levels is particularly important in modified atmosphere packaging.

d) Carbon Dioxide

Carbon dioxide helps preserve many packaged foods by slowing microbial growth. However, abnormal carbon dioxide levels may indicate microbial activity or package leakage.

e) Ethylene

Ethylene is a natural plant hormone produced by fruits such as bananas, apples, avocados etc. It accelerates ripening, which can be beneficial under controlled conditions but undesirable during long-term storage. Monitoring ethylene helps extend the shelf life of fresh produce.

Major Types of Sensors Used in Food Storage

1. Temperature Sensors

Temperature sensors are among the most widely used devices in food storage. They continuously measure storage temperatures in refrigerators, freezers, cold rooms, refrigerated trucks, and shipping containers.

Common types include:

- Thermistors
- Thermistors
- Thermocouples
- Resistance Temperature Detectors (RTDs)
- Digital temperature sensors

1.1 TEMPERATURE SENSORS USED IN FOOD GRAIN STORAGE AND COLD STORAGE OF PERISHABLE FOODS

Temperature sensors are essential for maintaining product quality, preventing spoilage, and ensuring safe storage conditions in both food grain storage and the cold storage of perishable foods. In grain storage, temperature monitoring helps detect localized heating caused by moisture migration, microbial activity, or insect infestation, enabling timely aeration and preventing quality deterioration. In contrast, cold storage of perishable foods relies on continuous temperature monitoring to maintain the cold chain, preserving the freshness, nutritional quality, and safety of products such as fruits, vegetables, dairy products, meat, seafood, frozen foods, and pharmaceuticals. Figure 1 shows a schematic diagram of a modern in-silo drying and aeration system with sensors.

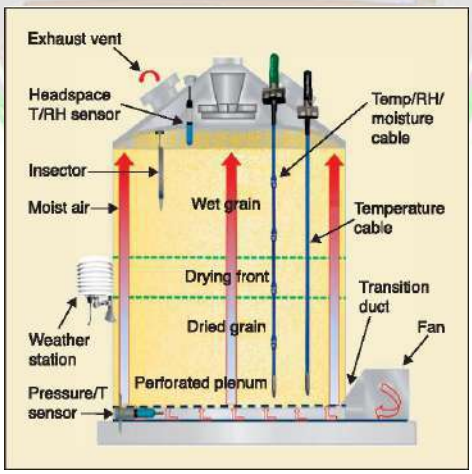


Figure 1. Schematic diagram of a modern in-silo drying and aeration system with sensors (*Source: Singh, C.B., & Fielke, J.M. (2017). Recent developments in stored grain sensors, monitoring and management technology*)

Thermistors are among the most commonly used temperature sensors in both applications due to their high sensitivity and rapid response to temperature changes. In grain storage, they are widely embedded along heavy-duty suspension cables installed vertically inside grain silos to

continuously monitor the temperature profile of the grain mass. Although thermistors provide excellent sensitivity, their resistance–temperature relationship is nonlinear and requires signal linearization. In perishable food storage, thermistors are commonly used in digital thermometers and refrigeration systems for rapid monitoring of product and storage temperatures, particularly for meat and dairy products.

Resistance Temperature Detectors (RTDs) provide highly accurate, stable, and repeatable temperature measurements over extended periods. They are extensively used in large commercial grain silos where precise monitoring is essential for inventory management and early detection of spoilage. In cold storage facilities, RTDs are considered the industry standard for refrigeration and food processing systems because they maintain high measurement accuracy over a typical operating range of −40°C to 150°C, with accuracies generally between ±0.3°C and ±0.5°C. Their main limitation is their higher cost compared with thermistors.

Digital temperature sensors are increasingly employed in modern storage systems because they provide direct digital outputs, eliminating the need for analog-to-digital conversion and improving immunity to electrical noise. In grain storage, they are integrated into wireless monitoring networks, including Internet of Things (IoT) and RFID-based systems, to enable continuous temperature monitoring throughout the silo. Similarly, in cold storage facilities, digital temperature sensors support automated refrigeration control, remote monitoring, and real-time temperature management within cold rooms and refrigerated transport systems.

Thermocouples are less commonly used for monitoring stored grain or refrigerated food because their accuracy is generally lower than that of RTDs and thermistors at normal storage temperatures. However, they are well suited for measuring high temperatures in grain dryers, heaters, food processing equipment, and industrial refrigeration components due to their wide operating temperature range, rugged construction, and fast response.

Temperature data loggers and IoT-based sensors have become increasingly important in both grain storage and cold-chain logistics. In grain storage, wireless sensor nodes continuously monitor temperature and transmit real-time data for automated aeration and early spoilage detection. In the cold chain, compact battery-powered data loggers and IoT tags attached to storage units, pallets, or transport containers continuously record temperature throughout storage and distribution, transmitting real-time alerts via cellular, Wi-Fi, Bluetooth, or LoRa communication networks whenever temperatures exceed safe limits.

Overall, thermistors, RTDs, digital temperature sensors, thermocouples, and IoT-enabled monitoring devices each play important roles in maintaining optimal storage conditions. The choice of sensor depends on the required measurement accuracy, response time, operating temperature range, installation environment, and cost, with RTDs and digital sensors being preferred for high-accuracy applications, thermistors for sensitive and economical monitoring, thermocouples for high-temperature processes, and IoT-based systems for continuous remote monitoring and automated storage management.

2. Humidity Sensors

High relative humidity can reduce grain quality by promoting moisture absorption, mold growth, insect infestation, loss of seed germination, and overall spoilage. Humidity sensors continuously monitor the moisture content of the surrounding air, helping maintain optimal storage conditions. The two most common types are capacitive and resistive sensors.

2.1 Humidity Sensors Used in Food Grain Storage and cold storage of perishable food

a) Capacitive humidity sensors

Capacitive humidity sensors are the most widely used in both food grain and perishable food storage because of their high accuracy, fast response time, excellent long-term stability, and low power consumption. They operate by measuring changes in the capacitance of a hygroscopic dielectric material as it absorbs or releases moisture from the surrounding air. These sensors are extensively used in grain silos, warehouses, seed storage facilities, cold storage rooms, refrigerated warehouses, food processing plants, and refrigerated transport systems. Their high reliability and compatibility with wireless and Internet of Things (IoT)-based monitoring systems make them the preferred choice for continuous environmental monitoring.

b) Resistive humidity sensors

Resistive humidity sensors determine relative humidity by measuring changes in the electrical resistance of a moisture-sensitive material. They are commonly used in grain bins, agricultural warehouses, seed storage facilities, and small refrigerated storage units where low-cost humidity monitoring is required. These sensors offer simple circuitry, ease of integration, and economical operation. However, they generally have lower long-term stability than capacitive sensors and require periodic calibration to maintain measurement accuracy, particularly in dusty or high-humidity environments.

3. Gas Sensors

Gas sensors monitor changes in the composition of gases surrounding stored food.

Oxygen Sensors: These sensors ensure that oxygen levels remain low in modified atmosphere packaging, reducing oxidation and slowing microbial growth.

Carbon Dioxide Sensors: Monitors carbon dioxide levels generated by respiration in fresh produce and stored grain. Elevated CO_2 concentrations can indicate increased respiration, insect activity, microbial growth, package leakage, or spoilage, providing an early warning of quality deterioration during storage.

Ethylene Sensors: Ethylene sensors are especially valuable in fruit storage facilities. Apples, bananas, mangoes, tomatoes, and avocados release ethylene gas as they ripen. Monitoring ethylene allows storage managers to separate highly active fruits from ethylene-sensitive produce, extending shelf life.

Ammonia Sensors: Ammonia is released during the decomposition of protein-rich foods such as meat and fish. Detecting ammonia provides an early warning of spoilage.

4. Pressure sensor

Monitors pressure changes in storage bins and aeration systems to help ensure safe operation and detect blockages or equipment issues.

5. Acoustic sensor

Acoustic sensors convert sound waves into electrical signals to detect and analyze sound in stored grain. They monitor the sounds produced by insect movement and feeding, allowing early detection of pest infestations without disturbing the grain. The sensor detects changes in air pressure caused by sound, converts these pressure fluctuations into electrical signals, and processes the signals to identify insect activity, enabling timely pest management and reducing storage losses.

6. VOC and ozone sensors

VOC (volatile organic compound) sensors detect gases released during grain deterioration, fungal growth, or pest activity. Ozone sensors monitor ozone levels when ozone is used as a disinfectant, ensuring effective treatment while maintaining safety.

6.1 Electronic nose (E-nose): An electronic nose is an advanced VOC sensing system that combines an array of gas sensors with pattern-recognition algorithms to identify the characteristic odor profiles of stored grains and foods. By analyzing the mixture of volatile

organic compounds released during storage, it can rapidly detect spoilage, fungal contamination, insect infestation, and quality deterioration at an early stage, providing a non-destructive and real-time tool for food storage monitoring (Figure 2).

7. Phosphine sensor

Measures phosphine gas concentration during fumigation, helping verify that pest control treatments are effective and ensuring worker safety by preventing hazardous exposure.



Figure 2. Image of Cyranose 320 Electronic Nose (*Source:* https://www.sensigent.com/cyranose-320.html)

8. Airflow sensor

Monitors the movement of air through stored grain during aeration, helping maintain uniform temperature and moisture levels while reducing the risk of spoilage and mold growth.

9. Moisture sensors

GRAIN MOISTURE SENSORS

Grain moisture sensors determine the moisture content of stored grains by measuring their electrical and dielectric properties (Figure 3(a)). In capacitive moisture sensing, the grains act as the dielectric medium between two conducting plates, and the dielectric constant increases with an increase in moisture content. As grain moisture rises, the capacitance of the sensor changes accordingly. In resistive moisture sensing, an electrical current is passed between two electrodes; grains with higher moisture content exhibit greater electrical conductivity, resulting in lower resistance values, whereas dry grains show higher resistance. A typical capacitive moisture sensor consists of two conducting plates separated by the grain material. The sensor can be integrated with a timer circuit or microcontroller system, such as an Arduino, to convert

capacitance variations into an analog voltage signal. The sensor operates as a voltage divider circuit, where one electrode is connected to a +5 V supply through a 10 kΩ resistor and the other electrode is connected to ground.



Figure 3. (a) Grain Moisture sensor (b) (Relative humidity sensor https://www.hengko.com/news/how-humidity-sensor-works-all-you-should-know/)

The output voltage varies approximately between 0 and 5 V depending on changes in grain moisture content, enabling real-time monitoring of grain storage conditions. These sensors are widely used in grain storage facilities to prevent spoilage, fungal growth, and quality deterioration by maintaining moisture levels within safe limits.

10. pH Sensors

As microorganisms grow, they produce acids or alkaline compounds that alter the pH of food. pH sensors are particularly useful for monitoring meat, fish, milk, cheese, fermented foods etc. Changes in pH often occur before visible spoilage becomes apparent.

11. Biosensors

Biosensors combine biological recognition elements with electronic detectors to identify specific microorganisms or chemicals. They can rapidly detect harmful pathogens such as *Salmonella*, *Escherichia coli* (*E. coli*) and *Listeria monocytogenes.* Unlike traditional laboratory testing, which may take several days, modern biosensors can provide results within minutes or hours, allowing contaminated products to be removed before reaching consumers.

12. Electrostatic sensor:

Electrostatic sensors monitor the movement and concentration of grain dust by detecting the electrical charge carried by individual dust particles. As particles move through storage or pneumatic conveying systems, they acquire electrostatic charges through collisions with other particles, pipe walls, and air. An insulated electrode detects these charges, allowing the sensor to estimate particle size distribution and dust concentration. This information helps assess grain

quality, identify excessive dust levels, improve storage safety, and reduce the risk of spoilage and dust-related hazards.

IoT-Based Smart Sensors

Internet of Things (IoT) technology allows multiple sensors to communicate with cloud-based monitoring systems. Managers can monitor warehouses or refrigerated trucks from anywhere using computers or smartphones. Benefits include real-time monitoring, automatic alerts, remote supervision, predictive maintenance, data analytics etc.

Benefits of Sensor Technology

The widespread use of sensors offers numerous advantages.

Improved Food Safety: Continuous monitoring reduces the risk of contaminated food reaching consumers.

Longer Shelf Life: Optimal storage conditions slow spoilage and preserve freshness.

Reduced Food Waste: Early detection of storage problems prevents unnecessary disposal of food.

Better Supply Chain Management: Real-time monitoring improves transportation, inventory control, and logistics.

Consumer Confidence: Smart labels provide reliable information about food freshness, helping consumers make informed purchasing decisions.

Regulatory Compliance: Food businesses can document storage conditions and demonstrate compliance with food safety standards.

Real-World Applications

Sensor technology is now used across the food industry.

Cold Storage Warehouses: Large refrigerated warehouses rely on sensor networks to monitor temperature and humidity continuously.

Supermarkets: Retailers use sensors to monitor refrigerated display cabinets, reducing losses caused by equipment failure.

Food Transportation: Refrigerated trucks and shipping containers use wireless sensors to maintain cold-chain integrity during long-distance transport.

Household Refrigerators: Modern smart refrigerators monitor internal temperature and humidity while sending maintenance alerts to users.

Fruit Storage Facilities: Ethylene monitoring systems help maintain the quality of apples, bananas, pears, mangoes, and other climacteric fruits.

Challenges

Despite their advantages, sensor technologies still face several challenges.

- High installation costs for advanced monitoring systems
- Need for regular calibration and maintenance
- Battery limitations in wireless devices
- Managing large volumes of sensor data
- Environmental concerns regarding electronic waste from disposable smart packaging

Researchers are working to develop low-cost, biodegradable, and printable sensors that are more sustainable.

The Future of Food Storage

The future of food storage is becoming increasingly intelligent.

Artificial intelligence is being integrated with sensor systems to predict spoilage before it occurs. Machine learning algorithms analyse sensor data to estimate remaining shelf life and recommend optimal storage conditions.

Researchers are also developing flexible printed sensors that can be incorporated directly into food packaging at low cost. Nanotechnology is enabling highly sensitive sensors capable of detecting minute amounts of gases or microbial metabolites.

In the coming years, consumers may use smartphone apps to scan food packages and receive real-time information about freshness, storage history, and nutritional quality. Combined with blockchain technology, sensor data could also improve traceability, allowing food products to be tracked from farm to table.

Conclusion

Sensors are becoming essential tools in modern food storage by enabling continuous monitoring and control of critical quality parameters such as temperature, humidity, gases, airflow, pressure, and biological activity. By providing early detection of spoilage, pest infestation, and unfavorable storage conditions, sensors help maintain food quality, enhance safety, reduce post-harvest losses, and improve storage efficiency across the supply chain. Although challenges related to cost, calibration, durability, and large-scale implementation remain, ongoing developments in sensor technology, data analytics, and automation are

expanding their applications. In the future, advanced sensor-based monitoring systems will play a key role in creating safer, more sustainable, and efficient food storage practices, supporting global food security and reducing food waste from farm to consumer.

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WHY THE FUTURE OF CLIMATE-SMART AG LIES BENEATH OUR FEET

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Introduction

When the agricultural sector discusses climate resilience, the spotlight almost always falls on above-ground innovations *viz.*, autonomous field drones, AI-driven predictive weather modeling and automated precision irrigation. While these technological advances unquestionably optimize efficiency, they treat only the surface of a much deeper equation. The true cornerstone of long-term agricultural resilience lies hidden beneath our feet within the soil microbiome. Far from being an inert medium designed merely to anchor plant roots, healthy soil is a dynamic, highly complex biological ecosystem. A single teaspoon of fertile earth harbors billions of microorganisms including bacteria, fungi, protozoa and functional algae operating as a collective engine. Together, this subterranean workforce cycles essential nutrients, stabilizes soil architecture, sequesters atmospheric carbon and buffers crops against volatile weather extremes. If climate-smart agriculture is to succeed, it must look beyond high-tech hardware and prioritize the biological living systems that sustain life from the ground up.

1. The Biological Engine of Yield and Resilience

The soil microbiome operates as an invisible biological workforce. Beneficial microbes engage in symbiotic relationships with root systems, executing metabolic functions critical to crop health

A. Bio-Nutrient Mobilization & Solubilization

While chemical fertilizers deliver readily soluble forms of nutrients, much of what is applied quickly becomes chemically locked (fixed) in the soil matrix or leaches into groundwater.

- **Phosphorus Unlocking:** In alkaline or acidic soils, up to 80–90% of applied phosphate binds with calcium, iron, or aluminum. Phosphate Solubilizing Bacteria (PSB) such as species of *Bacillus*, *Pseudomonas*, and *Aspergillus* excrete organic acids (e.g., gluconic acid, citric acid) that lower localized pH, chelating bound cations and liberating bioavailable HPO_4^{2-} and $H_2PO_4^-$ for plant absorption.
- **Biological Nitrogen Fixation (BNF):** Symbiotic diazotrophs (*Rhizobium* spp.) and free-living or endophytic fixers (*Azotobacter*, *Azospirillum*, *Gluconacetobacter*) reduce atmospheric nitrogen (N_2) into bioavailable ammonia (NH_3) via the oxygen-sensitive **nitrogenase enzyme complex**, bypassing the energy-intensive Haber-Bosch process.

B. Phytohormone Modulation & Stress Mitigation

Under climate-induced abiotic stress (e.g., elevated temperatures or high salinity), plants naturally overproduce **ethylene**, a stress hormone that triggers premature senescence, leaf abscission, and stunted root development.

- **ACC Deaminase Activity:** Plant Growth-Promoting Rhizobacteria (PGPR) produce the enzyme **1-aminocyclopropane-1-carboxylate (ACC) deaminase**. This enzyme hydrolyzes ACC (the immediate precursor to ethylene in plants) into α-ketobutyrate and ammonia, effectively damping down stress signaling.
- **Root Architecture Rewiring:** Microbial secretion of auxins (such as Indole-3-Acetic Acid, or IAA), gibberellins, and cytokinins stimulates lateral root branching and elongation. This expanded root system gives crops a deeper reach to tap subsoil water reserves during prolonged dry spells.

C. Biological Control & Niche Exclusion

Microbial diversity serves as the first line of defense against soil-borne vascular pathogens (e.g., *Fusarium*, *Rhizoctonia*, *Pythium*, and *Xanthomonas* spp.):

- **Siderophore Production:** Beneficial microbes synthesize high-affinity iron-chelating molecules called siderophores, starving pathogenic organisms of essential Fe^{3+} ions.
- **Antimicrobial Metabolites:** Genus members like *Bacillus velezensis* synthesize cyclic lipopeptides (surfactin, iturin, fengycin) that disrupt fungal cell membranes and suppress bacterial proliferation.

- **Induced Systemic Resistance (ISR):** Root colonization by beneficial microbes triggers systemic defense pathways throughout the plant, priming it to defend against foliar pathogens and chewing insects.

D. Soil Aggregate Stabilization

Soil structure relies heavily on biological "glues":

- **Glomalin:** Arbuscular Mycorrhizal Fungi (AMF) produce **glomalin**, a hydrophobic glycoprotein that acts as a long-lasting biological cement. Glomalin binds mineral particles and organic debris into stable macroaggregates.
- **Erosion Control & Aeration:** Aggregate stability prevents soil crusting, improves water infiltration rates, and maintains macropores necessary for root gas exchange (O_2/CO_2).

2. The Vulnerability of Soil Systems to Climate Stress

Climate change poses a direct threat to below-ground biology. Escalating global temperatures, erratic precipitation, prolonged heatwaves and flash flooding disrupt sensitive microbial dynamics

[Extreme Heat / Drought] ⟶ Decreased Microbial Activity ⟶ Slower Nutrient Cycling

|

[Severe Erosion / Floods] ⟶ Loss of Topsoil & Nutrients ⟶ Compromised Soil Structure

|

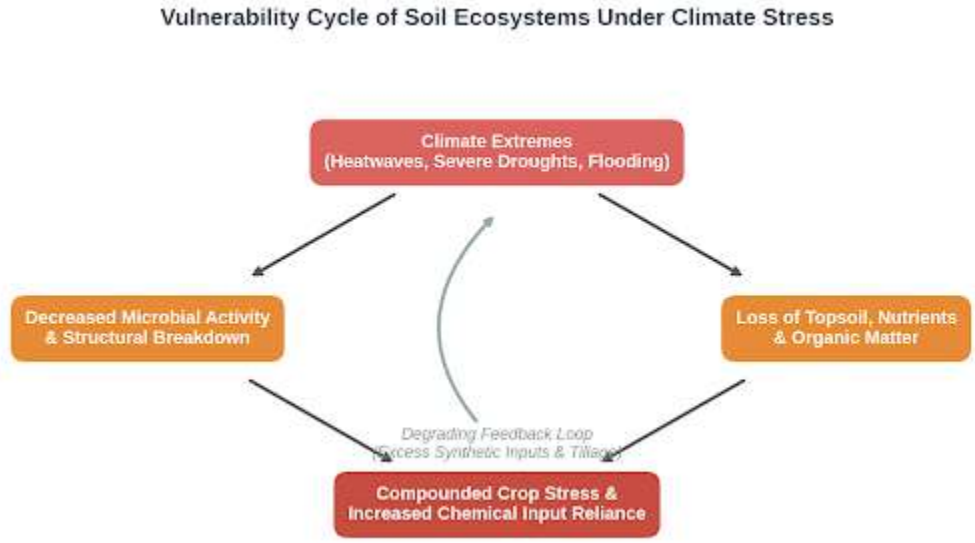
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Compounded Crop Stress & Chemical Input Reliance

When severe weather suppresses biological activity, nutrient cycling stalls, forcing farmers to rely more heavily on synthetic inputs. This creates a degrading feedback loop like over-application of chemical fertilizers and frequent mechanical tillage further disrupt soil biodiversity, compounding crop vulnerability over time.

When biology fails, farms often rely on increased applications of synthetic fertilizers and intensive tillage to maintain yields. However, this strategy can backfire:

1. **Chemical Overload:** High salt index synthetic inputs raise the electrical conductivity (EC) of the soil solution, drawing osmotic water out of microbial cells.
2. **Disrupted Symbiosis:** Excess synthetic nitrogen and phosphorus signal the plant to stop releasing root exudates, effectively shutting down natural mycorrhizal networks and nitrogen-fixing symbioses.



3. **Physical Destruction:** Intensive mechanical tillage shears fungal hyphae, disrupts soil pores, and accelerates the oxidation of biological carbon into CO_2.

3. Soil Organic Matter as a Climate Buffer

Rebuilding soil organic matter (SOM) is essential for breaking this cycle and strengthening farm resilience across three main pillars

Drought Resilience

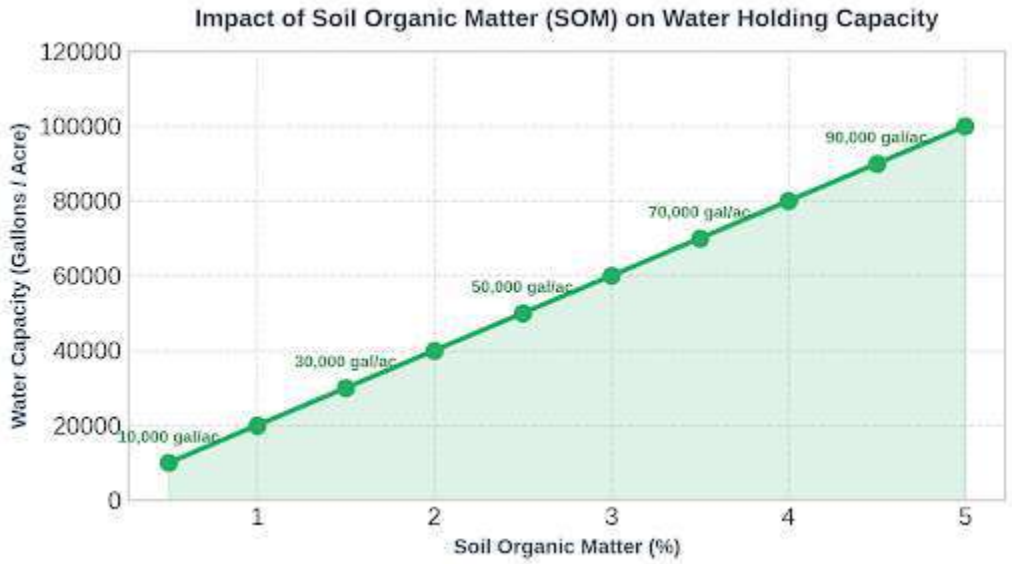
Soils rich in SOM act as biological sponges. Around 1% increase in soil organic matter enables soil to hold thousands of additional gallons of water per acre, allowing crops to sustain growth through extended dry spells.

Carbon Sequestration

Through photosynthesis, plants capture atmospheric carbon dioxide (CO_2) and exude carbon compounds into the rhizosphere. Healthy microbial communities convert this root-derived carbon into stable organic forms, effectively turning agricultural soils into vital carbon sinks.

Resource Efficiency

Improved aggregate stability minimizes surface runoff, retains applied nutrients within the root zone and significantly reduces fertilizer leaching into surrounding watersheds.



4. Operationalizing Regenerative Management Practices

Transitioning from input-heavy systems to biologically active soils rely on targeted agronomic management

Management Practices for Soil Biological Health

Practice	Mechanism	Agronomic Impact
Minimal / No-Till	Preserves fungal networks (hyphae) and soil pore structure.	Reduces moisture loss and prevents aggregate degradation.
Continuous Cover Crops	Provides steady root exudates to nourish subterranean microbes.	Prevents soil erosion, suppresses weed growth, and fixes atmospheric nitrogen.
Diverse Crop Rotations	Interrupts pest and disease cycles through varied root architecture.	Diversifies subterranean microbial populations across field profiles.
Organic Amendments	Supplies complex carbon compounds alongside beneficial microbial inoculants.	Restores depleted organic carbon reserves and stimulates biological activity.

5. The Convergence of AgTech and Soil Biology

Modern agriculture does not require choosing between biology and technology. The future of sustainable farming lies in their integration. Advanced molecular diagnostics, metagenomic sequencing and satellite-based soil moisture monitoring now allow producers to evaluate the biological health of their fields in real time. Biological inputs such as targeted microbial inoculants, bio-stimulants and bio-fertilizers are moving from fringe alternatives to core components of mainstream crop management. Rather than seeking to control nature through synthetic interventions alone, modern agronomy is increasingly designed to amplify natural biological processes.

Metagenomics & High-Throughput DNA Sequencing

Next-Generation Sequencing (NGS) allows researchers to read environmental DNA (*eDNA*) directly from soil samples. By sequencing 16S rRNA (for bacteria) and ITS regions (for fungi), agronomists can map a field's biological profile, assess functional biodiversity, and identify potential pathogen pressures before visual crop symptoms emerge.

Precision Bio-Formulations & Microencapsulation

Advances in bio-process engineering allow sensitive microbial strains to be coated with natural biopolymers. These protective coatings shield beneficial microbes from heat and desiccation, ensuring high survival rates when applied in-furrow or as seed treatments.

Remote Sensing and Soil Functional Mapping

Integrating high-resolution satellite imagery (NDVI, thermal band analysis) with ground-based IoT soil moisture and temperature sensors gives farmers real-time insights into field microclimates. This data helps optimize the timing of biological applications, ensuring maximum microbial establishment and effectiveness.

Conclusion

Rooting the future in living soil and building a climate-resilient food system requires measuring agricultural productivity not merely by seasonal yield per acre, but by the long-term vitality of the soil ecosystem. By prioritizing below-ground biodiversity, producers can cut input costs, build resilience against volatile weather patterns and contribute directly to global carbon reduction efforts. The evolution of climate-smart agriculture will continue to leverage automation, satellites and data science. However, its ultimate success will depend on how effectively those tools protect and nurture the living community beneath our feet.

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BACILLUS: THE BENEFICIAL BACTERIUM REVOLUTIONIZING SUSTAINABLE FARMING

Article ID: AG-V06-I07-149

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Introduction

When people think about the future of agriculture, they often imagine artificial intelligence, precision drones, automated tractors, or climate-resilient crop varieties. Yet, one of the most remarkable innovations in sustainable farming is invisible to the naked eye. Beneath every healthy crop lies a thriving community of beneficial microorganisms, quietly working to nourish plants, protect them from diseases, and restore soil health.

Among these microscopic allies, *Bacillus* has emerged as one of agriculture's greatest success stories. These naturally occurring soil bacteria are transforming the way farmers grow food by reducing dependence on chemical fertilizers and pesticides while improving crop productivity. Often referred to as **"nature's own biofactory,"** *Bacillus* species are proving that some of the most powerful agricultural technologies are already present beneath our feet.

What Exactly Is *Bacillus*?

Bacillus is a diverse group of beneficial bacteria commonly found in agricultural soils, plant roots, compost, and even harsh environments where many microorganisms cannot survive. Unlike many beneficial microbes that are sensitive to environmental changes, *Bacillus* species possess a unique survival strategy, they produce highly resistant structures called endospores.

These spores allow the bacteria to withstand drought, extreme temperatures, ultraviolet radiation, and nutrient scarcity for extended periods. Once environmental conditions improve, the spores germinate into active bacterial cells capable of colonizing plant roots and performing a

wide range of beneficial functions. Their exceptional resilience makes *Bacillus* one of the most reliable microorganisms used in commercial biofertilizers and biopesticides worldwide.

Feature	Chemical Farming Inputs	Bacillus-Based Biologicals
How They Work	Kill pests or supply nutrients using chemicals	Naturally protect plants, improve nutrient uptake, and boost plant immunity
Effect on the Environment	Can pollute water, harm beneficial organisms, and reduce soil health	Safe for the environment and helps build healthier, more fertile soils
Resistance to Diseases	Pests and pathogens can become resistant over time	Multiple natural actions make it much harder for pathogens to develop resistance
Shelf Life	Stable during storage but may leave chemical residues	Forms durable spores that remain effective for a long time
Benefits to Crops	Gives quick disease control or nutrient supply	Encourages stronger roots, healthier plants, better stress tolerance, and sustainable yields

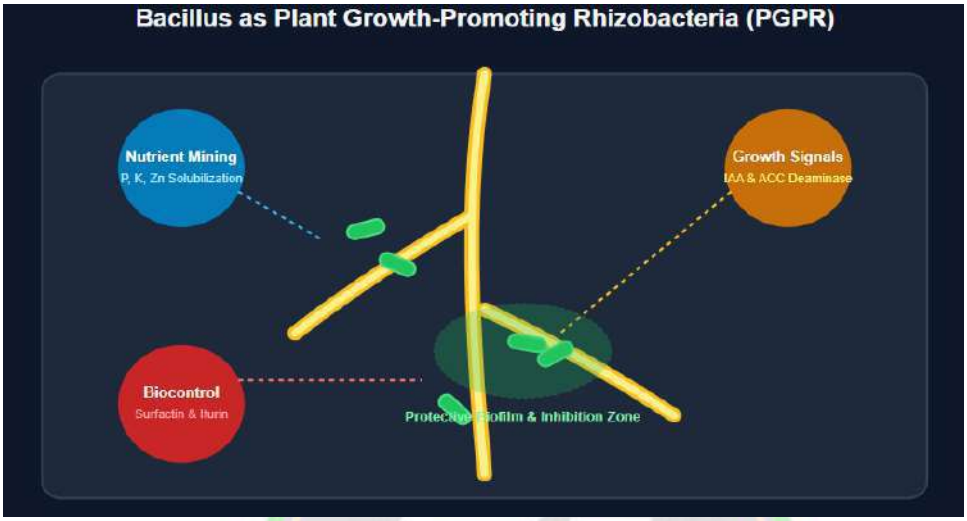
Nature's Plant Doctor: Mechanisms of Action

Healthy plants require more than sunlight and water. They constantly interact with microorganisms that influence their nutrition, growth, and resistance to stress. *Bacillus* acts as a multifunctional plant partner by supporting crops through several biological mechanisms.

A. Boosting Plant Growth Naturally

- **Phytohormone Biosynthesis:** Many *Bacillus* species stimulate plant development by producing natural phytohormones such as indole-3-acetic acid (IAA), which promotes root elongation and branching. A larger root system enables plants to absorb more water and nutrients, resulting in stronger growth and improved productivity.

- **Stress-Mitigating Enzymes:** Certain *Bacillus* strains produce ACC deaminase, an enzyme that degrades the ethylene precursor 1-aminocyclopropane-1-carboxylate, lowering stress-induced ethylene levels in plants. This helps crops tolerate drought, salinity, transplant shock, and other environmental stresses more effectively.



B. Unlocking Insoluble Soil Nutrients

A significant proportion of essential nutrients present in soils remains unavailable to plants because they exist in insoluble complexes. *Bacillus* bacteria function as microscopic nutrient miners by:

- Solubilizing phosphorus locked within soil minerals.
- Mobilizing potassium and zinc through mineral weathering and chelation.
- Producing high-affinity siderophores that sequester ferric iron (Fe^{3+}) for root uptake.
- Enhancing overall nutrient cycling through the enzymatic decomposition of organic matter.

4. A Natural Defender Against Plant Diseases

Instead of acting like conventional chemical pesticides, *Bacillus* employs multiple natural defense strategies simultaneously to protect crops against plant pathogens:

- **Producing Powerful Antimicrobial Compounds:** Many *Bacillus* species synthesize biologically active cyclic lipopeptides, including surfactins, iturins, and fengycins. These molecules target and damage the lipid membranes of harmful fungal and bacterial pathogens, preventing disease development.

- **Competing with Harmful Microorganisms:** Beneficial *Bacillus* strains rapidly colonize the rhizosphere—the narrow region surrounding plant roots—where they compete with pathogens for bioavailable nutrients and physical space. By occupying ecological niches before pathogens establish themselves, *Bacillus* creates a protective biological barrier around plant roots.
- **Activating Plant Immunity:** Through a process known as **Induced Systemic Resistance (ISR)**, *Bacillus* triggers internal plant defense pathways without causing host stress. Similar to how vaccines prepare the human immune system, ISR enables plants to respond more rapidly and aggressively when attacked by pathogens or insect pests.

Soil Restorative Health and Climate Mitigation

Soil health forms the foundation of sustainable agriculture, and *Bacillus* contributes significantly to structural and biological soil restoration:

- **Enhancing Organic Matter Decomposition:** Secreted extracellular hydrolases accelerate organic matter breakdown and nutrient mineralization.
- **Improving Soil Structure:** Bacterial exopolysaccharides (EPS) act as natural bio-adhesives, clumping micro-aggregates into structured soil macro-particles that improve water retention and prevent erosion.
- **Increasing Climate Resilience:** *Bacillus* supports plant survival during climate extremes by increasing drought tolerance, enhancing water-use efficiency, reducing oxidative stress, and maintaining root growth under adverse conditions.

Practical Field Application & Economic Advantages

Advances in microbiology, genomics, and biotechnology have accelerated the commercial deployment of *Bacillus*-based agricultural solutions across global crop systems. Today, *Bacillus* formulations are available as seed treatments, root dips, in-furrow drenches, granular biofertilizers, and liquid foliar sprays.

Modern genomic research has revealed that many *Bacillus* strains possess extensive biosynthetic gene clusters (BGCs) dedicated to producing antimicrobial metabolites, stress-protective molecules, plant growth promoters, and nutrient-mobilizing enzymes. These discoveries enable targeted strain selection for customized biostimulants and biopesticides that offer distinct advantages:

- **Environmental Benefits:** Reduces chemical pesticide and synthetic fertilizer reliance, decreases pollution, and preserves natural soil biodiversity.
- **Economic Benefits:** Lowers input costs, improves crop yields, optimizes nutrient-use efficiency, and reduces losses from disease outbreaks.
- **Agronomic Benefits:** Delivers stronger root networks, improves seed germination rates, and increases overall crop resilience.

Conclusion

The future of farming may not depend solely on bigger machines or stronger synthetic chemicals—it may depend on harnessing the extraordinary power of microscopic life. *Bacillus* exemplifies how nature itself offers elegant solutions to some of agriculture's greatest challenges. By promoting plant growth, improving nutrient availability, suppressing diseases, enhancing stress tolerance, and restoring soil health, this remarkable bacterium is helping reshape agriculture into a more sustainable and resilient enterprise.

Sometimes, the biggest revolution in farming begins with the smallest organism. And in that revolution, ***Bacillus* is leading the way.**

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FROM FARM TO PHARMA: COMMERCIAL CULTIVATION, VALUE ADDITION, AND MODERN PROCESSING OF HIGH-VALUE MEDICINAL CROPS

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Introduction

Key Takeaways for Farmers and Agri-Entrepreneurs

- **High Returns per Acre:** Shifting 10–20% of traditional farmland to medicinal crops can increase net farm income by 2x to 3x due to rising global demand for herbal pharmaceuticals and nutraceuticals.
- **Climate Resilience:** Many medicinal plants are naturally drought-tolerant, require fewer chemical pesticides, and thrive in marginal soils where traditional vegetables or cereals struggle.
- **Value Addition is Critical:** Selling raw, unprocessed herbs yields the lowest profit. Adopting simple post-harvest practices—such as scientific shade-drying, grading, and modern green extraction—multiplies commercial value.
- **Market Linkages:** Success relies on contract farming and meeting stringent quality standards to guarantee buyback from herbal formulations companies.

1. The Green Gold Rush in Agriculture

The global trade in medicinal and aromatic plants (MAPs) is experiencing unprecedented growth, driven by a consumer shift toward natural therapeutics, Ayurvedic formulations, and plant-based cosmetics. For decades, traditional horticulture has focused heavily on perishable fruit and vegetable crops, which often leave farmers vulnerable to sudden market price crashes, high cold-chain costs, and severe post-harvest losses.

Integrating medicinal crops into commercial farming systems offers a profitable, climate-resilient alternative. Unlike conventional crops that demand intensive chemical fertilizers and frequent irrigation, many medicinal plants are hardy species adapted to diverse agro-climatic zones. The true value of medicinal plants lies in the natural chemical compounds they produce, which serve as the foundation for modern medicines, skincare cosmetics, nutraceuticals, and herbal health products.

However, the transition from growing standard crops to cultivating medicinal plants requires a shift in mindset. Unlike cereals or vegetables, success is measured not only by physical biomass (total weight harvested) but also by "chemical yield"—the actual concentration and purity of the desired medicinal compound inside the plant.

2. Selecting the Right Crop: High-Value Options for Commercial Cultivation

Selecting the correct species depends on local soil economics, water availability, and regional market demand. Below are four high-potential medicinal crops suited for commercial cultivation, offering strong domestic and export potential.

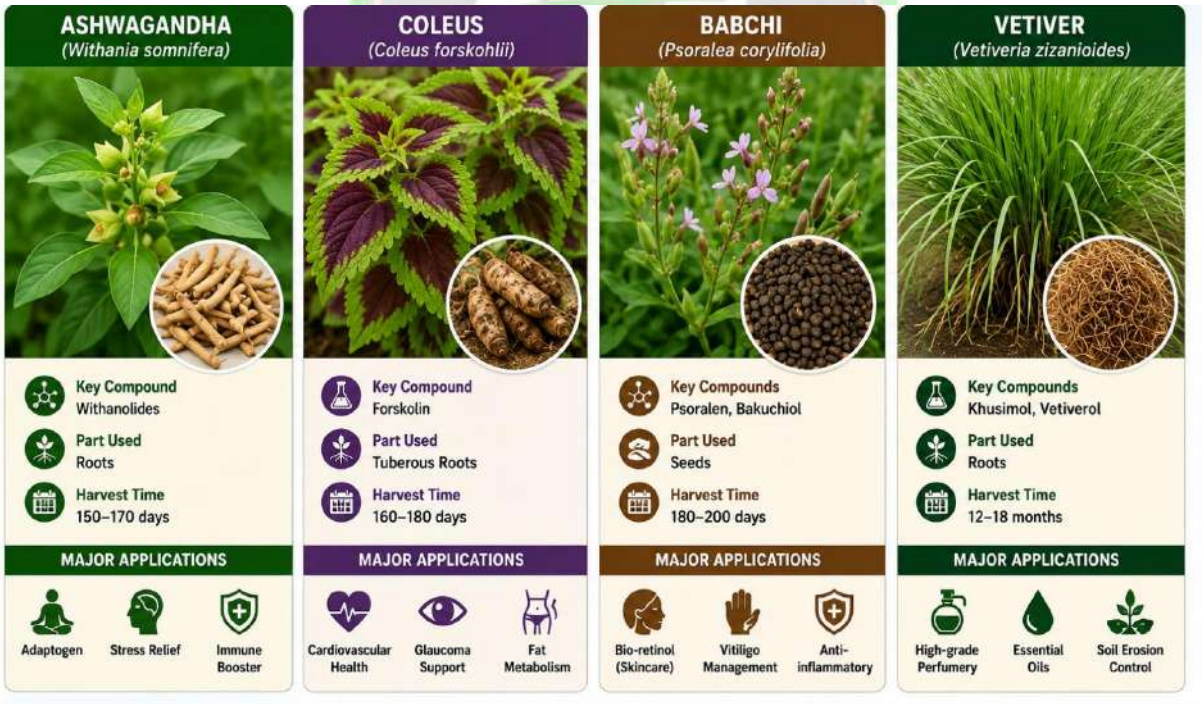


Figure 1: High-value medicinal crop collage showing Ashwagandha, Coleus, Babchi, and Vetiver in field conditions.

Table 1: Commercial Profile of Select High-Value Medicinal Crops

Crop Name & Botanical Name	Target Compound	Harvest Timeline	Economic Part Used	Major Market Application
Ashwagandha (*Withania somnifera*)	Withanolides	150–170 days	Roots	Adaptogen, stress relief, immune booster
Coleus (*Coleus forskohlii*)	Forskolin	160–180 days	Tuberous Roots	Cardiovascular health, glaucoma, fat metabolism
Babchi (*Psoralea corylifolia*)	Psoralen, Bakuchiol	180–200 days	Seeds	Bio-retinol (skincare), vitiligo, anti-inflammatory
Vetiver (*Vetiveria zizanioides*)	Khusimol, Vetiverol	12–18 months	Roots	High-grade perfumery, essential oils, soil erosion control

3. Good Agricultural Practices (GAP) for Maximum Chemical Yield

To sell directly to pharmaceutical buyers, growers must follow Good Agricultural Practices (GAP). Chemical toxicity from heavy metals or synthetic pesticides can result in the rejection of an entire harvest.

Soil Preparation & Organic Enrichment: Medicinal crops require well-drained loamy to sandy-loam soils; waterlogging triggers root rot in tuberous crops like *Coleus*. Deep ploughing followed by 2–3 harrowings creates a fine tilth. Incorporate 10–15 tons of well-decomposed Farm-Yard Manure (FYM) or vermicompost per hectare, enriched with bio-fertilizers like *Trichoderma viride* and *Pseudomonas fluorescens* (2–3 kg/ha) to naturally suppress soil-borne pathogens. Precision Irrigation and Nutritional Management

Precision Irrigation & Nutritional Stressing: While many medicinal plants survive under rainfed conditions, automated drip irrigation saves up to 40% water and prevents fungal diseases. Interestingly, mild water and nutritional stress during the maturation phase actually triggers the plant to synthesize more medicinal compounds as a natural defense mechanism. Over-fertilizing with synthetic nitrogen promotes lush green leaves but drastically lowers active chemical concentrations in roots and seeds.4. Post-Harvest Handling: Where 50% of the Value is Won or Lost

A farmer can grow an immaculate crop, but improper post-harvest handling will destroy the sensitive chemical compounds in days. Medicinal compounds are fragile and degrade quickly when exposed to direct sunlight, high heat, or moisture.

4. Post-Harvest Handling: Where 50% of the Value is Won or Lost

A farmer can grow an immaculate crop, but improper post-harvest handling will destroy sensitive chemical compounds in days. Medicinal phytochemicals degrade rapidly when exposed to direct sunlight, high heat, or stagnant moisture.

- **Stage-Specific Harvesting:** Timing is critical; harvesting two weeks early or late can reduce bioactive compound levels by half. Roots and tubers should be harvested during the dry season when leaves turn yellow, ensuring maximum alkaloid relocation to the roots. Seeds and fruits should be harvested when 70–80% of pods turn brown to prevent field shattering.
- **Scientific Washing & Shade Drying:** Immediately after harvest, roots must be washed with clean, pressurized running water—never soak roots in stagnant water, which initiates fermentation and leaches water-soluble compounds. Direct sun-drying destroys heat-sensitive oils. Crops must be spread thinly on raised wire-mesh racks in a well-ventilated shade shed, keeping moisture below 10% to prevent aflatoxin contamination. For large-scale operations, forced-air cabinet dryers at controlled temperatures (40°C–45°C) reduce drying time from weeks to hours while preserving natural color and chemical potency.

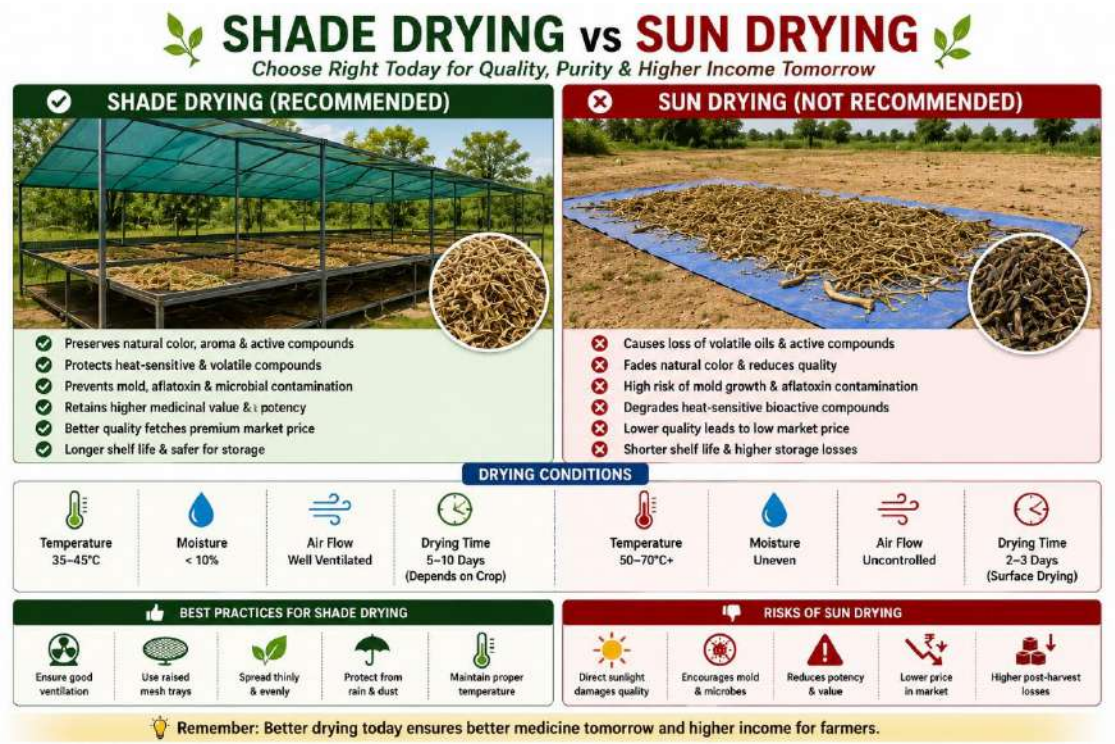


Figure 2: Side-by-side visual comparison of scientific wire-mesh shade drying versus traditional floor sun-drying.

5. Modern Value Addition: Moving Beyond Raw Biomass

To break away from fluctuating commodity prices, growers and Farmer Producer Organizations (FPOs) must transition toward **value addition**. Transforming raw herbs into standardized powders, essential oils, or enriched extracts significantly increases profit margins.

Why Traditional Extraction is Changing

Traditional solvent extraction is gradually being supplemented or replaced by greener extraction technologies in many high-value applications. Conventional boiling in harsh chemicals (like hexane or methanol) consumes massive amounts of energy, leaves behind unwanted solvent residues, and applies excessive heat that can damage delicate plant medicines.

The Rise of "Green Extraction" Technologies

Modern agricultural processing is rapidly adopting **Green Extraction**—eco-friendly methods that use less energy, avoid toxic solvents, and capture purer botanical compounds. For agricultural cooperatives and processing units, three practical technologies are leading this shift:

Microwave-Assisted Extraction (MAE): Uses targeted microwave energy to gently heat natural moisture inside plant cells, causing them to rupture and release medicinal oils into a clean

solvent. It dramatically reduces processing time from 6–8 hours down to 15–30 minutes, lowering utility costs while increasing extract yield.

Ultrasound-Assisted Extraction (UAE): Uses high-frequency sound waves to create microscopic cavitation bubbles that gently collapse against herbs, washing out active compounds without destructive heat. It is ideal for preserving heat-sensitive antioxidants and vitamins for premium cosmetic brands.

Supercritical Fluid Extraction (SFE): An advanced technique using pressurized carbon dioxide (CO_2) instead of liquid chemicals to extract essential oils and oleoresins. Following depressurization, carbon dioxide separates from the extract without leaving solvent residues, yielding a 100% pure product that meets stringent European and North American export standards.

6. Real-World Success: How Collectives are Winning with Medicinal Crops

The transition from traditional farming to medicinal horticulture is not just theoretical—across India, farmer collectives and self-help groups are already proving its commercial viability.

Case Study 1: Eliminating Middlemen through Collective Grading (Madhya Pradesh)

In the Neemuch and Mandsaur belts, individual farmers previously sold raw Ashwagandha roots to traders at ungraded, flat rates. Recognizing that pharmaceutical buyers pay premiums for thicker, high-alkaloid roots, a local FPO established a community sorting and solar-drying center. Farmers were trained to separate roots into three distinct commercial grades based on length, thickness, and fiber content. By bypassing middlemen and entering a direct contract farming agreement with a leading Ayurvedic formulations company, participating farmers increased net returns by 40% per kilogram simply through scientific grading.

Case Study 2: Women-Led SHGs Turning Erosion Grass into Luxury Aroma (Tamil Nadu / Kerala Border)

Vetiver (*Vetiveria zizanioides*) is traditionally planted along boundaries for soil erosion control. A women-led Self-Help Group (SHG) recognized the massive commercial value of the aromatic oil trapped in its roots. With support from horticultural extension officers, they installed a decentralized hydro-distillation unit. Instead of selling raw dried roots for ₹100/kg, they began extracting pure Vetiver essential oil. Commanding prices upwards of ₹20,000 to ₹25,000 per kilogram in aromatherapy markets, the SHG now supplies organic perfume manufacturers directly, transforming a humble boundary grass into year-round community income.



Figure 3: Photograph of a rural women-led SHG or FPO engaged in the sorting, grading, and decentralized processing of medicinal herbs.

7. Economics & Market Feasibility: A Farmer's Cost-Benefit Analysis

To demonstrate the financial viability of diversifying into medicinal horticulture, below is a comparative economic model for cultivating **Ashwagandha (*Withania somnifera*)** over a 6-month cycle on 1 hectare of land compared to a standard cereal crop.

Table 2: Indicative Cost-Benefit Analysis (1 Hectare Model)

Expense / Income Category	**Traditional Cereal Crop (e.g., Maize/Wheat)**	**High-Value Medicinal Crop (Withania somnifera)**
Seed / Planting Material Cost	₹3,500	₹2,500 (High-quality certified seed)
Land Prep & Organic Manure	₹8,000	₹15,000 (Heavy FYM / Bio-fertilizer focus)
Irrigation & Labor Costs	₹12,000	₹14,000 (Weeding and root harvesting labor)

Post-Harvest (Washing/Drying)	₹3,000	₹8,500 (Shade drying & grading)
Total Estimated Expenditure	**₹26,500**	**₹39,500**
Average Expected Yield	4,000 kg (Grain)	700 kg (Dry Root) + 50 kg (Seed)
Average Market Price	₹22 per kg	₹220 per kg (Root) + ₹150 per kg (Seed)
Gross Return	₹88,000	₹1,61,500
Net Profit per Hectare	**₹61,500**	**₹1,22,000**
Cost-Benefit Ratio	**1 : 2.3**	**1 : 3.08**

8. Challenges and the Way Forward

Despite the clear economic advantages, the medicinal plant sector faces structural hurdles that require organized action from agronomists, institutions, and farming communities:

1. **Lack of Quality Standardization:** Many local markets still trade herbs by physical appearance rather than chemical profiling. Extension programs must connect FPOs with university and analytical labs for quick **HPLC (High-Performance Liquid Chromatography)** testing to certify compound purity, empowering farmers to demand premium pricing.
2. **Volatile Market Linkages:** Growing medicinal crops without a confirmed buyer is risky. The most reliable path forward is **Contract Farming**, where pharmaceutical brands enter into formal buyback agreements with farmer cooperatives before sowing begins, guaranteeing a minimum support price.
3. **Establishing Rural Processing Hubs:** Instead of individual farmers selling raw, perishable biomass, government grants and agricultural subsidies should focus on establishing community-level processing hubs equipped with solar shade-dryers, pulverizers, and small-scale green extraction units.

The future of horticulture lies not just in feeding the population, but in healing it. By combining traditional agricultural wisdom with precision farming, collective post-harvest grading, and

modern green extraction technologies, medicinal plant cultivation can transform rural economies and secure a profitable, sustainable future for modern farmers.

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MAJOR DISEASES, PESTS AND COMPREHENSIVE PRODUCTION TECHNOLOGY OF MOTHBEAN (*VIGNA ACONITIFOLIA*)

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Abstract

Moth bean (*Vigna aconitifolia*), also known as mat bean, dew bean, or Turkish gram, is an exceptionally drought-tolerant, annual legume primarily cultivated in the arid and semi-arid regions of Rajasthan, Gujarat and MP. Renowned for its resilience to extreme heat and moisture stress, it serves as a vital source of high-quality dietary protein, carbohydrates, and essential minerals for rural populations, while its nitrogen-fixing capabilities and soil-binding growth habit prevent wind erosion and improve soil fertility. A comprehensive overview of the optimized production technology required to maximize moth bean yields, alongside management strategies for its major diseases and insect pests. Key agronomic practices include the selection of climate-resilient, high-yielding varieties (such as RMO-40, RMO-257, and CZM-45), precise sowing windows matching monsoon onset, optimal seed rates, and strategic nutrient management emphasizing phosphorus application and *Rhizobium* seed inoculation.the critical biotic constraints affecting the crop. Major fungal and viral diseases including Yellow Mosaic Virus (YMV), Macrophomina blight (dry root rot), and powdery mildew are evaluated along with their management protocols. The paper also addresses devastating insect pests such as whiteflies (the vector for YMV), jassids, aphids, and pod borers, emphasizing an Integrated Pest Management (IPM) approach that combines cultural, biological, and targeted chemical interventions. Adopting these comprehensive production technologies and crop protection

strategies can significantly bridge the yield gap, ensuring food and nutritional security in fragile arid ecosystems.

Key World: YMV, *Rhizobium,*

Introduction

Moth bean (*Vigna aconitifolia* (Jacq.) Marechal Syn. *Phaseolus aconitifolius* (2n = 2x=22) is an orphan legume and underutilised, drought tolerant minor grain legume crop which is belong to Fabaceae (Leguminosae) family. Commonly known as moth bean, mat bean, or dew bean, and Moth in Hindi. The crop is believed to have originated in the north-western arid and semi-arid regions of India, particularly in Rajasthan and adjoining areas, where it has been cultivated for centuries under rainfed conditions. Mothbean is a self-pollinated annual legume well adapted to hot, dry climates and poor soils, making it an important pulse crop for dryland agriculture. It is grown primarily for its nutritious seeds, fodder, and soil-improving properties through biological nitrogen fixation. Due to its excellent drought tolerance and adaptability, mothbean plays a significant role in ensuring food and nutritional security in the arid regions of India.





In terms of the nutritional aspects of moth bean, is good and inexpensive source of protein in cereal-based vegetarian diets among the people of developing nations. The protein content in moth bean seeds ranges from 20 to 24%. It is rich in the essential amino acids, lysine (6.63 g/100 g protein) and leucine (7.85 g/100 g) that are deficient in cereals and thus complements the amino acid profile of cereals. Among the total soluble protein present in moth, the glutelin fraction was found to be the highest at 63.93 g/100 g of total soluble protein, followed by glutelin, albumin and prolamin. Additionally, the total carbohydrate content in moth bean was found to range from 52 to 68%, the total fat ranged from 1.1 to 3.9% while the crude fiber content ranged from 3.9 to 4.5%. Moth bean is also found to be rich in minerals such as calcium, magnesium, iron, phosphorus and potassium as well as vitamins like niacin, thiamine and riboflavin

Mothbean is a warm-season pulse crop that is highly adapted to arid and semi-arid regions. It grows best in areas with a hot and dry climate and can tolerate prolonged drought conditions better than most other legumes. The optimum temperature for germination and growth ranges from 25°C to 35°C, while temperatures up to 45°C can be tolerated during the vegetative stage. Mothbean requires a well-distributed annual rainfall of about 200–500 mm, making it suitable for rainfed cultivation in dry regions. Due to its deep root system and efficient moisture utilization, mothbean is considered one of the most drought-resistant pulse crops and is widely cultivated in the hot desert and dryland areas of India, particularly in Rajasthan.

SOIL REQUIREMENTS:

Mothbean cultivated on wide range of soil but perform well in well-drained sandy loam to loamy sand soils with good aeration. The crop is highly suitable for light-textured soils of arid and semi-arid regions and can tolerate poor soil fertility better than many other pulse crops. However, heavy clay soils and waterlogged conditions should be avoided, as they adversely affect root growth and nodulation. The optimum soil pH ranges from 6.5 to 8.0, although mothbean can tolerate slightly alkaline soils up to pH 8.5. Proper drainage is essential for obtaining good plant growth and yield. Land preparation is done during sowing by ploughed one or two times, followed by harrowing. In dryland areas, minimum tillage is often practiced to conserve soil moisture. All crop residues, weeds, and stubbles should be removed from the field before sowing. The land should be levelled properly to ensure uniform distribution of rainwater and facilitate intercultural operations. Application of well-decomposed farmyard manure (FYM) at 5–10 tonnes per hectare during the final land preparation helps improve soil structure, moisture retention, and nutrient availability, resulting in better crop establishment and productivity.

SEED AND SOWING:

Seed are sown with onset of monsoon in June–July and under irrigated conditions in late June to mid-July. Seed rate of the crop as sole crop is 12–15 kg/ha, Broadcasting: 18–20 kg/ha and intercropping is 8–10 kg/ha. During the sowing seed must be treatment with Carbendazim 50 WP @ 2 g/kg seed or Thiram @ 3 g/kg seed and with Biofertilizer treatment of Rhizobium culture @ 25 g/kg seed or PSB (Phosphate Solubilizing Bacteria) @ 25 g/kg seed. Maintaining the spacing of 30-45 cm X 10-15cm plant to plant and row to row spacing respectively.

VARITIES:

Indian Council of Agricultural Research (ICAR) and the Central Arid Zone Research Institute (CAZRI) have developed several high-yielding, pest-resistant, and disease-resistant varieties to improve yields.

- **RMO-435 (Maru Bahar)**: It is a short-duration, maturing in 65–67 days, with an average seed yield of 6–6.5 quintals per hectare. It effectively escapes terminal drought. Its showed high resistance to major sucking pests like whiteflies and jassids, and possesses moderate tolerance to Mung bean Yellow Mosaic Virus (MYMV). Highly suitable for dry rainfed conditions in Rajasthan, Gujarat, and Maharashtra.
- **CAZRI Moth-2 (CZM-45)**: An early-maturing, drought-hardy variety that completes its cycle in just 60–65 days. It maintains high production stability even under low-rainfall scenarios Developed by CAZRI specifically for hyper-arid zones. Showcases field tolerance against key sucking pests and common leaf diseases prevalent in dry zones. Widely recommended across Rajasthan, Gujarat, Maharashtra, and Haryana.
- **CAZRI Moth-3 (CZM-99)**: Another elite, drought-hardy mutant cultivar engineered for erratic monsoon conditions. : Early-maturing variety (60–65 days) that yields remarkably well under wide-row crop management Bred with a tough genetic baseline to resist severe infestations from foliage-damaging pests and dry-zone viral outbreaks. Recommended for farmers in Rajasthan, Gujarat, Maharashtra, and Haryana.
- **RMO-257**: A widely accepted selection known for strong field performance. Early maturity 60–65 days, it ideal for late-season planting. High resistance to terminal drought stress and common localized viral variants like the Yellow Mosaic Virus (YMV). Extensively cultivated across the rainfed belts of Rajasthan and Gujarat.
- **TMV 1**: Regional high-yielding release. Average yields 1,060 kg/ha (10.6 q/ha). Shows strong tolerance to root rot and localized pulse viruses under humid-to-dry transition climates. Successfully adapted for rainfed RABI season cultivation in states like Tamil Nadu.
- **RMO-225 (also known as Marudhar or RMO-2251)** is a fast-growing, drought-tolerant. **Maturation Time is** 63 to 67 days. 6 to 7.5 quintals per hectare. Survives well in very dry and hot weather. Resists the yellow mosaic virus. It also fights off pests like white flies. The plant stays green until harvest, providing animal feed.

NUTRIENT MANAGEMENT

According to recommendations of SAU and ICAR institutions the required fertilizer dose of NPK for deficient soil is 20 kg/ha of N, 40 kg/ha P and 20 kg/ha K apply full dose at sowing

S. No.	Maturity Class	Duration (Days)	Key Target Varieties	Major Breeding Focus
1.	**Early Maturity**	60–65 Days	RMO-257, CAZRI Moth-2, CAZRI Moth-3E	scape terminal drought; Resistant to YMV
2.	**Medium Maturity**	70–90 Days	CZM 1, IPCMO 912	Well-distributed rainfall zones; Leaf-spot tolerance
3.	**Normal Maturity**	>90 Days	Moth Guj. 1 (MG-1), Jwala, IPCMO 880	Maximum protein traits; Uniform season yield

time. Application of micronutrients Zinc Sulphate @ 25 kg/ha in zinc-deficient soils and Sulphur @ 20 kg/ha improves yield and protein content.

IRRIGATION MANAGEMENT

Mothbean is primarily cultivated as a rainfed crop in arid and semi-arid regions due to its excellent drought tolerance and low water requirement. The crop generally requires 200–500 mm of rainfall during its growing season for satisfactory growth and yield. Under normal rainfed conditions, irrigation is usually not required. However, when grown under irrigated conditions or during prolonged dry spells, one to three irrigations may be beneficial depending on soil type and weather conditions.

The most critical stages for moisture availability are flowering and pod development. The first irrigation, if needed, may be given about 20–25 days after sowing, followed by additional irrigations during flowering and pod filling stages. Excessive irrigation and waterlogging should be strictly avoided, as mothbean is highly sensitive to stagnant water, which can lead to poor root growth, nodulation failure, and increased incidence of root rot and other diseases. Light and uniform irrigation is recommended to maintain optimum soil moisture without causing water stagnation. Proper drainage should always be ensured for healthy crop growth and maximum productivity.

MAJOR DISEASES AND THEIR MANAGEMENT

1. Yellow Mosaic Virus (YMV):

Yellow Mosaic Virus (YMV) is the most destructive viral disease of mothbean (*Vigna aconitifolia*) and considered major constraints in pulse production. The disease is caused mainly by **Mungbean Yellow Mosaic Virus (MYMV)** and **Mungbean Yellow Mosaic India Virus (MYMIV)**, which belong to the genus *Begomovirus* and family *Geminiviridae*. The disease is transmitted by the whitefly, *Bemisia tabaci*, and can cause yield losses 10% to 100% depending on the stage of infection and severity of disease. Mothbean is one of the important hosts of MYMV in India. It is widespred in the Mothbean growing area in India particularly Rajasthan, Gujarat, Haryana, Punjab, Uttar Pradesh, and Madhya Pradesh

Symptoms:



At Early stage produce small yellow specks appear on young leaves with Irregular yellow spots develop between veins which showed mosaic pattern of alternating green and yellow patches. During Advanced stage entire leaves become yellow and severe chlorosis and mottling, stunted plant growth, reduced flowering and pod formation produce small, malformed pods result in poor seed development and severely infected plants may remain barren. The virus survives in infected host plants and weeds. Whiteflies acquire the virus while feeding on infected plants and transmit it to healthy plants.

Favourable Conditions:

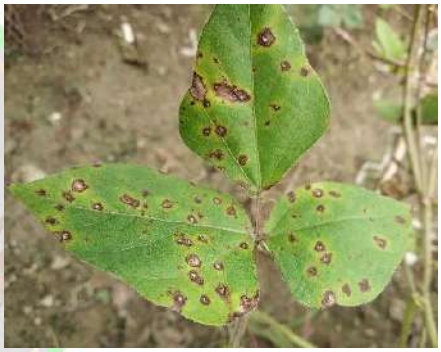
Temperature between 25–35°C, Warm and humid weather, low to moderate rainfall, high whitefly population, presence of alternate weed hosts and late sowing of the crop favour disease development.

Management of Yellow Mosaic Virus in Mothbean:

- **Cultural Control:** Use certified disease-free seed and sown the crop in recommended time. Remove the infected plants parts and burn them. Follow crop rotation with non-leguminous crops. Use the resistant and tolerant verity, the most effective and widely grown resistant or tolerant moth bean varieties in India include RMO-40, RMO-225 (Marudhar), RMO-257, and CAZRI Moth-1.

- **Mechanical Control:** Install yellow sticky traps @ 10–12 traps per hectare for monitoring and reducing whitefly populations.
- **Biological control**: YMV is control by using Control Natural Enemies of Whitefly eg. *Chrysoperla zastrowi sillemi* (Green lacewing), Ladybird beetles (*Coccinella septempunctata*), Predatory spiders, *Encarsia* spp. parasitoids whereas also use Biopesticides i.e. *Beauveria bassiana* 1.15 WP% @ 5 g/L water, *Lecanicillium lecanii* @ 5 g/L water, Neem oil 3–5 ml/L water and Azadirachtin 1500–3000 ppm @ 2–5 ml/L water.
- **Chemical control**: Foliar spray of Imidacloprid 600 FS @ 5 ml/kg seed or Imidacloprid 17.8 SL@ 0.3 ml/L water or Thiamethoxam25 WG@ 0.25 g/L water or Acetamiprid 20 SP@ 0.2–0.25 g/L water and Dimethoate30 EC1 ml/L water

2. Cercospora Leaf Spot (*Cercospora canescens*):



Cercospora leaf spot is an important fungal disease of mothbean (*Vigna aconitifolia*). The disease is caused by species of *Cercospora*, primarily *Cercospora canescens* and *Cercospora cruenta*. It is prevalent in most mothbean-growing regions of India, especially during the kharif season when warm temperatures and high humidity favour disease development.

Symptoms:

Leaf show small, circular to irregular brown spots initially appear on leaves later these spots enlarge and develop gray or ash-colored centres with reddish-brown margins and multiple lesions coalesce to form large necrotic patches. Severely infected leaves turn yellow and fall prematurely. Similarly on Stem and Petiole elongated brown to dark brown lesions develop on petioles and stems. On pod Small dark brown to black spots severely infected and pods may become shrivelled and produce poorly developed

Disease Cycle and favourable condition:

The fungus survives on infected crop debris, volunteer plants, and infected seed. During favourable conditions, spores are produced and spread through wind, rain splash, irrigation water, and farm operations. The disease is favoured in 25-30 °C temperature with 85% relative humidity and dense cropping with frequent rainfall favour the more incidence of disease.

Management of Cercospora Leaf Spot in Mothbean

- **Cultural Control:** Use certified disease-free seed. Follow crop rotation with non-leguminous crops for 2–3 years. Avoid continuous cultivation of mothbean and other pulse crops. Avoid excessive nitrogen fertilization.
- **Biological Control:** Seed are treated with Trichoderma *harzianum* @ 4–10 g/kg seed or *Trichoderma viride* @ 4–10 g/kg seed and *Pseudomonas fluorescens* @ 10 g/kg seed.
- **Chemical Control:** (Recommended) Seed Treatment with Carbendazim 50 WP @ 2 g/kg seed rr Thiram 75 WP @ 2–3 g/kg seed or Carbendazim + Thiram @ 3 g/kg seed. Foliar Spray of Carbendazim 12% + Mancozeb 63% WP @ 2.0 g per litre of water. Recommended Spray Schedule/ Copper Oxychloride 50 WP @ 3.0 g per litre of water and Propiconazole 25 EC @ 1.0 ml per litre of water and Azoxystrobin 23 SC @ 1.0 ml per litre of water

3. Root Rot (*Macrophomina phaseolina*):

Root rot is most important soil-borne diseases of mothbean. The disease is mainly caused by *Rhizoctonia bataticola* (syn. *Macrophomina phaseolina*). The disease is particularly severe under hot and dry conditions and can cause considerable yield losses range from 10–60% depending on disease severity.



Symptoms

At the Seedling Stage there is poor germination and brown lesions on roots near the soil surface which cause seedling mortality and at young stage Damping-off symptoms are seen in seedlings. During vegetative stage yellowing of lower leaves followed by drooping and wilting during hot hours where plant showed stunted growth. At very advanced stag sudden wilting and death of plants, tap root and lateral roots become dark brown to black. Bark of roots becomes shredded and easily detachable, numerous black microsclerotia appear on infected roots and plants can be easily pulled from the soil.

Disease Cycle

The fungus survives in soil and infected crop residues as microsclerotia. Under favourable conditions, the pathogen infects roots and collar regions. Infection spreads through soil, irrigation water, infected plant debris, and contaminated farm implements. The disease is

favoured under 30-35 °C low soil moisture and drought stress where soil is sandy and light-textured

Management of Root Rot in Mothbean

- **Cultural Control** Use certified healthy seed and follow crop rotation with cereals such as pearl millet, sorghum, or wheat for 2–3 years, Incorporate well-decomposed farmyard manure (FYM), Deep summer ploughing to expose fungal structures to sunlight.
- **Biological Control :** Seed Treatment of *Trichoderma harzianum* @ 4–10 g/kg seed or *Trichoderma viride* @ 4–10 g/kg seed or *Pseudomonas fluorescens* @ 10 g/kg seed is effective control for root rot **or the Soil Application of** *Trichoderma harzianum* @ 2.5 kg/ha mixed with 50 kg well-decomposed FYM and applied to soil before sowing.
- **Chemically Seed are Treated with** Carbendazim 50 WP @ 2 g/kg seed **or** Thiram 75 WP @ 3 g/kg seed **or** Carbendazim + Thiram @ 3 g/kg seed **or** Carboxin 37.5% + Thiram 37.5% WS @ 3 g/kg seed **and Soil Drenching with** Carbendazim 50 WP @ 1 g/L water or Copper Oxychloride 50 WP @ 3 g/L water **is effective control measure which is applied** around the root zone immediately after appearance of disease symptoms

4. **Powdery Mildew** (*Erysiphe polygoni*):

Erysiphe polygoni causing powdery mildew in mothbean.



Symptoms:

Small white powdery spots appear on the upper surface of older leaves. Spots enlarge rapidly and merge to form a white powdery coating. White fungal growth may spread to stems, petioles, flowers, and pods. Infected leaves become yellow, curl, dry, and fall prematurely. Severe infection gives the entire plant a whitish appearance. Plants become weak and stunted. Pod formation is reduced and seeds remain shrivelled.

Disease Cycle

The fungus survives on infected crop residues and alternate leguminous hosts. Primary infection occurs through airborne spores. Secondary spread occurs through conidia dispersed by wind. Disease spreads rapidly under favourable weather conditions where temperature **20–30°C** with Relative humidity: **60–80%**

Management of Powdery Mildew

- **Cultural Control** Use disease-free seed. Avoid excessive nitrogen fertilizer application. Sow the crop at the recommended time. Grow tolerant or resistant varieties whenever available.
- **Biological Control** Spray ***Trichoderma harzianum*** formulations as a preventive measure. Use ***Pseudomonas fluorescens*** as a foliar application to suppress disease development.
- **Chemical Control Foliar Spray of** Wettable Sulphur 80 WP @ 2.5–3.0 g/L water or Propiconazole 25 EC @ 1 ml/L water **or** Dinocap 48 EC @ 0.5 ml/L water. Start spraying immediately after the appearance of disease symptoms. Apply **2–3 sprays** at **10–15 day intervals** depending on disease severity. Ensure complete coverage of both leaf surfaces.

MAJOR INSECT PESTS AND THEIR MANAGEMENT

1. **Whitefly (*Bemisia tabaci*)**: It is widely distributed in arid and semi-arid regions and causes severe damage during hot and dry weather conditions.

Nature of Damage

Both nymphs and adults suck sap from leaves. Infested leaves become yellow, curl, and dry prematurely. Heavy infestation causes stunted plant growth. Honeydew excreted by whiteflies promotes the growth of sooty mold, reducing photosynthesis. Severe attack results in flower shedding, poor pod formation, and significant yield reduction. Acts as a vector of viral diseases in legumes.



Identification Adult:

Small, soft-bodied insects about 1–1.5 mm long. Yellowish body covered with white waxy powder. Wings are white and held roof-like over the body. Eggs tiny, oval, pale yellow eggs. Laid singly on the underside of young leaves. Nymph's Flat, oval, scale-like, greenish-yellow in color. Remain attached to the lower leaf surface and suck plant sap.

Favourable Conditions:

Temperature of 25–35°C. Dry weather with low to moderate humidity. Dense crop canopy and excessive nitrogen fertilization favour multiplication.

Management

- **Cultural Control**: Remove alternate weed hosts. Follow crop rotation with non-host crops. Remove heavily infested leaves and destroy them. Install yellow sticky traps (10–15 traps/ha) to monitor and reduce adult populations.
- **Biological Control** Conserve natural enemies such as *Chrysoperla carnea* (green lacewing), *Coccinella septempunctata* (ladybird beetle), *Encarsia formosa* (parasitoid) Avoid unnecessary broad-spectrum insecticide applications that may kill beneficial insects.
- **Chemical Control:** When the pest population reaches the economic threshold level, spray any one of the Imidacloprid 17.8 SL @ 0.3 ml/L water or Thiamethoxam 25 WG @ 0.25 g/L water or Acetamiprid 20 SP @ 0.2 g/L water or Dimethoate 30 EC @ 1.0 ml/L water

2. Aphid (*Aphis craccivora*)

Aphid (*Aphis craccivora* Koch), commonly known as the cowpea aphid.

Nature of Damage

Aphids damage mothbean plants by sucking cell sap from leaves, shoots, flowers, and pods. Dense colonies on the underside of leaves and tender shoots. Heavy infestation causes lead to leaf curling, twisted, and distorted. Sticky honeydew deposits on plant surfaces due to that black sooty mold growth on leaves occurs. Poor plant vigor and reduced pod formation.

Identification Adult Aphids



Small, soft-bodied insects measuring about 1.5–2.5 mm in length. Color varies from dark brown to black. Pear-shaped body with long legs and antennae. Wingless and winged forms may occur. **Nymph** Smaller than adults. Similar in appearance but lighter in colour. Found in colonies on young plant parts.

Favourable Conditions:

Temperature: 20–30°C. Low to moderate rainfall. Dry weather with high humidity. Excessive nitrogen fertilization. Dense crop canopy.

Management:

- **Biological Control** Several natural enemies effectively suppress aphid populations:
  - ✓ **Predators:** Ladybird beetles (*Coccinella septempunctata*, *Cheilomenes sexmaculata*) **Green** lacewing (*Chrysoperla zastrowi sillemi*) Hoverfly larvae (*Syrphus* spp.) **Parasitoids:** *Aphidius colemani Lysiphlebus* spp.

- ✓ **Entomopathogenic Fungi:** *Beauveria bassiana Verticillium lecanii* (currently known as *Lecanicillium lecanii*) *Metarhizium anisopliae*
- ✓ **Recommended Biopesticides** Spray *Beauveria bassiana* @ 5 g or 5 ml per litre of water. Spray *Lecanicillium lecanii* @ 5 g per litre of water during humid conditions.

- **Chemical Control**
  - ✓ When aphid colonies first appear Spray **Imidacloprid 17.8 SL @ 0.3 ml/L water**, or Spray **Thiamethoxam 25 WG @ 0.25–0.30 g/L water**.
  - ✓ Under severe infestation: Spray **Dimethoate 30 EC @ 1 ml/L water**. Ensure thorough coverage of the lower leaf surface where aphids congregate

1. **Jassid (*Empoasca kerri*)** Commonly known as the green leafhopper.

Nature of Damage

Both nymphs and adults suck plant sap from leaves and tender shoots. Continuous feeding causes: Yellowing of leaf margins. Leaf curling and cupping. "Hopper burn" symptoms. Drying and brittleness of leaves. Stunted plant growth. Reduced flowering and pod setting. Yield loss under severe infestation.



Symptoms of Infestation Yellow discoloration along leaf margins. Downward curling and cupping of leaves. Browning and drying of leaf edges. Leaves become brittle and may fall prematurely. Severe infestation leads to hopper burn and poor crop vigor.

Identification Adult Small, wedge-shaped, green insects about 2.5–3.0 mm long. Highly active and fly away when disturbed. Usually found on the lower surface of leaves. **Nymph** Green, wingless, and smaller than adults. Move sideways rapidly on leaves. Feed on the underside of leaves.

Management of Jassid in Mothbean

- **Biological Control**
  - **Predators** Ladybird beetles (*Coccinella septempunctata*) Green lacewing (*Chrysoperla zastrowi sillemi*) **Spiders**
  - **Biopesticides** Neem oil @ 3–5 ml/L water. Azadirachtin (1500–3000 ppm) @ 2–5 ml/L water. *Lecanicillium lecanii* @ 2–5 g/L water.

- **Chemical Control-** Imidacloprid 17.8 SL @ 0.3 ml/L water Thiamethoxam 25 WG @ 0.25 g/L water Methyl-O-Demeton 25 EC @ 750 ml/ha

2. Pod Borer (*Helicoverpa armigera*)



Pod borer (*Helicoverpa armigera* Hubner), also known as gram pod borer

Nature of Damage:

The larvae initially feed on leaves, flower buds, and flowers. Later instars bore into developing pods and feed on seeds. Usually, the larva inserts only its head inside the pod while the remaining body remains outside.

Symptoms of Infestation: Circular holes on pods. Damaged flowers and flower buds. Presence of excreta (frass) near pod holes. Partially eaten or hollow seeds. Visible caterpillars on plants during early morning and evening. Premature dropping of flowers and pods. Reduced seed quality and yield.

Identification Adult Moth:

Medium-sized moth with a wingspan of 30–40 mm. Forewings are yellowish-brown with dark markings. Hind wings are pale with a broad dark band along the margin. Active during evening and night hours. **Larva (Caterpillar):** Newly hatched larvae are yellowish white. Mature larvae are green, brown, or black with longitudinal stripes. Body is covered with small hairs. Larvae grow up to 35–40 mm in length. **Pupa:** Brown-colored pupa found in soil at a depth of 5–10 cm.

Management

Install bird perches (25–30 per hectare) to encourage predatory birds. Hand collection and destruction of egg masses and larvae during early infestation. Installation of pheromone traps @ 5 traps/ha for monitoring. Use pheromone traps @ 10–12 traps/ha for mass trapping.

- **Biological Control:**
  - ✓ **Predators** Ladybird beetles (*Coccinella septempunctata*) Green lacewing (*Chrysoperla zastrowi sillemi*) Spiders Predatory bugs
  - ✓ **Parasitoids** *Trichogramma chilonis* (egg parasitoid) *Campoletis chlorideae* (larval parasitoid)

- ✓ **Microbial Control** *Helicoverpa armigera* Nucleopolyhedrovirus (HaNPV) @ 250 LE/ha. *Bacillus thuringiensis* (Bt) formulations @ 1–2 kg/ha. *Beauveria bassiana* @ 5 g/L water.

- **Chemical Control:**

Chlorantraniliprole 18.5 SC @ 0.3 ml/L water Emamectin Benzoate 5 SG @ 0.4 g/L water Spinosad 45 SC @ 0.3 ml/L water Indoxacarb 14.5 SC @ 1 ml/L water

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ANTIOXIDANTS IN PLANTS: PROTECTING CROPS FROM OXIDATIVE STRESS AND CLIMATE CHANGE

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Abstract

Plants produce reactive oxygen species (ROS) as inherent by-products of respiration and photosynthesis. Oxidative stress is induced by the accumulation of ROS beyond normal levels in the presence of adverse environmental conditions, including drought, salinity, extreme temperatures, heavy metal toxicity, ultraviolet radiation, and pathogen attack. Oxidative stress destroys lipids, proteins, nucleic acids, and cellular membranes. Plants have developed an effective antioxidant defense system that includes enzymatic antioxidants, such as superoxide dismutase, catalase, peroxidases, and glutathione reductase, as well as non-enzymatic antioxidants, such as ascorbic acid, glutathione, carotenoids, tocopherols, and phenolic compounds, to mitigate these effects. These antioxidants detoxify ROS, protect cellular structures, maintain cellular redox balance, and improve stress tolerance. This article emphasises the origins, categorisation, mechanisms, and roles of antioxidants, their function in alleviating environmental stressors, techniques for assessing antioxidant efficacy, and plant-based foods abundant in antioxidants. The breeding, biotechnology, and crop management of climate-resilient crop varieties require an understanding of antioxidant defense mechanisms to promote sustainable agriculture and global food security.

Keywords: abiotic stress; reactive oxygen species (ROS); oxidative stress; climate-resilient crops

Introduction

Reactive oxygen species (ROS), such as superoxide anion ($O_2^{\bullet -}$), hydroxyl radical (•OH), hydrogen peroxide (H_2O_2), and singlet oxygen ($^1O_2$), are constantly produced by plants as

byproducts of photosynthesis and respiration. ROS are essential signalling molecules under normal circumstances, but environmental stressors, such as drought, salinity, extreme temperatures, heavy metals, UV radiation, and pathogen attack, induce excessive ROS accumulation. Ultimately, oxidative stress is induced when the antioxidant defense capacity of a plant is surpassed, resulting in damage to lipids, proteins, nucleic acids, and cell membranes. This ultimately reduces plant growth, productivity, and survival.

Plants have developed a remarkably effective antioxidant defense mechanism, consisting of both enzymatic and non-enzymatic antioxidants, to safeguard cells from oxidative harm induced by reactive oxygen species (ROS). Superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), guaiacol peroxidase (GPX), monodehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR), and glutathione reductase (GR) are examples of enzymatic antioxidants. Non-enzymatic antioxidants, such as ascorbic acid, glutathione, carotenoids, tocopherols, and phenolic compounds, also play important roles in scavenging excess ROS and maintaining cellular redox balance. Plants detoxify reactive oxygen species (ROS), reduce oxidative damage, and increase their resistance to environmental stresses as a result of a robust antioxidant system. Thus, improving antioxidant capacity through breeding, biotechnology, and crop management is an important strategy for developing climate-resilient crop varieties.

Antioxidants: Definition and Chemical Properties

Antioxidants are compounds that inhibit or diminish the oxidation of other substances by neutralising reactive oxygen species (ROS) and free radicals. They function as electron donors, transforming detrimental reactive substances into more stable and less harmful molecules.

Definitions

Chemical Definition: A substance that opposes oxidation or inhibits reactions promoted by oxygen or peroxides.

Biological Definition: Natural or synthetic substances that prevent or delay oxidative damage to living tissues.

Institute of Medicine Definition: A substance that significantly reduces the harmful effects of reactive oxygen or nitrogen species on normal physiological function.

Chemical Properties and Functions

- ✓ Provide electrons to neutralise free radicals

- ✓ Oxidation protects cellular components.
- ✓ Prevent electron transfer between oxygen and organic molecules
- ✓ They stabilise free radicals and stop chain reactions.
- ✓ Shield lipids, proteins, DNA, and cell membranes from oxidative damage.
- ✓ Antioxidants have a limited ability to neutralise free radicals, necessitating continuous replenishment.

Role and Functions of Antioxidants

Antioxidants safeguard cells against oxidative harm by counteracting free radicals and reactive oxygen species (ROS). They constitute a vital defense mechanism that preserves cellular integrity and standard physiological operations.

Major Functions of Antioxidants

- ✓ Removal of free radicals and reactive oxygen species (ROS).
- ✓ It reduces superoxide radicals, hydroxyl radicals, and various detrimental oxidants.
- ✓ Reduce lipid peroxidation and safeguard cellular membranes
- ✓ Safeguard DNA against oxidative harm and genetic alterations
- ✓ Mitigating protein oxidation and preserving enzymatic function.
- ✓ Chelates metallic ions such as iron (Fe) and copper (Cu), thereby diminishing the formation of reactive oxygen species (ROS).
- ✓ Suppresses the enzymes that facilitate free radical production.
- ✓ Stimulate and bolster endogenous antioxidant defense enzymes
- ✓ Augment the resilience of flora and fauna to ecological pressures.
- ✓ Enhance immune system and foster comprehensive cellular well-being

Types of antioxidants and their role

Antioxidants protect cells from damage caused by reactive oxygen species (ROS) and free radicals. They are classified into three main types.

Primary antioxidants: These inhibit the generation of new free radicals by transforming chemically reactive molecules into less detrimental compounds. Metal-binding proteins, superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and glutathione reductase are examples of such compounds.

Secondary antioxidants neutralise or scavenge free radicals, thereby preventing chain reactions that damage cells. Examples include vitamin C (ascorbic acid), vitamin E (α-tocopherol), β-

carotene, uric acid, bilirubin, and methionine.

Tertiary antioxidants: These repair biomolecules are damaged by free radicals. Examples include DNA repair enzymes and methionine sulfoxide reductases.

Antioxidants are categorised as water-soluble (hydrophilic) and fat-soluble (lipophilic). Hydrophilic antioxidants shield the cytoplasm of cells, whereas lipophilic antioxidants protect cell membranes against lipid peroxidation. Reactive oxygen species, including superoxide radicals, hydroxyl radicals, and hydrogen peroxide, are continuously produced during standard metabolic processes, such as respiration and photosynthesis. An overabundance of reactive oxygen species can harm lipids, proteins, and DNA, causing cellular degeneration and senescence. Antioxidants constitute a cohesive defence mechanism that counteracts reactive oxygen species, averts oxidative harm, and preserves cellular vitality and physiological operations.

Free radicals and ROS

Reactive oxygen species (ROS), including superoxide anions ($O_2^{\bullet -}$), hydroxyl radicals (•OH), and hydrogen peroxide (H_2O_2), are inherently generated during respiration, photosynthesis, and various metabolic activities. An overabundance of ROS can harm lipids, proteins, DNA, and cellular membranes, resulting in stunted growth, ageing, and cellular mortality.

Importance of antioxidants

Antioxidants form a vital defense system that neutralises ROS, prevents oxidative damage, maintains cellular integrity, and enhances stress tolerance. By protecting biomolecules and regulating cellular functions, antioxidants play a crucial role in plant growth, productivity, and survival under adverse environmental conditions.

Antioxidative defence system in plants

Reactive oxygen species (ROS) are continuously generated by plants during normal metabolism, with chloroplasts, mitochondria, and peroxisomes as the primary sources. ROS production increases in response to stress conditions, including drought, salinity, extreme temperatures, and heavy metal toxicity, resulting in the oxidative damage. Plants have a sophisticated antioxidative defense system that includes both non-enzymatic and enzymatic antioxidants.

Non-Enzymatic Antioxidants: These include

- ✓ Ascorbic acid (vitamin C): scavenges ROS and protects cellular components.
- ✓ Glutathione (GSH): maintains the cellular redox balance and detoxifies ROS.
- ✓ Tocopherols (Vitamin E) protect membrane lipids from oxidative damage.
- ✓ Carotenoids: quench singlet oxygen and protect the photosynthetic apparatus.
- ✓ Phenolic compounds: scavenge free radicals and chelate metal ions.

Enzymatic Antioxidants: Key antioxidant enzymes include the following:

- ✓ Superoxide dismutase (SOD): converts superoxide radicals into hydrogen peroxide.
- ✓ Catalase (CAT): breaks down hydrogen peroxide into water and oxygen.
- ✓ Guaiacol peroxidase (GPX): detoxifies hydrogen peroxide and organic peroxides.
- ✓ Ascorbate peroxidase (APX): removes hydrogen peroxide using ascorbate.
- ✓ Monodehydroascorbate reductase (MDHAR) and dehydroascorbate reductase (DHAR) regenerate ascorbate.
- ✓ Glutathione reductase (GR): maintains glutathione in its reduced and active form.

Antioxidants under Drought Stress

Plants produce relatively low levels of reactive oxygen species (ROS) under normal conditions. Drought stress increases ROS production, including superoxide radicals ($O_2^{\bullet -}$), hydrogen peroxide (H_2O_2), and hydroxyl radicals (•OH), which can cause oxidative stress and cell damage. Drought-induced stomatal closure restricts carbon dioxide access, impairs photosynthesis, and increases electron leakage in chloroplasts, ultimately leading to elevated ROS production. Increased ROS concentrations lead to lipid peroxidation, chlorophyll breakdown, protein oxidation, and membrane impairment, ultimately impacting plant growth and yield.

Plants use antioxidant defense systems to counteract these negative effects. Drought-resistant flora typically demonstrates elevated antioxidant enzyme activities, including superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), glutathione reductase (GR), and peroxidases (POD), as well as heightened concentrations of non-enzymatic antioxidants, such as ascorbate (ASA), glutathione (GSH), tocopherols, and carotenoids. Research indicates that drought-resistant crop varieties exhibit reduced reactive oxygen species (ROS) accumulation and enhanced antioxidant capabilities compared to susceptible varieties. Consequently, a robust antioxidant defense mechanism is essential for safeguarding plants against oxidative harm caused by drought and for improving their resilience to stress.

Antioxidants under environmental stresses

Environmental factors, such as salinity, cold temperatures, drought, and heavy metal toxicity, interfere with cellular metabolism and increase the generation of reactive oxygen species (ROS), resulting in oxidative stress. Plants activate both enzymatic and non-enzymatic antioxidant defense systems to mitigate damage.

Salinity Stress: Salt stress elevates the generation of reactive oxygen species by impairing photosynthesis, respiration, and cellular electron transport. An overabundance of reactive oxygen species leads to lipid peroxidation, protein degradation, and membrane impairment. Salt-resistant flora typically sustains elevated concentrations of antioxidants, such as ascorbate (AsA), glutathione (GSH), and various antioxidant enzymes such as SOD, CAT, APX, GPX, and GR, which mitigate oxidative harm and enhance salt resilience.

Chilling Stress: Lower temperatures impede photosynthesis and respiration, resulting in the overproduction of reactive oxygen species. Chilling-induced oxidative stress leads to membrane impairment, protein oxidation, and diminished photosynthetic efficacy. Elevated activities of SOD, CAT, APX, GR, MDHAR, and DHAR, coupled with higher concentrations of ASA, GSH, carotenoids, and tocopherols, help safeguard plants from chilling damage. Chilling-resistant varieties typically exhibit more robust antioxidant mechanisms compared to susceptible varieties.

Metal toxicity: Heavy metals, such as aluminium, cadmium, copper, arsenic, and nickel, stimulate the generation of reactive oxygen species by interfering with cellular metabolism and photosynthesis. An overabundance of reactive oxygen species damages lipids, proteins, DNA, and cellular membranes. Plants react by augmenting antioxidant enzymes (SOD, APX, GPX, POD, GR) and elevating non-enzymatic antioxidants, such as glutathione and ascorbate. Metal-resistant genotypes generally demonstrate enhanced antioxidant mechanisms and reduced oxidative harm. In general, improved antioxidant activity serves as a crucial adaptive strategy that allows plants to endure environmental pressures by preserving cellular redox equilibrium and safeguarding essential biological processes.

Antioxidants under UV-B Radiation and Pathogen Stress

UV-B radiation hinders photosynthesis, diminishes CO_2 uptake, and escalates the production of reactive oxygen species (ROS), resulting in oxidative stress. An overabundance of ROS can harm chlorophyll, proteins, lipids, and cellular membranes. To safeguard themselves, plants initiate antioxidant defense mechanisms that include enzymatic antioxidants, such as

superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and ascorbate peroxidase (APX), as well as non-enzymatic antioxidants, such as ascorbic acid (AsA), glutathione (GSH), and carotenoids. These antioxidants help preserve cellular redox equilibrium and mitigate oxidative damage caused by UV-B exposure. Plants with elevated antioxidant capacity typically demonstrate enhanced resilience to UV-B stress.

Pathogen Attack: Pathogen invasion induces a swift oxidative surge marked by the generation of reactive oxygen species, including superoxide radicals and hydrogen peroxide. These molecules are crucial for signalling in plant defence, yet they may cause cellular damage when generated in excess. To modulate ROS concentrations, plants augment the functions of antioxidant enzymes such as SOD, CAT, POD, and APX. Enhanced antioxidant activity helps detoxify excess reactive oxygen species, mitigate oxidative damage, and fortify plant defence mechanisms. Plants that exhibit disease resistance frequently possess more robust antioxidant mechanisms compared to their susceptible counterparts, enhancing their defence against pathogens.

Methods for Assessing Antioxidant Potential in Plants

The antioxidant potential of plants can be evaluated using both in vitro and in vivo assays. These methods help determine the ability of plant extracts and phytochemicals to neutralise reactive oxygen species (ROS) and protect against oxidative damage.

1. In Vitro Assays: In vitro methods are widely used to screen antioxidant activity and understand the mechanisms of action of plant antioxidants. They are broadly classified into:

Hydrogen atom transfer (HAT)-based assays: HAT-based assays assess the capacity of antioxidants to transfer hydrogen atoms and mitigate free radicals by obstructing oxidative chain reactions. Prevalent techniques include the ORAC, TRAP, and β-carotene bleaching assays, which evaluate the hydrogen-donating and free radical-neutralising abilities of antioxidants. Electron transfer (ET)-based assays: ET-based assays assess the capacity of antioxidants to donate electrons and neutralise free radicals or oxidising agents, indicating their reducing efficacy. Prevalent techniques include TEAC, FRAP, DPPH, superoxide anion, hydrogen peroxide, and nitric oxide radical-scavenging assays, as well as the total phenolic content (TPC) assay, which quantifies phenolic compounds that enhance antioxidant activity.

2. In Vivo Assays

In vivo techniques evaluate antioxidant efficacy in living organisms by quantifying

antioxidant enzymes and oxidative stress indicators before and after stress exposure. Common in vivo metrics include Lipid Peroxidation (LPO), Reduced Glutathione (GSH), Glutathione Peroxidase (GPx), Glutathione Reductase (GR), Glutathione-S-Transferase (GST), Superoxide Dismutase (SOD), Catalase (CAT), Total Protein Content, Lactate Dehydrogenase (LDH), Ornithine Decarboxylase (ODC), Glucose-6-Phosphatase (G6P), and Creatine Phosphokinase (CPK). These techniques yield significant insights into the antioxidant potential of flora and assist in recognising stress-resistant species, assessing plant vitality, and formulating approaches to bolster resilience against environmental challenges.

Antioxidant Content in Plants

Vegetation serves as an abundant reservoir of natural antioxidants that safeguard against oxidative stress and enhance well-being. Prominent antioxidants include sulfur compounds (garlic, onion), anthocyanins (berries, grapes), β-carotene (carrot, pumpkin, spinach), catechins and flavonoids (tea, citrus, apple), lutein (leafy greens), lycopene (tomato, watermelon), polyphenols (herbs), vitamins C and E (fruits, vegetables, nuts, and seeds), and mineral antioxidants such as zinc, copper, manganese, and selenium. A varied plant-centric diet offers these synergistic antioxidants, which together counteract reactive oxygen species (ROS), safeguard cellular structures, and promote the health of both plants and humans.

Major dietary source of Antioxidants

S.No.	Functional Group	Antioxidants	Major Sources
1	Vitamins	Vitamins A, B, C, E, and K	Fruits, vegetables, citrus fruits, dairy products, fish, and meat
2	Alkaloids	Capsaicinoids, Berberine, Caffeine	Chilli, coffee, tea, medicinal herbs, and spices
3	Polyamines	Putrescine, Spermidine, Spermine	Peas, apples, citrus fruits, spices, liver, and meat
4	Phytosterols	Campesterol, Stigmasterol	Vegetables, nuts, seeds, and plant oils
5	Ferulic Acid Esters	Oryzanol	Rice bran oil

6	Isoprenoid Derivatives	Carotenoids (β-carotene, lycopene, lutein)	Carrot, tomato, pumpkin, mango, and palm oil
7	Benzopyran Derivatives (Polyphenols/Flavonoids)	Proanthocyanins, Anthocyanins, Catechins, Flavonols, Lignans, Flavones, Isoflavones, Gallic Acid	Grapes, apples, pomegranate, banana, pineapple, brinjal, cucumber, olive oil, green tea, beverages, and oilseeds
8	Minerals	Zinc, Selenium, Copper, Manganese	Vegetables, meat, eggs, dairy products, nuts, and whole grains

Importance of antioxidant-rich foods

Antioxidant-rich foods help to neutralise reactive oxygen species (ROS) and free radicals, thereby lowering oxidative stress and protecting cells from damage. Consuming fruits, vegetables, whole grains, nuts, seeds, herbs, and antioxidant-rich beverages on a regular basis helps living organisms improve their health, immunity, and reduce their risk of chronic diseases and adapt to stress.

Conclusion

Reactive oxygen species (ROS) are unavoidable byproducts of plant metabolism, but excessive accumulation during environmental stresses causes oxidative damage, limiting plant growth and productivity. Plants overcome this challenge by utilising a coordinated antioxidant defense system that includes both enzymatic and non-enzymatic antioxidants, which maintain cellular redox balance and protect vital biomolecules. Increasing antioxidant capacity through breeding, biotechnology, and improved crop management is critical for improving stress tolerance, developing climate-resilient crop varieties, and ensuring long-term agricultural production under changing environmental conditions.

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ENDOGENOUS RETROVIRUSES IN AQUATIC ANIMALS: HIDDEN VIRAL FOSSILS AND THEIR SIGNIFICANCE IN AQUACULTURE

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Abstract

Endogenous retroviruses (ERVs) are ancient viral sequences that have become permanently integrated into the genomes of vertebrates through infection of germ cells by ancestral retroviruses. Unlike exogenous retroviruses, ERVs are inherited across generations as part of the host genome and represent molecular evidence of historical host–virus interactions. Recent advances in genomic technologies have identified numerous endogenous retrovirus-like elements in aquatic animals, including teleost fishes such as zebrafish, Atlantic salmon, rainbow trout, medaka, and pufferfish. Although most ERVs have lost their ability to produce infectious viral particles due to accumulated mutations, they continue to influence genome evolution, gene regulation, embryonic development, and immune responses. In aquatic animals, ERVs are increasingly recognized for their potential roles in antiviral defence, adaptation to environmental stress, and modulation of host immunity. Their study also provides valuable insights into host–virus co-evolution and the evolutionary history of fish genomes. Furthermore, ERVs have emerged as promising molecular markers for genomic selection, disease resistance, and health monitoring in aquaculture. Continued research using next-generation sequencing, transcriptomics, and genome-editing technologies is expected to reveal the functional significance of these viral elements and their applications in sustainable aquaculture. Understanding endogenous retroviruses will contribute to improved fish health management, selective breeding programmes, and the development of disease-resilient aquaculture systems.

Keywords: Endogenous retroviruses, Aquatic animals, Fish genomics, Retroviridae, Genome evolution, Host–virus co-evolution, Disease resistance, Aquaculture.

Introduction

Aquaculture is one of the fastest-growing food-producing sectors in the world and plays a vital role in ensuring global food security. However, viral diseases continue to pose significant challenges to sustainable aquaculture by causing severe economic losses and reducing fish productivity. While most studies focus on viruses that actively infect and cause disease, scientists have discovered that some viruses have become a permanent part of animal genomes through millions of years of evolution. These ancient viral remnants are known as **Endogenous Retroviruses (ERVs)**.

Endogenous retroviruses originate from retroviruses that infected the reproductive cells of ancestral animals. Once integrated into the DNA of germ cells, these viral sequences became heritable and were transmitted to successive generations. Consequently, ERVs serve as molecular fossils that preserve evidence of ancient viral infections within the genome. Although most endogenous retroviruses are no longer capable of producing infectious viral particles, they continue to influence gene regulation, immune responses, embryonic development, and genome evolution.Recent advances in whole-genome sequencing have identified numerous endogenous retrovirus-like elements in aquatic animals, particularly teleost fishes. Their discovery has transformed our understanding of the relationship between viruses and their hosts. Rather than being viewed solely as disease-causing agents, viruses are now recognized as important contributors to genome evolution and biological innovation. In aquaculture, understanding endogenous retroviruses may provide new opportunities for improving disease resistance, selective breeding, and fish health management. (FAO, 2024; ICTV, 2023) (Johnson, 2019; Feschotte & Gilbert, 2012)

What are endogenous retroviruses?

Endogenous retroviruses are inherited viral DNA sequences permanently integrated into the chromosomes of an organism. They originate from retroviruses belonging to the family **Retroviridae**, which possess RNA as their genetic material. During infection, the viral RNA is converted into DNA by the enzyme **reverse transcriptase**. The newly synthesized viral DNA is then inserted into the host chromosome by another viral enzyme called **integrase**.If this integration occurs in somatic cells, it affects only the infected individual. However, when retroviruses infect sperm or egg cells, the viral DNA becomes part of the host's hereditary genome and is transmitted to future generations. Over millions of years, these viral sequences

accumulate mutations that eliminate their ability to produce infectious viruses. Nevertheless, many ERVs retain regulatory elements and protein-coding regions that continue to influence host biological processes.Thus, endogenous retroviruses represent ancient viral infections that have become permanent components of the genomes of vertebrates, including several aquatic animals. (Coffin et al., 1997; Johnson, 2019)

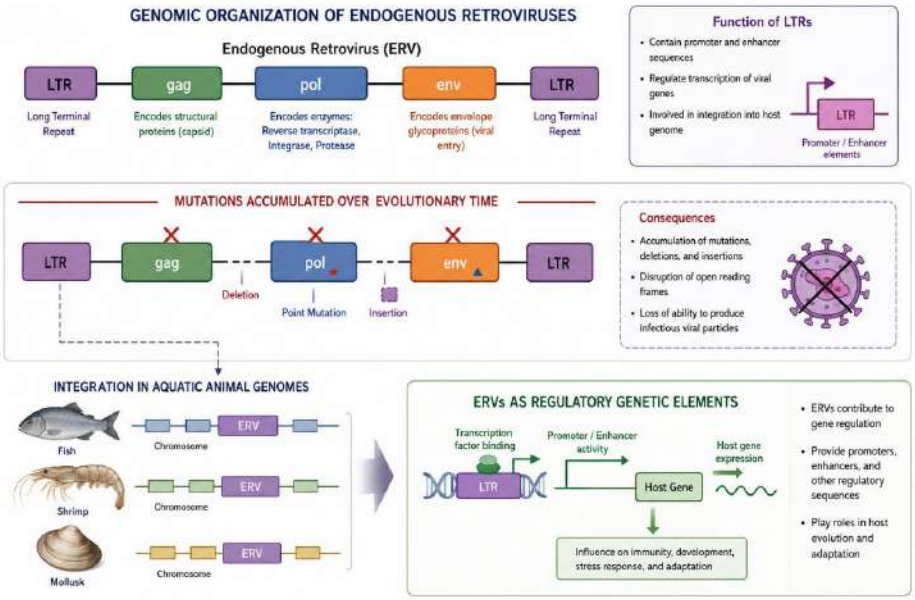
Distribution of Endogenous Retroviruses in Aquatic Animals

Comparative genomic studies have demonstrated that endogenous retrovirus-like elements are widely distributed among aquatic vertebrates. Their presence has been confirmed in several economically and scientifically important fish species, including zebrafish (DANIO RERIO), Atlantic salmon (SALMO SALAR), rainbow trout (ONCORHYNCHUS MYKISS), Japanese medaka (ORYZIAS LATIPES), pufferfish (TAKIFUGU RUBRIPES), and coelacanth (LATIMERIA CHALUMNAE). These findings indicate that retroviral integration has occurred repeatedly throughout vertebrate evolution.

The diversity of ERVs varies among fish species because different ancestral retroviruses infected their genomes at different evolutionary periods. Comparative analyses of these viral elements provide valuable information about host evolution, species divergence, and historical viral epidemics. As genome sequencing becomes increasingly common in aquaculture species, many additional endogenous retrovirus-like elements are expected to be discovered. (Belyi et al., 2010; Aiewsakun & Katzourakis, 2017)

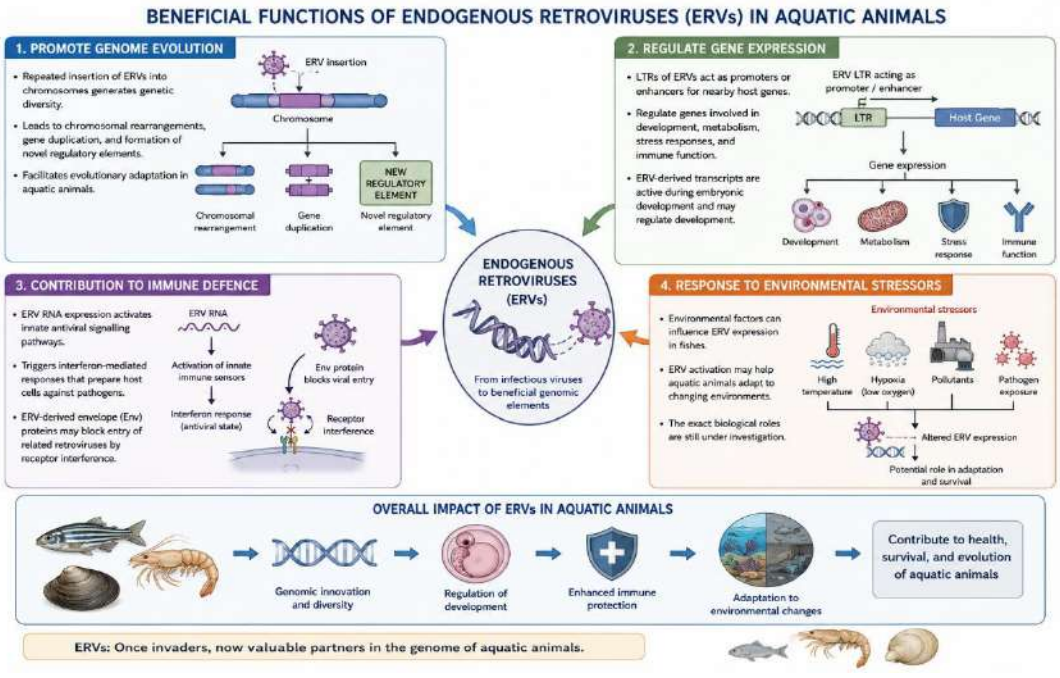
Structure of Endogenous Retroviruses

The genomic organization of endogenous retroviruses closely resembles that of infectious retroviruses. Their genome contains two **Long Terminal Repeats (LTRs)** located at both ends, which regulate transcription and integration. Between these LTRs are three principal genes: **gag**, **pol**, and **env**. The GAG gene encodes structural proteins that form the viral capsid, the POL gene encodes reverse transcriptase, integrase, and protease enzymes required for viral replication, while the ENV gene encodes envelope glycoproteins responsible for viral entry into host cells In most aquatic animal genomes, however, these genes have accumulated numerous mutations, deletions, and insertions over evolutionary time. Consequently, the majority of endogenous retroviruses have lost their ability to produce infectious viral particles. Despite this loss of infectivity, many ERVs continue to function as regulatory genetic elements that influence host gene expression. (Bannert & Kurth, 2006; Feschotte & Gilbert, 2012)



Bological Functions of Endogenous Retroviruses

Although endogenous retroviruses originated as infectious viruses, they now perform several beneficial functions within the genomes of aquatic animals. One of their most important roles is promoting genome evolution by generating genetic diversity. Repeated insertion of ERVs into chromosomes has contributed to chromosomal rearrangements, gene duplication, and the formation of novel regulatory elements that facilitate evolutionary adaptation.Endogenous retroviruses also regulate gene expression through their Long Terminal Repeat sequences, which



function as promoters or enhancers for nearby host genes. These regulatory activities influence genes involved in development, metabolism, stress responses, and immune function. Recent studies have shown that certain ERV-derived transcripts become active during embryonic development, suggesting their involvement in developmental regulation.

Another significant role of ERVs is their contribution to immune defence. Expression of endogenous retroviral RNA can activate innate antiviral signalling pathways, particularly interferon-mediated responses that prepare host cells to combat invading pathogens. In some cases, ERV-derived envelope proteins may interfere with infection by related retroviruses through receptor interference, thereby reducing susceptibility to viral infection.Environmental stressors, including elevated water temperature, hypoxia, pollutants, and pathogen exposure, have also been reported to influence ERV expression in fishes. Although the precise biological significance of these responses is still under investigation, they indicate that endogenous retroviruses may participate in adaptation to environmental changes. (Chuong et al., 2016; Frank & Feschotte, 2017)

Importance in Aquaculture

The rapid development of genomics has increased interest in endogenous retroviruses as valuable genetic resources for aquaculture. Identification of ERV-associated molecular markers may assist selective breeding programmes aimed at improving disease resistance, growth performance, and environmental tolerance in cultured fish species.Endogenous retroviruses also provide important information about host–virus co-evolution, enabling researchers to understand how fish populations have naturally adapted to viral infections over millions of years. This knowledge may contribute to the development of disease-resistant breeding lines and more effective health management strategies.Furthermore, ERVs may serve as biomarkers for monitoring fish health and immune status. As genomic selection becomes more widely adopted in aquaculture, understanding the biological functions of endogenous retroviruses will become increasingly important for sustainable fish production. (Yáñez et al., 2015; Houston et al., 2020)

Endogenous Retroviruses and Fish Health

Unlike infectious viruses such as **Tilapia Lake Virus (TiLV)**, **Infectious Salmon Anaemia Virus (ISAV)**, or **Viral Haemorrhagic Septicaemia Virus (VHSV)**, endogenous retroviruses generally do not cause infectious disease because they have lost the ability to replicate independently. However, their expression may increase during viral infections,

environmental stress, or immune activation.Current research suggests that ERVs may influence host immunity by regulating interferon responses, inflammatory pathways, and antiviral gene expression. Some studies indicate that abnormal ERV activation could alter susceptibility to infectious diseases, although definitive evidence in aquatic animals is still limited. Continued research is therefore required to understand how these ancient viral elements contribute to fish health and disease resistance. (Johnson, 2019; ICTV, 2023)

Modern Research and Future Prospects

The availability of next-generation sequencing, transcriptomics, comparative genomics, and CRISPR-Cas genome-editing technologies has greatly accelerated ERV research. Scientists are now investigating how endogenous retroviruses regulate host genes, interact with immune pathways, and influence adaptation to environmental stress.Future research is expected to identify functional ERVs associated with disease resistance, develop ERV-based molecular biomarkers for health monitoring, and integrate ERV information into genomic breeding programmes. Understanding the interactions between endogenous retroviruses and emerging aquatic pathogens may also support the development of innovative disease control strategies for sustainable aquaculture. (Houston et al., 2020; Hryhorowicz et al., 2017)

Conclusion

Endogenous retroviruses are ancient viral remnants that have become permanent components of aquatic animal genomes through millions of years of evolution. Although they are no longer infectious, these viral elements continue to influence genome evolution, gene regulation, immune responses, and adaptation to environmental stress. Their discovery has fundamentally changed the understanding of viruses from simple disease-causing agents to important contributors to host biology and evolution. In aquaculture, endogenous retroviruses represent an emerging area of research with significant potential for improving disease resistance, genomic selection, and fish health management. Continued investigation of these hidden viral fossils will provide valuable insights into host–virus interactions and contribute to the development of sustainable and resilient aquaculture systems.

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GREEN CARE INTERVENTIONS: THE ROLE OF HORTICULTURE THERAPY IN SUSTAINABLE HEALTH PROMOTION

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Abstract

The growing prevalence of chronic diseases, mental disorders, and other age-related health conditions has highlighted the need for a more effective, holistic, and sustainable approach to health promotion and rehabilitation. Apart from well-established medical treatments, nature-based interventions have been gaining recognition for their ability to improve the physical, physiological, and social well-being of an individual. Among these, "Green Care" Horticulture Therapy is an emerging therapeutic practice involving gardening activities and plant interactions for the enhancement of human life and the social well-being of an individual. This article presents a comprehensive overview of HT (Horticulture Therapy) through its development, theoretical foundations, health benefits, and applications.

Keywords: Horticulture Therapy, Therapeutic values, Greencare Intervention, Sustainable health care, Rehabilitation.

Introduction

Horticultural therapy is a well-organized, goal-oriented intervention, facilitated by skilled professionals, in which participants engage in gardening activities to achieve therapeutic outcomes. Horticulture Therapy is designed to address the physical, cognitive, emotional, and social needs of an individual, thereby making it applicable to various healthcare settings.

History & Foundation of Horticulture Therapy

The concept of Horticulture Therapy is rooted back to ancient times, where gardens and green spaces have been recognized as places meant for healing, relaxation, and restoration. The therapeutic use of gardens dates back to ancient civilizations, including Egypt, Greece, Rome,

China, and Japan, where natural landscapes were incorporated into healing practices to improve the physical, mental, and spiritual well-being of an individual (Shoemaker, 2004).

Theoretical Foundations of Horticulture Therapy

Beyond its historical roots, Horticulture Therapy is supported by a set of established theoretical frameworks drawn from environmental psychology and health science, which together explain why interaction with plants and gardens produces measurable therapeutic effects.

- **Attention Restoration Theory (Kaplan & Kaplan, 1989):** proposes that natural environments engage "involuntary attention," allowing directed attention and mental fatigue to recover. Gardening tasks provide the qualities of being away, extent, fascination, and compatibility that this theory identifies as restorative.
- **Stress Reduction Theory (Ulrich, 1984):** (also called the Psycho-evolutionary Theory) suggests that humans have an innate, evolutionarily adaptive response to natural settings, which triggers rapid reductions in physiological stress markers such as heart rate, blood pressure, and cortisol upon exposure to greenery.
- **Biophilia Hypothesis (Wilson, 1984):** argues that human beings possess an inherent affinity for nature and living systems. This innate connection underlies the sense of calm, curiosity, and engagement people experience while tending to plants.
- **Self-Efficacy Theory (Bandura, 1977):** frames gardening as a structured, incremental task in which participants set goals, perform actions, and observe tangible outcomes (plant growth), reinforcing confidence, motivation, and a sense of mastery relevant to rehabilitation.
- **Ecological / Person-Environment Fit Models:** positions the garden as an ecological system in which the person, the activity, and the natural environment interact continuously, supporting adaptive functioning across physical, psychological, and social domains.

Together, these frameworks provide the scientific rationale for Horticulture Therapy's multi-domain benefits and form the conceptual bridge between its ancient historical practice and its modern clinical application.

Working Mechanism of HT

Horticulture Therapy promotes health and well-being through a combination of

physiological, psychological, cognitive, social, and environmental mechanisms, which collectively contribute to improvements in physical health, mental well-being, cognitive function, and overall quality of life (Hartig et al., 2011; Chen et al., 2023). Each of these mechanisms operates through distinct but interconnected pathways, described below.

1. Physiological Mechanism

Gardening activities involve sustained, moderate-intensity physical movement, such as digging, planting, watering, weeding, and pruning, which function as a form of light-to-moderate exercise. Regular engagement in these tasks has been associated with:

- **Cortisol regulation:** Repeated contact with soil and green environments is linked to measurable reductions in salivary cortisol, indicating lowered physiological stress response.
- **Blood pressure (BP):** The calming effect of natural surroundings, combined with light physical activity, contributes to healthier blood pressure regulation over time.
- **Fitness:** The repetitive motor demands of gardening build cardiovascular endurance, muscular strength, and overall physical fitness.
- **Mobility:** Tasks requiring bending, reaching, gripping, and walking help maintain and improve joint flexibility, balance, and functional mobility, which is particularly valuable in elderly and rehabilitation populations.

2. Psychological Mechanism

The nurturing and restorative nature of plant care addresses emotional and psychological needs by offering a sense of purpose and a healthy outlet for stress. Key psychological effects include:

- **Anxiety reduction:** Immersion in a calming, sensory-rich garden environment reduces feelings of worry and nervous tension, consistent with Attention Restoration and Stress Reduction Theories.
- **Depression:** The rhythmic, purposeful nature of gardening tasks, along with visible plant growth, helps alleviate depressive symptoms by fostering hope and engagement.
- **Mood improvement:** Regular exposure to greenery and accomplishment of small, achievable gardening goals elevates overall mood states.
- **Self-esteem:** Successfully nurturing a plant from seed to growth builds a tangible sense of achievement, competence, and self-worth.

3. Cognitive Mechanism

Horticultural tasks require sequencing, planning, and sustained mental engagement, which actively stimulate cognitive processes:

- **Memory:** Recalling planting schedules, watering routines, and plant-care instructions exercises both short-term and long-term memory.
- **Attention:** Tasks such as identifying weeds, monitoring plant health, and following multi-step instructions demand sustained and selective attention.
- **Executive function:** Planning a garden layout, organizing tasks, and problem-solving around plant care needs strengthens executive function, an area particularly beneficial for individuals with cognitive decline or neurological conditions.

4. Social Mechanism

Horticulture Therapy is frequently delivered in group settings, which creates natural opportunities for interpersonal engagement:

- **Social interaction:** Group gardening activities encourage communication, cooperation, and shared decision-making among participants.
- **Isolation reduction:** Participation in a shared activity reduces feelings of loneliness, particularly among older adults, individuals with disabilities, or those in institutional or long-term care settings.
- **Support:** The shared responsibility of caring for a garden fosters mutual encouragement, a sense of belonging, and peer support networks.

5. Environmental Mechanism

The garden setting itself contributes an independent therapeutic effect, separate from the act of gardening:

- **Exposure to green spaces:** Simple visual and physical contact with green spaces has been shown to lower physiological arousal and promote relaxation, even without active participation in gardening tasks.
- **Sensory stimulation:** The multisensory qualities of a garden, including scent, texture, color, and sound, engage the senses in a way that is calming, grounding, and restorative.

Challenges of Horticulture Therapy

Despite growing scientific evidence supporting the positive effects of Horticulture Therapy, several challenges continue to limit its widespread implementation in healthcare. These

include a lack of standardized intervention protocols, limited high-quality clinical evidence, a shortage of trained horticultural therapists, limited awareness and policy support, financial and infrastructural constraints, and cultural and geographical variability.

Future Perspectives of Horticulture Therapy

The future of Horticulture Therapy is bright, owing to the increasing recognition of nature-based green care interventions within the healthcare community. The integration of smart therapeutic gardens, equipped with environmental sensors, automated irrigation systems, and accessible landscape designs, has the potential to enhance the therapeutic experience while promoting sustainability.

Conclusion

Horticulture Therapy represents a promising, valuable, and sustainable approach to promoting health and well-being by connecting individuals with nature through horticultural activities. As the global burden of physical and mental health conditions continues to increase, the integration of Horticulture Therapy alongside conventional healthcare practice has the ability to enhance quality of life and support the development of healthier, more resilient communities.

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RAJMA RISING: HOW ANDHRA PRADESH'S TRIBAL HILLS ARE CULTIVATING, HEALTH AND PROSPERITY

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Introduction

Rajma (kidney bean) has emerged as a vital crop in the tribal hills of Andhra Pradesh, combining nutrition, sustainability and economic opportunity. Once limited due to ganja cultivation and poor market access, rajma cultivation has revived dramatically, with modern varieties and semi-organic practices boosting yields by up to 40%. Farmers benefit from assured prices through cooperative procurement, while training on improved cultivation techniques, organic practices, and eco-friendly pest management has enhanced crop health and soil fertility. Beyond local consumption, rajma offers value addition opportunities through ready-to-cook mixes, protein snacks and fortified foods, as well as potential for export. Today, rajma stands as a symbol of resilient, sustainable farming that strengthens tribal livelihoods, ensures food security, and promotes rural prosperity in the Eastern Ghats.

Keywords: Kidney bean, Tribal Farming, Costs and Profitability

Rajma: The Protein-Packed Bean of Andhra Pradesh Hills

Rajma (kidney bean) is a highly nutritious legume, rich in protein, fibre and essential minerals like iron, potassium and folate. In the tribal hilly regions of Visakhapatnam district, located in the Eastern Ghats at altitudes ranging from 900–1,200 meters, rajma is both a staple food and a source of income for local communities. A decade ago, over 5,000 hectares were under rajma cultivation in these areas. However, expansion of ganja farming and poor market connectivity reduced this area to less than 2,000 hectares, threatening both local nutrition and livelihoods.

Revival and Growth in Tribal Areas

Today, the story of rajma in the study area has changed remarkably. With government support, cooperative interventions and rising market demand, cultivation has expanded to nearly 10,000 hectares. The Chintapally red and white varieties are the most widely grown, with the white variety prized for its delicate flavour and semi-organic cultivation. Assured procurement prices from private traders and the Girijan Cooperative Corporation (₹60–90 per kg) have made rajma cultivation profitable, encouraging many tribal farmers to return to this traditional crop.

Challenges in Cultivation

Despite its profitability, rajma cultivation faces several challenges. The hilly terrain of the Eastern Ghats, with steep slopes, shallow soils, and uneven nutrient distribution, limits productivity. The crop is highly sensitive to both biotic stresses, such as bacterial wilt, Fusarium wilt, rust, and insect pests, and abiotic stresses, including drought, heat, and nutrient deficiencies. A weak root system makes rajma especially vulnerable under adverse conditions, and many farmers lack awareness of modern cultivation techniques, biofertilizer use, and pest management.

Sustainable and Soil-Friendly Crop

As a legume, rajma enriches soil nitrogen naturally through biological fixation, reducing the need for synthetic fertilizers. When included in crop rotations, it improves soil structure and fertility, supporting long-term sustainability. Its short duration and moderate water requirements make it a climate-resilient crop, suitable for the rainfed hilly regions of the Eastern Ghats.

Research, Innovation and Farmer Training

Institutions like Acharya N. G. Ranga Agricultural University (ANGRAU), ICAR-IIPR and NBPGR have contributed to improving rajma productivity and utilization. Research has shown that kidney beans can be used not only as a pulse but also in value-added products, such as protein-rich dhokla mixes made from red and white rajma flours.

In the study area, tribal farmers have benefited from training on improved cultivation practices, including the use of high-yielding varieties, biofertilizers, organic farming techniques and eco-friendly pest management. These interventions have led to better crop health, increased yields by up to 40%, and higher family incomes. Community-based seed preservation and sharing practices have further encouraged sustainable adoption of improved rajma varieties across the hills.

Costs, Profitability and Market Potential

The cost of cultivating one hectare of rajma in Visakhapatnam is estimated at around ₹18,869, covering labour, seeds, fertilizers and equipment. While farmers face challenges like pest attacks, high input costs and transport bottlenecks, support through government programs, cooperative procurement and guaranteed prices helps mitigate risks.

Beyond its nutritional value, rajma offers immense opportunities for value addition. Research indicates that rajma flour can be used in ready-to-cook mixes, protein snacks, and fortified bakery products. Encouraging women's self-help groups and tribal cooperatives to adopt such products can generate additional income and employment opportunities, complementing farm earnings.

Rising Local and Global Demand

India's rajma is increasingly in demand not just locally but also internationally. With global interest in plant-based proteins and health foods rising, regional varieties like Chitra, Black, and White rajma are gaining recognition in overseas markets. While local farmers benefit from assured prices, export potential further highlights the economic importance of high-quality rajma from Andhra Pradesh.

Conclusion

The revival of rajma in Andhra Pradesh's tribal hills is a story of resilience, nutrition and economic empowerment. With modern varieties, organic practices, scientific training and cooperative market support, tribal communities are growing healthier crops, earning better incomes and sharing agricultural knowledge. Rajma has become more than just a pulse it is a symbol of sustainable farming, food security, and rural prosperity. With continued support, awareness and market access, the Eastern Ghats can truly become a hub of high-quality, nutritious rajma, benefiting both farmers and consumers alike.

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BIOLOGY OF PACIFIC WHITE SHRIMP

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Introduction

Pacific white shrimp also called as white leg shrimp or Mexican white shrimp and consisted scientific name of *Litopenaeus vannamei*, which was discovered and named by Pearl Lee Boone, Invertebrate Zoologist at the Smithsonian's National Museum of Natural History (NMNH) located on the national mall in Washington, D.C., United States in the year of 1931. It is a decapod crustacean that has become one of the most economically important species in global aquaculture due to its rapid growth, adaptability to high-density farming, and tolerance to a wide range of environmental conditions. Originated from the Eastern Pacific Ocean and distributed worldwide, leading to significant research on its biology to optimize culture practices and mitigate associated risks (Dugassa and Gaetan, 2018).

1. Taxonomy and Habitat

Litopenaeus vannamei comes under genus Litopenaeus, family Penaeidae and order Decapoda. It identified by its greyish-white coloration and omnivorous scavenging behavior, with least aggression compared to species like *Penaeus monodon*. Native to the coastal waters of the Eastern Pacific, ranging from northern Mexico to Tumbes in Peru, it inhabits brackish environments with low salinities from 1-2 ppt to hypersaline conditions up to 40 ppt, preferring clayey loam soils in estuaries, lagoons, mangroves, and marine habitats. The species tolerates a wide salinity ranges of 0-50 ppt, optimal temperatures of 30-34°C, and pH levels of 7-9 (optimal 8.0), enabling successful culture in diverse systems, including freshwater with desalinized larvae

(De Silva, et al., 2021). In aquaculture, it is often farmed in marine ponds, such as in India and Thailand, but as an exotic species, its introductions can impact native biodiversity through competition and pathogen spread.

2. Life Cycle and Development

The life cycle of *Litopenaeus vannamei* is complex, completing in approximately 1.5 years, and undergoes distinct embryonic, larval, and post larval stages. Females mature faster and grow larger up to 120g in the wild and 20g in culture than males, which grows up to 80g in the wild, with maturation often accelerated via unilateral eye stalk ablation in farming. Spawning occurs in females weighing at 30-45g and capable to produce up to 100,000-250,000 eggs in single cycle, but egg development requires salinities above 22 ppt, with less weight spermatophore and fertilization at lower levels (e.g., 5 ppt) (De Silva, et al., 2021).

Early development begins with the embryo stage (zygote to larva in membrane), progressing through six nauplius stages (NI-NVI), which are non feeding stages and depends on yolk, three zoea stages (ZI-ZIII), which initiates feeding on algae and formulated diets, three mysis stages (MI-MIII), which preferably feeds on artemia and diets, and post larvae (P1 onward), which exhibits benthic transition. These transitions involve dramatic morphological changes, such as histogenesis, muscle development, and exoskeleton reconstruction, regulated by hormones like ecdysone and genes including Ecdysone Receptor (EcR), Retinoid X Receptors (RXR), Fushi Tarazu Factor 1 (FTZ-F1), and Ecdysone induced protein 75 (E75). Transcriptomic studies reveal up-regulation of digestive enzymes (trypsin, chymotrypsin, amylase) during nauplius-to-zoea shifts, muscle-related genes Myosin Heavy Chain (MYH) in zoea-to-mysis, and cuticle proteins in mysis-to-postlarvae (Wei, et al., 2014).

3. Morphology and Physiology

Morphologically, *L. vannamei* features an open thelyca reproductive system, unique among penaeids, with complex spermatophores and no seminal receptacles in females, facilitating external fertilization. Physiologically, it is an omnivorous scavenger with low protein needs, exhibiting rapid growth in intensive systems (De Silva, et al., 2021). Digestive physiology centers on the hepatopancreas, where trypsin activity (polymorphic with three sequences) varies with transcription rates, diet, molting stages (lowest in D3/A-B, highest in D1/D1'), and diurnal cycles. Environmental stressors like ammonia, nitrite, temperature fluctuations, and high densities impair intestinal barrier function, alter gut microbiota (e.g.,

increased Formosa, decreased Photobacterium), and suppress mucin genes and immune compounds. Hematopoiesis occurs in specialized tissues, but can lead to neoplasms associated with viruses like IHHNV (Stentiford, 2012). Pigmentation involves carotenoids like astaxanthin, extractable from waste, with stability affected by UV, pH, salinity, and heat.

4. Feeding Behavior of *Litopenaeus vannamei*

The Pacific white shrimp, exhibits complex feeding behaviors influenced by chemosensory cues, environmental conditions, and dietary composition. As an omnivorous scavenger in the wild, it adapts well to formulated feeds in aquaculture, but factors such as temperature, water quality, and feed ingredients can modulate intake, foraging, and efficiency.

4.1. Environmental Factors Influencing Feeding

Environmental stressors significantly affect feeding activity, among them temperature is a primary alternater, when it rises from 20°C to 32°C intake increases from 0.46 g to 0.95 g per 30 minutes with corresponding rises in acoustic clicks (from 388 to 2947) and feeding time, while low temperatures suppress activity. Ammonia nitrogen at 12 mg/L and nitrite nitrogen at 40 mg/L reduce consumption by 0.15 g, decrease clicks, and increase quiescent time, likely due to gill damage and metabolic stress. Passive acoustic monitoring (PAM) validates these effects, showing strong correlations between click counts and feed intake ($R^2 = 0.73$), and redundancy analysis indicates temperature explains 63% of behavioral variance (Zhang, et al., 2025). Salinity, feed processing (e.g., extruded vs. pelleted), and protein sources also interact with feeding, though specific combined effects require further exploration (Moss, et al., 2024).

4.2. Dietary Influences and Attractability

Diet composition impacts attractability and feed intake. Protein sources like squid meal (SqM), fish protein hydrolysate (FPH), fish meal (FM), and casein (CN) enhance consumption rates compared to bland controls, with SqM showing the highest attractability (hazard ratio 1.617). These ingredients release chemosensory stimulants such as amino acids, accelerating pellet ingestion in bioassays measuring survival curves of remaining feed (Yuan, et al., 2021). However, rapeseed meal (RSM) induces anorexia: replacing 50% soybean meal with fermented RSM reduces dietary visits, increases discarding, and leaves more residual feed. Transcriptomics reveals 1047 differentially expressed genes, enriching pathways like signal transduction and endocrine systems, with seven neuropeptides (e.g., neuroparsin, orcokinin) mediating appetite suppression (Zhou, et al., 2024). Additives like krill meal, krill oil, and fish hydrolysate in

soybean-based diets also improve behavior and growth, though specific mechanisms vary (Soares, et al., 2021).

4.3. Monitoring and Assessment Techniques

Passive acoustic detection effectively monitors feeding. Systems recording "click" sounds during mandibulation show correlations with intake, supporting pattern analysis in varied diets and densities (Wei, et al., 2020). Short-term feed deprivation and molt status influence behavior, with post-molt shrimp showing increased foraging post-starvation (Bardera, et al., 2019).

5. Immune Performances of *Litopenaeus vannamei*

Litopenaeus vannamei possesses an innate immune system lacking adaptive immunity, relying on cellular and humoral components to combat pathogens and stressors. This system includes hemocytes for phagocytosis, encapsulation, and apoptosis, alongside humoral factors like antimicrobial peptides (AMPs), the prophenoloxidase (proPO) system, and clotting mechanisms. Immune performance is modulated by environmental factors, nutrition, and infections, with key pathways such as Toll, IMD, and JAK/STAT regulating responses (Sangklai, et al., 2024).

5.1. Innate Immune Components

The innate immunity of Mexican white hrimp features cellular responses via hemocytes (hyaline for phagocytosis, semi-granular/granular for encapsulation and cytotoxicity) and humoral elements including AMPs (penaeidins, crustins, lysozymes), lectins, and enzymes like phenoloxidase (PO) and superoxide dismutase (SOD) (Lin, et al., 2012). Pattern recognition receptors (PRRs) detect PAMPs, activating Toll (via MyD88 and Dorsal) and JAK/STAT (via DOME, JAK, STAT) pathways to induce AMP expression (Sangklai, et al., 2024). Key organs include the hepatopancreas (metabolism and immunity), hemolymph (circulating factors), and gills (barrier function) (Yu, et al., 2022). Immune performance metrics encompass total hemocyte count (THC), PO activity, SOD, lysozyme, phagocytosis, respiratory bursts (RB), and gene expressions (e.g., proPO, Toll1, hemocyanin) (Shakweer, et al., 2023).

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SILICON: THE UNSUNG HERO OF SOIL AND PLANT HEALTH

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Abstract

Silicon, the second most abundant element in the Earth's crust, has long been overlooked in plant nutrition because it is not classified as an essential nutrient. However, growing scientific evidence highlights its remarkable role in improving soil health, enhancing crop productivity and strengthening resilience against environmental stresses. This article explores how silicon functions at the soil-plant interface by improving soil structure, stimulating beneficial microbial communities, increasing nutrient availability and enhancing plant tolerance to drought, salinity, heavy metals and diseases. As climate change and soil degradation continue to threaten global food production, integrating silicon into soil and crop management practices offers a promising approach to building resilient agroecosystems and ensuring long-term agricultural sustainability.

Keywords: Silicon, Soil health, Soil microbiome, Nutrient availability, Plant stress, Sustainable agriculture.

Introduction

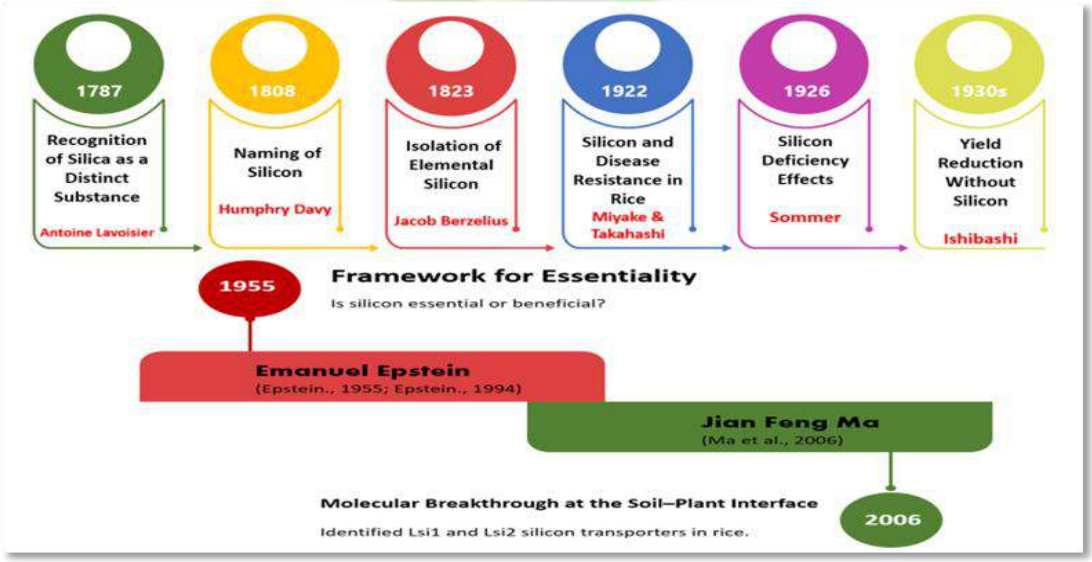
Plants grow in soil, engaged in a constant exchange with the world beneath their roots. This exchange, called mineral nutrition is the biochemical backbone of plant life: the absorption, transport and use of mineral elements that power everything from photosynthesis to grain filling. For decades plant nutrition has followed a hierarchy, the primary nutrients (nitrogen, phosphorus, potassium) dominate, secondary nutrients (calcium, magnesium, sulphur) play supporting roles and micronutrients (iron, zinc, copper) matter in trace amounts. Together, these are the "essential" elements without which plants cannot survive. But beyond this list lies a quieter category, the beneficial elements. These aren't strictly required for survival, yet they

sharpen plant resilience, strengthen defences and boost productivity when conditions turn tough. Silicon is the standout among them. Silicon makes up roughly 28% of Earth's crust, yet for centuries, it sat in the shadows of nitrogen, phosphorus and potassium. But as climate change intensifies and soils degrade worldwide, scientists have identified that, silicon might just be the missing piece in our quest for resilient and sustainable agriculture. At the soil-plant interface, the living boundary where roots, microbes, water and minerals collide, silicon is no bystander. It reshapes microbial communities, unlocks trapped nutrients like phosphorus, hardens plant tissues against pests and arms crops against drought, salinity and toxic metals.

From Curiosity to Crop Science

The story of silicon in agriculture stretches back nearly two centuries. In 1787, the French chemist Antoine Lavoisier first recognized silica as a distinct substance. By 1808, Humphry Davy had named the element "silicon" and in 1823, Jacob Berzelius successfully isolated it in pure form. But it wasn't until the early 20th century that scientists began suspecting silicon might matter to plants.

In 1922, Japanese researchers Miyake and Takahashi noticed something peculiar that, rice plants without adequate silicon were more susceptible to disease. By the 1930s, farmers were observing yield drops in silicon-deficient fields. Yet the real breakthrough came in 2006, when scientist Jian Feng Ma identified Lsi1 and Lsi2, the specialized silicon transporters in rice roots. These molecular gateways proved that plants don't just passively absorb silicon, they actively seek it out.



What Silicon Actually Does in Soil

Silicon exists in soil mainly as silicates and silica minerals. For plants to use it, these minerals must dissolve into monosilicic acid [$Si(OH)_4$], the soluble and bioavailable form that roots can take up. When farmers apply silicon fertilizers, whether calcium silicate, magnesium silicate or potassium silicate, a fascinating chain of events unfolds. The fertilizer dissolves, releasing monosilicic acid into the soil solution. This soluble silicon then interacts with iron and aluminum oxides, clay minerals and organic matter. Some gets adsorbed onto soil particles, some moves with soil water and some is eagerly taken up by plant roots.

Silicon doesn't just remain in soil waiting to be absorbed instead, it actively shapes the soil environment. It promotes soil aggregation that clumps soil particles into stable structures that resist erosion. It improves water infiltration and retention, helping soils hold moisture during dry spells. It reduces compaction, allowing roots to penetrate deeper. And perhaps most importantly, it creates a thriving habitat for soil microorganisms.

Building a Healthier Soil Microbiome

When silicon is applied to soil, it raises soil pH creating a more alkaline environment, that favours beneficial microbes over harmful ones. But silicon's influence goes deeper. It changes how roots behave, specifically altering the root exudates that is, the sugars, amino acids, organic acids and signalling molecules that roots leak into the soil. These exudates are essentially invitations to microbes to colonize, protect and find nutrients.

Silicon-enhanced roots produce different exudate profiles, which in turn recruit different microbial communities. Long-term silicon application in rice fields, for example, has been shown to boost the diversity and richness of soil microbes, particularly favouring Proteobacteria and Actinobacteria groups associated with nutrient cycling and disease suppression. Even more striking, silicon can suppress disease-causing organisms. Sodium silicate treatments have been found to promote beneficial bacterial and fungal groups while inhibiting pathogenic taxa. It's like silicon helps the soil build its own immune system.

Unlocking Trapped Nutrients

One of agriculture's oldest frustrations is phosphorus. Plants need it desperately for energy transfer, root development and flowering. Yet in many soils, up to 80% of applied phosphorus becomes locked away, bound tightly to iron and aluminum oxides, essentially unreachable by roots. Silicon offers an elegant solution. Silicic acid competes with phosphate for

the same adsorption sites on soil minerals. When silicon enters the picture, it displaces the trapped phosphorus, setting it free into the soil solution where roots and microbes can access it.

The carbon story is equally compelling. Silicon boosts plant biomass, which means more roots, more shoots and ultimately more organic matter returned to the soil. This increased carbon input feeds soil microorganisms, which in turn drive the decomposition and nutrient cycling that keep soils fertile. Overall, silicon creates a virtuous cycle like healthier plants gives more organic matter which turn increases microbial activity, that helps in better nutrient availability and healthier plants.

Standing Tall Against Stress

Salinity stress affects roughly 20% of irrigated lands worldwide. When soils accumulate excess salts, plants struggle to draw water, enzymes malfunction and cell membranes break down. Silicon steps in by improving water regulation within plant tissues, reducing sodium uptake and maintaining cellular integrity. Crops from wheat and rice to cucumber and tomato have all shown improved salt tolerance with silicon supplementation.

Drought stress is equally devastating. Water scarcity triggers a cascade of damage like stomata close to prevent water loss, but this also blocks CO_2 entry, reducing photosynthesis. Meanwhile, reactive oxygen species (ROS) accumulate like toxic waste, damaging cells and proteins. Silicon strengthens root systems, enabling plants to forage deeper for water. It enhances antioxidant defences, neutralizing ROS before they can wreak. And at the molecular level, it regulates genes involved in stress responses, essentially reprogramming plants to cope better with dehydration.

Heavy metal contamination from cadmium, lead, arsenic, chromium and others is an escalating crisis in industrial and mining regions. These metals reduces photosynthesis, disrupt nutrient uptake and stunt growth. Silicon acts as a multi-layered shield, it reduces metal uptake by roots, sequesters metals in plant tissues where they can't cause harm and protects chlorophyll and cell membranes from metal-induced damage. In chilli plants exposed to cadmium and lead, silicon not only preserved leaf pigments but also boosted antioxidant enzyme activity and activated defence genes, a comprehensive protective response.

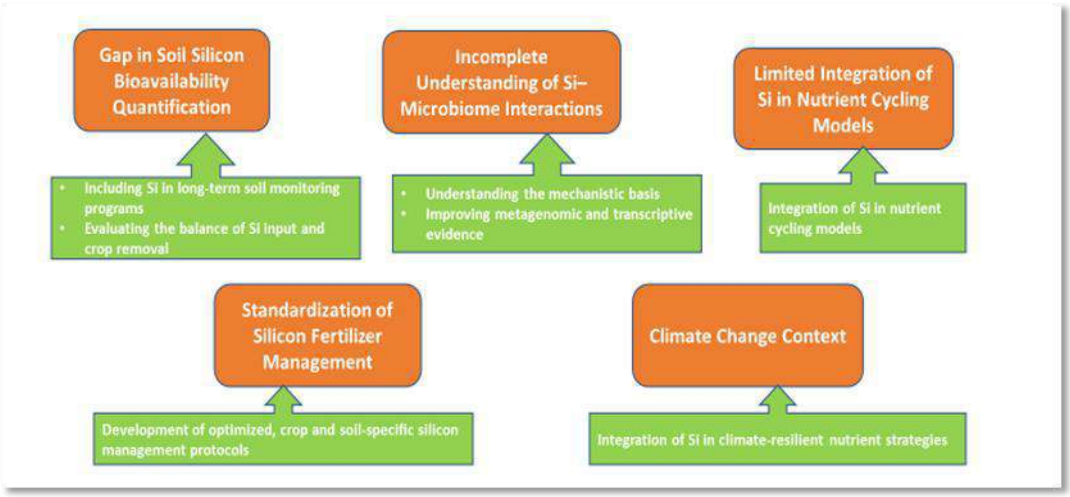
Biotic stresses like the attacks by fungi, bacteria, viruses, nematodes and insects are another frontier where silicon proves its worth. Silicon-deposited tissues become physically tougher, creating barriers that pathogens struggle to penetrate. But silicon also triggers plant

immune responses, priming defence mechanisms before attacks even occur. It's like giving plants both armor and a trained immune system.



The Road Ahead

Despite these remarkable benefits, silicon remains underutilized in mainstream agriculture. Several gaps persist in our understanding and application. We still lack standardized methods to quantify bioavailable silicon in soils. Knowing total silicon content tells us little about what plants can actually use. The intricate conversations between silicon, roots and microbes are only beginning to be decoded. Nutrient cycling models largely ignore silicon, treating it as an inert bystander rather than an active participant. And fertilizer management protocols remain inconsistent, with little guidance tailored to specific crops and soil types.



Climate change adds urgency to these issues. As temperatures rise and rainfall patterns shift, silicon-integrated strategies have significant potential to enhance agricultural adaptation and resilience. Incorporating silicon into long-term soil monitoring programs could improve the assessment and sustainable management of soil health. Maintaining a balance between silicon inputs and crop removal at harvest is essential to prevent the gradual depletion of plant-available silicon in agricultural soils. Addressing these challenges will require continued research, long-term field trials and a renewed approach to sustainable soil and nutrient management.

Conclusion

Silicon may not be classified as an essential nutrient in the strictest sense, since most plants can complete their life cycle without it. Yet, under the realities of modern agriculture such as stressed soils, changing climates and growing food demands, it has emerged as a vital ally. More than simply supporting plant growth, silicon helps crops withstand drought, salinity, pests, diseases and other environmental challenges, making it a key contributor to resilient farming. Its benefits extend beyond the plant itself. By strengthening plant tissues, encouraging beneficial soil microorganisms and improving nutrient availability, silicon supports healthier soils and more productive cropping systems. These multiple roles highlight how a naturally abundant element can quietly influence the sustainability of agriculture.

Sometimes, the most powerful solutions are the ones we have overlooked for years. Although silicon is the second most abundant element in the Earth's crust, its agricultural potential is only now receiving the attention it deserves. As the world strives to produce more food with fewer resources while adapting to climate change, silicon offers a practical and environmentally friendly pathway toward sustainable agriculture. The future of farming begins beneath our feet, and silicon is proving to be one of the silent architects of healthy soils, resilient crops and food security.

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THE FUTURE OF ORGANIC FARMING IN THE ERA OF CLIMATE CHANGE

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Abstract

Climate change has become a major challenge for agriculture worldwide, affecting food production, natural ecosystems, and the livelihoods of farming communities. Increasing temperatures, unpredictable rainfall, frequent droughts, floods, and the spread of pests and diseases have significantly impacted crop productivity and agricultural sustainability. In response to these challenges, organic farming has gained recognition as an environmentally sustainable approach that strengthens the resilience of agricultural systems. By improving soil fertility, promoting biodiversity, and relying on natural resource management rather than synthetic inputs, organic farming supports both climate change mitigation and adaptation. Despite its many advantages, the expansion of organic farming is constrained by factors such as reduced yields during the conversion period, high certification expenses, limited market access, and insufficient technical support. Nevertheless, advances in sustainable agricultural technologies, favorable government initiatives, and increasing consumer preference for eco-friendly and chemical-free food products are creating new opportunities for its wider adoption. This chapter examines the contribution of organic farming to climate change resilience, highlights its environmental and socio-economic benefits, discusses the challenges affecting its implementation, and explores future prospects for promoting sustainable agricultural development.

Keywords: Organic farming, Climate change, Sustainable agriculture, Soil health, Biodiversity, Climate resilience

Introduction

Agriculture is one of the sectors most affected by climate change because crop and

livestock production depend strongly on stable environmental conditions. Rising global temperatures, altered precipitation patterns, soil degradation and increasing frequency of extreme weather events are already affecting agricultural productivity and threatening food security worldwide. These impacts are particularly severe in developing regions, where millions of people depend on agriculture as their primary source of income and livelihood (Parry *et al.*, 2007; IPCC, 2023). Therefore, the development of agricultural systems that can maintain productivity while adapting to changing climatic conditions has become a global priority.

At the same time, agriculture is a significant contributor to climate change through the emission of greenhouse gases (GHGs). Direct agricultural activities contribute approximately 10–12% of global anthropogenic GHG emissions, however, the overall contribution of the food system is considerably higher when emissions associated with agricultural inputs, land-use change, food processing, transportation, and other supply-chain activities are included (Metz *et al.*, 2007; FAO, 2021). Agricultural practices such as synthetic fertilizer application, livestock production, fossil fuel consumption and land conversion are major sources of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions. Agriculture accounts for approximately 53% of global anthropogenic methane emissions and 78% of nitrous oxide emissions, highlighting the importance of transforming agricultural practices to achieve global climate targets (FAO, 2021). Despite increased efforts toward emission reduction, greenhouse gas emissions from agri-food systems have shown only limited declines, while emissions from activities beyond the farm level, including processing and transportation, have continued to increase (FAO, 2024). This situation demonstrates that agricultural systems must become part of the solution by reducing emissions and enhancing ecosystem resilience.

Organic farming has gained increasing global recognition as a sustainable alternative to conventional agricultural systems because of its ecological approach to food production. Organic agriculture is based on principles that promote the use of organic manures, compost, crop rotation, green manuring, biological pest control and conservation of natural resources while reducing dependence on synthetic fertilizers and pesticides. These practices contribute not only to the production of food but also to the maintenance of ecosystem services, soil fertility, biodiversity and long-term agricultural sustainability (Scialabba & Müller-Lindenlauf, 2010). By improving soil organic matter, organic farming enhances soil structure, water-holding capacity,

and nutrient cycling, allowing agricultural systems to better withstand drought conditions, heavy rainfall, and other climate-related stresses.

One of the major contributions of organic farming to climate change adaptation is its ability to improve soil health and ecosystem stability. The application of compost, farmyard manure, crop residues and green manure increases soil organic carbon and improves soil moisture retention, thereby reducing vulnerability to drought and erosion. Furthermore, organic farming systems generally support greater biodiversity by providing habitats for pollinators, beneficial insects, birds and soil microorganisms. This enhanced biological diversity strengthens ecosystem functions, improves natural pest regulation and increases resilience against climate-induced disturbances. Organic agricultural practices such as cover cropping, conservation tillage, agroforestry and carbon enrichment of soils also contribute to climate change mitigation by reducing greenhouse gas emissions and increasing carbon sequestration (Scialabba & Müller-Lindenlauf, 2010).

The global adoption of organic agriculture has expanded considerably in recent years, reflecting growing interest in environmentally sustainable food production. According to Willer *et al.* (2024), certified organic farmland reached approximately 96.4 million hectares in 2023, representing around 2% of the world's agricultural land, with more than 4.5 million certified organic farmers worldwide. In addition to certified systems, many small-scale farmers and indigenous agricultural communities practice organic and ecological farming methods without formal certification (Willer *et al.*, 2024). This expansion indicates increasing recognition of organic farming as a potential pathway toward sustainable agriculture and climate resilience.

However, despite its environmental benefits, organic agriculture faces several challenges in reaching its full climate mitigation potential. Current organic certification standards mainly focus on restricting synthetic inputs, while climate-specific requirements such as greenhouse gas reduction, carbon sequestration, and climate adaptation strategies are not consistently incorporated into organic standards (Scialabba & Müller-Lindenlauf, 2025). As a result, alternative approaches such as regenerative agriculture and agroecology have gained attention due to their emphasis on soil restoration, carbon storage, biodiversity conservation, and climate resilience (Kumar et al., 2024). Although these approaches share similarities with organic farming, they often lack universally accepted definitions and certification frameworks (Hatt *et al.*, 2024).

Therefore, the future of organic farming in the era of climate change will depend on its ability to evolve beyond input restrictions and incorporate stronger climate-focused management strategies. Integrating improved soil carbon management, biodiversity conservation, resource-efficient practices, and climate adaptation measures into organic systems can enhance their contribution to sustainable food production. By combining traditional ecological knowledge with scientific innovations, organic farming has the potential to become an important component of resilient, low-emission, and climate-adapted agricultural systems.

How Organic Farming Helps Address Climate Change

As the world faces rising temperatures, unpredictable weather, and growing pressure on food production, farming itself has become both a contributor to and a potential solution for climate change. Organic farming offers an alternative approach by working with nature rather than relying heavily on synthetic chemicals and intensive resource use.

One of the biggest climate benefits of organic farming is its reduced dependence on synthetic fertilizers. Manufacturing nitrogen fertilizers is highly energy-intensive and contributes significantly to global greenhouse gas emissions. By eliminating these fertilizers, organic farming avoids emissions from both fertilizer production and application, while also reducing the release of nitrous oxide (N_2O)—a greenhouse gas nearly 300 times more powerful than carbon dioxide in trapping heat over a 100-year period (IPCC, 2007; Eggleston *et al.*, 2006).

Healthy soil is another powerful climate ally. Organic farmers use practices such as composting, crop rotation, cover cropping, and the application of organic manure to build soil organic matter. These methods enable soils to capture and store carbon from the atmosphere, a process known as carbon sequestration. Healthier soils also retain more water, resist erosion and remain productive during droughts and heavy rainfall, making farms more resilient to the increasing impacts of climate change (Lal, 2004; Niggli *et al.*, 2009).

Organic farming also supports biodiversity, which strengthens the resilience of agricultural ecosystems. Instead of relying on monocultures, organic farms often grow a wider variety of crops, preserve native plant species, and maintain natural habitats such as hedgerows, trees, wetlands, and grasslands. These landscapes provide shelter for pollinators, birds, and beneficial insects that naturally control pests while improving ecosystem stability (Smith *et al.*, 2007).

Another important advantage is the efficient recycling of nutrients. Organic systems integrate crop and livestock production wherever possible so that animal manure becomes a valuable source of plant nutrients instead of waste. This reduces nutrient pollution, minimizes greenhouse gas emissions associated with excess fertilizer use, and lowers the need for manufactured agricultural inputs.

Organic farming also discourages environmentally harmful practices such as deforestation and biomass burning. Many organic standards prohibit the conversion of primary forests into farmland and encourage agro-forestry the integration of trees with crops and livestock. These practices help preserve natural carbon sinks while enhancing biodiversity and protecting soils from degradation.

Perhaps most importantly, organic farming builds resilience. Diverse cropping systems, healthier soils, and lower dependence on expensive synthetic inputs help farmers adapt to changing weather patterns and volatile input prices. In many low-input farming regions, particularly in developing countries, organic practices have been shown to maintain or even increase crop yields while restoring degraded land and improving long-term food security (Badgley *et al.*, 2007; Pretty *et al.*, 2006).

Although organic farming is not a complete solution to climate change, it demonstrates how agriculture can become part of the answer. By reducing emissions, storing carbon in soils, protecting biodiversity, and helping farming systems adapt to a changing climate, organic agriculture represents an important pathway toward a more sustainable and climate-resilient food future.

Challenges and Future Prospects

Organic farming provides significant environmental advantages, but its wider adoption is constrained by several economic, technical, and institutional challenges. During the conversion from conventional to organic production, farmers often experience temporary reductions in crop yields as soil ecosystems stabilize and alternative nutrient and pest management practices become effective. In addition, the costs associated with organic certification, compliance with standards, and documentation can be prohibitive, particularly for small-scale producers. Limited access to premium markets, inadequate extension services, insufficient technical expertise, and weak supply chains further hinder the expansion of organic agriculture, especially in developing regions.

Climate change also creates new challenges for organic farming. Increasing temperatures, irregular rainfall, and more frequent extreme weather events can intensify pest infestations, disease outbreaks, and environmental stresses, making crop management more complex. These conditions highlight the need for continued research on climate-resilient crop varieties, improved biological pest control strategies, and adaptive organic farming practices that can withstand changing climatic conditions.

Despite these constraints, the long-term outlook for organic agriculture remains positive. Technological innovations, including precision farming tools, remote sensing technologies, digital advisory services, improved weather forecasting, and advanced biological pest management techniques, are enhancing the productivity and resource-use efficiency of organic production systems. At the same time, many governments are encouraging the adoption of organic farming through financial assistance, certification support, research funding, and farmer capacity-building initiatives. Growing public awareness of environmental conservation, food safety, and healthy dietary choices is also driving a steady increase in global demand for organically produced food.

Future efforts should prioritize research aimed at improving crop productivity under organic management, developing location-specific production technologies, optimizing nutrient recycling and soil fertility management, and integrating organic farming with climate-smart agricultural approaches. Combining scientific advances with traditional ecological knowledge can further strengthen the resilience, sustainability, and long-term viability of organic farming systems in the face of climate change.

Conclusion

Climate change is creating serious challenges for agricultural systems across the world, increasing the need for farming practices that can sustain food production while protecting natural resources. Organic farming provides a viable pathway toward sustainable agriculture by improving soil quality, preserving biodiversity, enhancing the efficient use of water, and lowering greenhouse gas emissions through reduced dependence on synthetic inputs. Despite challenges such as higher production costs, limited technical expertise, and certification requirements, the expansion of organic farming can be accelerated through stronger policy support, scientific research, farmer training, and technological advancements. As global efforts continue to focus on climate resilience and sustainable development, organic agriculture is likely

to play an increasingly important role in future farming systems by supporting environmental conservation, strengthening ecosystem resilience, and ensuring sustainable and secure food production for future generations.

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TRANSLUCENT POST-LARVAE DISEASE (TPD): AN EMERGING HYPERVIRULENT THREAT TO GLOBAL SHRIMP AQUACULTURE

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Abstract

Translucent post-larvae disease (TPD), colloquially designated as "glass post-larvae disease," has recently emerged as a highly catastrophic epizootic within global Pacific white shrimp (Penaeus vannamei) hatcheries. The pathognomonic clinical features include a completely transparent body column, an atrophied or pale hepatopancreas, and a chronically empty gastrointestinal tract. Unlike acute hepatopancreatic necrosis disease (AHPND), which depends on binary pirA/pirB toxins, TPD is driven by a non-AHPND hypervirulent strain of Vibrio parahaemolyticus (VpTPD). This strain carries a novel mega-plasmid harboring a multi-subunit toxin complex encoding Vibrio High Virulent Proteins 1 and 2 (VHVP-1 and VHVP-2). Experimental immersion bioassays demonstrate that VpTPD achieves cumulative mortalities exceeding 90% within 24–48 hours in early post-larvae (PL10–PL15). Histopathological evaluation reveals profound necrotic sloughing of hepatopancreatic tubule epithelia alongside severe hemocytic enteritis within the midgut mucosa. Mitigating this biosecurity threat necessitates early PCR diagnostics, optimized hatchery hygiene, and the implementation of organic acid-based natural antimicrobials.

Keywords: Translucent post-larvae disease, *Vibrio parahaemolyticus*, *Penaeus vannamei*, Vibrio High Virulent Protein, Hepatopancreatic necrosis.

Introduction

The global sustainability of white-leg shrimp (Penaeus vannamei) aquaculture faces recurring threats from emerging bacterial pathogens belonging to the genus Vibrio. Following

the global devastation wrought by acute hepatopancreatic necrosis disease (AHPND), shrimp hatcheries have faced a new hyperacute mortality syndrome termed Translucent Post-Larvae Disease (TPD) or Glass Post-Larvae Disease (GPD)1. First documented during early 2020 within coastal nurseries in China, where it decimated 70% to 80% of regional seed stocks1, TPD has demonstrated rapid transboundary dissemination to neighboring Southeast Asian production hubs and hatcheries outside of mainland Asia2.

The clinical hallmark of TPD is the rapid manifestation of a completely transparent or translucent cephalothorax and abdomen in post-larvae between stages PL4 and PL15. Infected larvae display an empty midgut and a pale, severely shrunk hepatopancreas, resulting in massive mortality cascades approaching 90–100% within two days of initial onset. Initial diagnostic ambiguity led many hatchery operators to mistake TPD for early-stage AHPND or high-virulence viral syndromes. However, recent comparative genomic assessments have conclusively established that TPD is driven by distinct, non-AHPND strains of Vibrio parahaemolyticus (VpTPD) that lack the pirAB binary toxin genes but possess a distinct plasmid-mediated virulent mechanism1,3. The purpose of this investigation is to delineate the precise pathogenic mechanisms, histopathological features, and biosecurity counterstrategies required to control this emerging disease.

Contents

Pathogen Isolation and Molecular Characterization

The causative agent, VpTPD, can be selectively isolated from infected, moribund post-larvae showing glass-like bodies. Tissues homogenized in sterile phosphate-buffered saline (PBS) are plated on Thiosulfate Citrate Bile Salts Sucrose (TCBS) agar, yielding characteristic green, sucrose-negative colonies. Whole-genome sequencing reveals a ~5.5 Mb architecture split across two distinct chromosomes and multiple unique extrachromosomal elements.

Crucially, virulence is governed by a novel 180–187 kb plasmid encoding a toxin complex known as Vibrio High Virulent Proteins (VHVP). Comparative epidemiologic mapping has confirmed that the disease phenotype depends completely on the expression of these novel virulence components, specifically a high molecular weight protein complex greater than 100 kDa consisting of tandemly arrayed genes vhvp-1 and vhvp-21. Deletion mutant assays (Δvhvp-2) exhibit a virtual abolition of virulence, demonstrating cumulative mortalities of under 5%, which matches baseline non-pathogenic marine Vibrio control lines1.

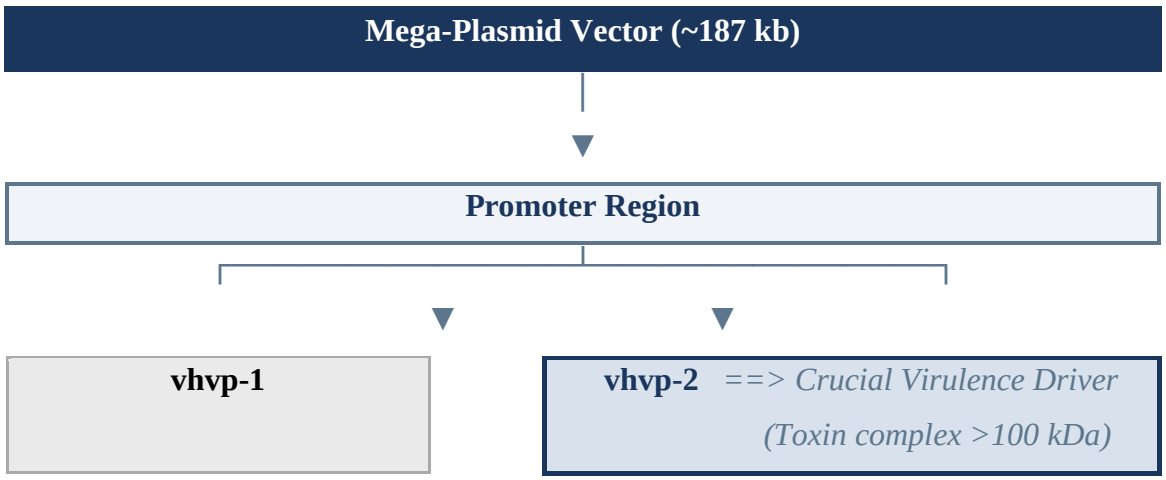


Figure 1: Simplified schematic illustration of the unique VpTPD plasmid regulatory unit.

Experimental Bioassays & Host Susceptibility

Immersion challenge protocols using healthy P. vannamei post-larvae reveal a stark, dose-dependent, and age-dependent mortality structure. When exposed to an operational immersion dosage of 1 × 10^4 CFU/mL, early post-larval stages (PL10–PL15) exhibit rapid onset of translucent clinical signs within 12 hours post-exposure (hpe).

Data compiled across multiple uniform tank groups indicate that younger larval structures have a significantly lower median lethal concentration (LC50) than older post-larvae. At 96 hpe, PL15 groups demonstrate an LC50 threshold of 8.51 × 10^2 CFU/mL, highlighting its extreme potency compared to traditional AHPND lines2. Conversely, advanced post-larvae (PL30) demonstrate a pronounced capacity for survival, maintaining less than 20% cumulative mortality under equivalent exposure regimens, suggesting a development-dependent maturation of the gut mucosal barrier or systemic immunity.

Histopathology: Target Organs and Systemic Alterations

Histological profiles of VpTPD-infected post-larvae show distinct, acute lesions centered on two primary target zones: the hepatopancreas and the midgut. Fixation of diseased tissue specimens in Davidson's fixative followed by hematoxylin and eosin (H&E) staining highlights the pathognomonic features detailed below:

- **Hepatopancreatic Tubule Disruption:** The primary event is characterized by the absolute loss of specialized epithelial cell types (B, F, R, and E cells). The tubule epithelium displays marked vacuolation followed by extensive necrotic desquamation into the central tubule

lumen. Massive microcolony arrays of Gram-negative rods actively infiltrate the sloughed cell mass.

- **Hemocytic Enteritis:** Unlike standard AHPND, VpTPD induces a severe inflammatory pathology within the midgut proper. The mucosal epithelium undergoes detached degeneration, accompanied by a heavy accumulation of systemic hemocytes forming a dense, thick layer within the intestinal sub-mucosa, causing an inflammatory block.

Diagnostic Feature	AHPND Pathology (VpAHPND)	TPD Pathology (VpTPD)
Primary Toxin Origin	Plasmid-encoded binary pirA/pirB toxin	Plasmid-encoded toxin complex (vhvp-1/vhvp-2)
Target Organ Focus	Exclusively restricted to Hepatopancreas	Concurrent Hepatopancreas & Midgut damage
Intestinal Lesions	Primarily clear or containing fluid	Hemocytic enteritis with thick mucosal inflammation
Susceptible Stages	Post-larvae, Juveniles, and Adults	Highly restricted to early Post-Larvae (PL4–PL15)

Table 1: Differential pathological and molecular diagnosis separating AHPND from emerging TPD.

Biosecurity Interventions and Therapeutic Management

Given the velocity of VpTPD mortality, traditional therapeutic options are highly constrained. Standard antibiotic profiling reveals that while these environmental strains are consistently resistant to common β-lactams, they remain sensitive to florfenicol and doxycycline2. However, prophylactic use of antibiotics faces intense global regulatory restrictions due to resistance concerns.

Consequently, research has shifted toward natural antimicrobial additives as non-antibiotic alternatives. Synergistic liquid formulations comprised of organic acid networks combined with plant extracts (such as citrus and olive active compounds) have demonstrated strong potential. At sub-inhibitory inclusion limits (0.05%), these natural matrices significantly downregulate the transcript expression levels of critical virulence factors (vhvp-1 and vhvp-2) while concurrently protecting primary shrimp gut cells from bacterial adhesion and subsequent oxidative damage4.

Acknowledgement

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EX POST FACTO RESEARCH DESIGN IN THE ERA OF BIG DATA AND ARTIFICIAL INTELLIGENCE

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Abstract

The emergence of big data and artificial intelligence (AI) has transformed research by enabling the analysis of large and complex datasets. In this context, ex post facto research design has gained renewed importance as it allows researchers to investigate relationships among variables without manipulating them. This design is particularly valuable in fields such as agriculture, forestry, education, health and social sciences, where experimental studies are often impractical or unethical. The integration of AI, machine learning, remote sensing and data analytics has improved the accuracy, efficiency and predictive capability of ex post facto studies. This article explores the concept of ex post facto research design, its relevance in the era of big data, the role of AI in enhancing observational research, and its emerging applications across various disciplines. It also highlights the opportunities and challenges associated with using advanced digital technologies in non-experimental research. The article aims to provide researchers with a clear understanding of how modern analytical tools are reshaping ex post facto research and expanding its potential for evidence-based decision-making.

Keywords: Ex post facto research design, Big data, Artificial intelligence, Machine learning, Observational research, Data analytics.

Introduction

The rapid growth of digital technologies has transformed the way research is conducted

across scientific disciplines. The increasing availability of big data, advances in artificial intelligence (AI) and the widespread use of digital technologies have enabled researchers to analyze complex problems with greater speed, accuracy and efficiency. These developments have expanded the scope of research methodologies, particularly those that rely on existing data rather than controlled experimentation.

Ex post facto research is a non-experimental research design used to investigate relationships among variables after events have already occurred. Unlike experimental research, the researcher does not manipulate the independent variables but observes and analyzes naturally existing conditions to understand possible associations or outcomes. This design is particularly useful when experimental manipulation is impractical, unethical or impossible making it widely applicable in agriculture, forestry, education, health sciences, economics, environmental studies and other social sciences.In recent years, the availability of large-scale datasets from satellite imagery, remote sensing, sensor networks, mobile applications, electronic health records, government databases, and social media has created new opportunities for ex post facto research. At the same time, AI-powered techniques such as machine learning, data mining, and predictive analytics have enabled researchers to extract meaningful patterns, identify hidden relationships and generate evidence from complex observational data. These technologies complement traditional statistical methods by improving the efficiency and depth of data analysis.The integration of big data and AI has therefore transformed ex post facto research from a conventional observational approach into a more robust, data-driven methodology. Researchers can now investigate complex real-world phenomena, develop predictive models, and support evidence-based decision-making with greater confidence. However, the increasing reliance on digital data also raises important concerns regarding data quality, privacy, ethical use and the interpretation of AI-generated findings.

This article provides an overview of ex post facto research design in the context of the digital era. It discusses the fundamental principles of the design, explores the contributions of big data and artificial intelligence to observational research and highlights their applications, opportunities, and challenges across diverse research fields.

Ex Post Facto Research: A Brief Overview

The term *ex post facto* is a Latin phrase meaning **"after the fact."** Ex post facto research is one of the most widely used non-experimental research designs for investigating naturally

occurring events and phenomena. Rather than manipulating variables, researchers examine existing conditions to understand possible relationships among them. This approach is particularly valuable when experimental studies are impractical, unethical, or impossible to conduct. Over the years, ex post facto research has become an important tool for generating evidence from real-world situations, helping researchers understand complex issues and supporting informed decision-making across various disciplines.

Key Characteristics of Ex Post Facto Research:

- **Non-experimental design** -Variables are not manipulated by the researcher.
- **After the event study** -Research is conducted after the occurrence of an event or phenomenon.
- **Observational approach** - Data are collected under natural conditions without intervention.
- **Use of existing information** -Relies on surveys, records, databases, reports, satellite imagery, or historical data.
- **No random assignment** - Study groups exist naturally rather than being experimentally formed.
- **Suitable for real-world problems** -Useful where experimentation is impractical or unethical.
- **Supports decision-making** -Helps identify associations, trends, and patterns that can guide future research and policy.

How Big Data is Transforming Ex Post Facto Research?

The digital era has transformed the way ex post facto research is conducted. Researchers now have access to vast amounts of information generated from satellite imagery, remote sensing, drones, sensor networks, government databases, mobile applications, electronic records and social media. These large and diverse datasets, collectively known as **big data**, provide a comprehensive picture of real-world events and processes.Unlike traditional studies that relied on limited observations, big data enables researchers to analyse thousands or even millions of records across different locations and time periods. This not only improves the reliability of research findings but also allows the identification of trends and relationships that might otherwise remain unnoticed. Consequently, big data has greatly expanded the scope and practical value of ex post facto research.

The Role of Artificial Intelligence:

Artificial intelligence (AI) is revolutionizing ex post facto research by making data analysis faster, smarter and more accurate. AI techniques such as machine learning, data mining, deep learning and predictive analytics can process large datasets efficiently, uncover hidden patterns, classify information and forecast future outcomes.For example, AI can analyse years of weather records to predict crop productivity, interpret satellite images to monitor forest health, or evaluate farmers' management practices to identify factors affecting yield. By automating complex analyses and improving predictive accuracy, AI enables researchers to derive meaningful insights from observational data that would be difficult to obtain through conventional statistical methods alone.

Big Data and AI: A Powerful Combination

The integration of big data and artificial intelligence has significantly strengthened ex post facto research. While big data provides extensive information from multiple sources, AI converts these data into useful knowledge through advanced analytical techniques. Together they enable researchers to investigate complex problems with greater precision, efficiency, and confidence.This combination is particularly valuable for studying large-scale and long-term issues such as climate change, forest degradation, agricultural productivity, disease outbreaks and socio-economic development. Rather than replacing traditional research methods, big data and AI complement them by improving data analysis and supporting evidence-based decision-making.

Applications Across Disciplines:

The integration of ex post facto research with big data and AI has created new opportunities across several disciplines.

- **Agriculture:** Crop yield prediction, nutrient management, pest and disease forecasting, precision farming.
- **Forestry:** Biomass estimation, forest health monitoring, carbon stock assessment, wildfire prediction bamboo plantation management.
- **Health Sciences:** Disease surveillance, risk assessment and public health planning.
- **Education:** Student performance analysis, learning behaviour and educational policy evaluation.

- **Social Sciences:** Behavioural studies, demographic analysis, socio-economic research and policy assessment.

These applications demonstrate how observational research supported by modern technologies contributes to solving practical problems and improving decision-making.

Benefits of Ex Post Facto Research in the Era of Big Data and Artificial Intelligence

- Enables analysis of large and diverse datasets from multiple sources.
- Reduces dependence on costly and time-consuming experimental studies.
- Facilitates the study of real-world problems where experimentation is impractical or unethical.
- AI-powered tools improve the speed and accuracy of data analysis.
- Machine learning helps identify hidden patterns and complex relationships in observational data.
- Enhances predictive modelling for agriculture, forestry, healthcare, and environmental management.
- Integrates data from satellites, drones, IoT sensors, GIS, and digital databases for comprehensive analysis.
- Supports evidence-based decision-making in research, policy, and resource management.
- Allows continuous monitoring of long-term trends using historical and real-time data.
- Improves the scalability of research by analysing data across regions, populations and time periods.
- Encourages interdisciplinary research by integrating information from multiple scientific fields.
- Supports sustainable development through data-driven planning and management.

Challenges of Ex Post Facto Research in the Era of Big Data and Artificial Intelligence

- Cannot establish definitive cause-and-effect relationships due to the absence of experimental control.
- Quality of findings depends heavily on the accuracy and completeness of available data.
- Integrating data from multiple sources can be difficult because of differences in formats, scales, and standards.
- AI models may produce biased results if trained on incomplete or unrepresentative datasets.

- Raises concerns about data privacy, security and ethical use of digital information.
- Requires advanced skills in data science, machine learning, statistics, GIS and programming.
- Large datasets demand substantial computational power and storage infrastructure.
- Complex AI algorithms may lack transparency, making results difficult to interpret (black-box problem).
- Missing, inconsistent, or noisy data can reduce the reliability of analyses.
- Over-reliance on AI may lead researchers to overlook contextual or field-based knowledge.
- Limited access to high-quality datasets and advanced technologies can restrict research, especially in developing regions.
- Ensuring the reproducibility and validation of AI-based findings remains a significant challenge.

Future Outlook

The future of ex post facto research lies in the continued integration of artificial intelligence, big data, cloud computing, remote sensing, geographic information systems (GIS) and Internet of Things (IoT) technologies. These innovations will enable researchers to analyse complex datasets in real time, improve predictive modelling and support sustainable solutions in agriculture, forestry, environmental management, healthcare and education.As digital technologies continue to advance, ex post facto research is expected to become more accurate, efficient and influential in addressing emerging scientific and societal challenges.

Conclusion

Ex post facto research remains one of the most practical and widely used non-experimental research designs for studying naturally occurring events. The emergence of big data and artificial intelligence has transformed this approach by enabling researchers to analyse extensive observational datasets with greater speed and accuracy. Although the design cannot establish definite causality, it provides valuable evidence for understanding complex real world problems and supporting informed decision-making. By integrating traditional observational methods with modern analytical technologies, ex post facto research is poised to play an increasingly important role in scientific discovery and sustainable development.

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MULTI- SEED WASTE WATER FILTRATION SYSTEM

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Abstract

A simple and low cost water filter made by using three components which is considered as agricultural waste i.e seeds of mango, dates and tamarind .It is converted into biochar through a process called pyrolysis (Degrading at high temperature 300-900°c in an oxygen free environment). In this article let us get to know how seeds help in filtration

Introduction

Water pollution is a major draw back in all over countries. People in rural areas mostly consume water from pond which is turbid and dirt as they couldn't afford clean and purified water through filters since it's costly and people can't afford it. Considering this seeds which are thrown from industries, juice shops, etc are collected and made into biochar and used to purify muddy water



Principle and how it works:

Biochar is a black material obtained through a process of pyrolysis (heating at high temperature in an oxygen free environment to degrade it). It has a major role in purifying muddy water it has minute pores and thus it withhold the dust into it and sends off purified water.



Similar to act as a sponge

Three different seeds play three different role :

1. Dates seed - It removes bad odour
2. Mango seed - It removes heavy metals
3. Tamarind seed - It maintains ph balance

The principle behind this is gravity fed principle:

Step 1: Pour dirty water

Step 2: Cotton (Traps small particles)

Step 3: Sand (Fine particles removed)

Step 4: Fruit - seed activated carbon (dates + mango + tamaranid)

Step 5: Gravel (supports entire later)

Step 6: Filtered water obtained

No electricity need only it works with gravity



Cost economics:

Plastic bottle	1 piece	₹ 200
Mango seed	1 kg	₹60
Date seed	1 kg	₹60
Tamarind seed	1 kg	₹30
Sand and gravel	1 kg	₹15
Cotton	3 piece	₹60
Beaker / cup	1 piece	₹60
	Total cost =	₹ 475

Environmental impacts :

Since many people focus on reducing carbon dioxide emissions this help to reduce when are seeds (organic material) converted to biochar. It helps to maintain climate since it act as carbon sink by trapping carbon dioxide on it

This is important now ! Why ?

✓ It has been said that , around 1 million seeds of mango round year from juice pulp factories throw it as waste

✓ These seeds have no use in most countries

✓ No electricity need

✓ No special equipment needed

- ✓ No chemicals needed
- ✓ Any village or community of people can easily afford it
- ✓ Easily made by individuals
- ✓ carbon has to be replaced 6 months once

Research says that

Around 2.1 to 2.2 billion people lack clean and purified drinking water it seems to be unsafe. considering their health and free from water borne diseases like chlorea and typhoid etc....it has to be ensured to drink purified water

Scientific support:

Studies reveal that mango seed biochar can remove upto 80% of toxic elements, dates seed can removes odour and 85% of industrial dyes etc and tamarind seeds alters and maintain pH. It's not just a theory it's a solid science.

Future opportunities:

Some low cost and cheap sensors may be added to the filter to check and monitor the pH, turbidity (muddiness) and tell when the biochar has to be replaced

Nothing goes waste here since the removed biochar can be added to soil.since , it enhance the fertility of soil

Conclusion

It's concluded that something that is thrown and unnoticed plays a major role in converting trash to cash. It's an simple and easy to purify water and can be easily afforded by anyone mostly people surviving in rural areas. Since it's is simple and cheap

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Dried java plum (*syzygium cumini)* seeds as an alternative activated carbon present in water filter.Carga regional science high school retrieved from scribd

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CAN ORGANIC AGRICULTURE HELP END WORLD HUNGER?

Article ID: AG-VO6-I07-162

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Abstract

The world produces enough food to feed everyone, yet millions of people still suffer from hunger. This shows that hunger is not only caused by low food production but also by poverty, unequal food distribution, conflict, climate change, food loss and waste, and economic challenges. As people become more concerned about protecting the environment and producing safe food, organic agriculture has gained worldwide attention. Organic farming helps improve soil health, conserve biodiversity, reduce pollution, and make farming more resilient to climate change. However, it also faces challenges such as lower yields in some crops, higher labour requirements, and limited availability of organic nutrient sources. Therefore, organic agriculture alone cannot end world hunger. A lasting solution requires better food distribution, reduced food waste, supportive government policies, scientific innovation, and sustainable farming practices. Organic agriculture can play an important role as part of this broader approach, helping to build a healthier, more sustainable, and food-secure future for people and the planet.

Keyword: Organic agriculture; world hunger; food security; sustainable agriculture; climate resilience.

Introduction

The world has never produced as much food as it does today. According to the Food and Agriculture Organization (FAO), global cereal production has exceeded 2.8 billion tonnes annually (**FAO, 2024**). Advances in agricultural technology, improved crop varieties, irrigation, fertilizers, and mechanization have enabled food production to keep pace with a global

population that has now surpassed 8 billion (**United Nations, 2024**). Yet, despite this achievement, hunger continues to be one of the greatest challenges. Recent UN estimates show that more than 730 million people suffered from hunger in 2023, while over 2 billion people experienced moderate or severe food insecurity. Countries such as Somalia, South Sudan, Yemen, Chad, the Central African Republic, Burundi, and Madagascar continue to record some of the highest levels of hunger due to a combination of poverty, conflict, climate change, and economic instability (**Concern Worldwide and Welthungerhilfe, 2024**). These statistics highlight an important fact that, the world hunger is not simply a problem of producing enough food but of ensuring that food reaches those who need it.

As concerns about climate change, soil degradation, biodiversity loss, and environmental pollution continue to grow, attention has increasingly turned towards organic agriculture as a more sustainable way of producing food. Unlike conventional farming, organic agriculture relies on natural nutrient sources, crop rotations, biological pest management, and healthy soil ecosystems while avoiding synthetic fertilizers and pesticides. The organic farming sector has expanded steadily over the past two decades. Today, more than 98 million hectares of agricultural land across nearly 190 countries are managed organically. However, this represents only about 2% of the world's agricultural land, meaning that most global food production still comes from conventional farming systems (**Willer et al., 2025**). Although demand for organic food continues to increase, its contribution to the food supply remains relatively small.

This has led to one of the most debated questions in modern agriculture: Can organic agriculture feed the world? Critics argue that lower yields, limited availability of organic nutrient sources, higher labour requirements, and difficulties in managing pests and diseases make it challenging for organic farming alone to meet the food demands of a growing global population. Supporters, however, believe that healthier soils, improved biodiversity, reduced environmental impacts, and greater resilience to climate change make organic agriculture an essential component of future food systems.

Is hunger really caused by a lack of food?

At first glance, the solution to world hunger appears to be producing more food. But the world already grows enough food to feed its entire population. Every year, billions of tonnes of cereals, fruits, vegetables, pulses, and other food commodities are produced worldwide. Yet, millions of people still go hungry. The reason is that hunger is not merely a consequence of

insufficient food production. Poverty remains the biggest barrier, preventing millions of families from purchasing nutritious food even when it is available. In many developing countries, poor transportation, inadequate storage facilities, and weak market infrastructure prevent food from reaching remote communities. Large quantities of food are also lost during harvesting, storage, transportation, and retailing, while enormous amounts are wasted by consumers.

According to the United Nations, nearly one-third of the food produced globally is either lost or wasted. Wars disrupt farming activities, damage infrastructure, and interrupt food supply chains, leaving entire populations vulnerable to hunger. Climate change adds another layer of complexity that reduce agricultural productivity. These realities clearly show that hunger is more a problem of access than availability. The factors influencing on world hunger is given in figure

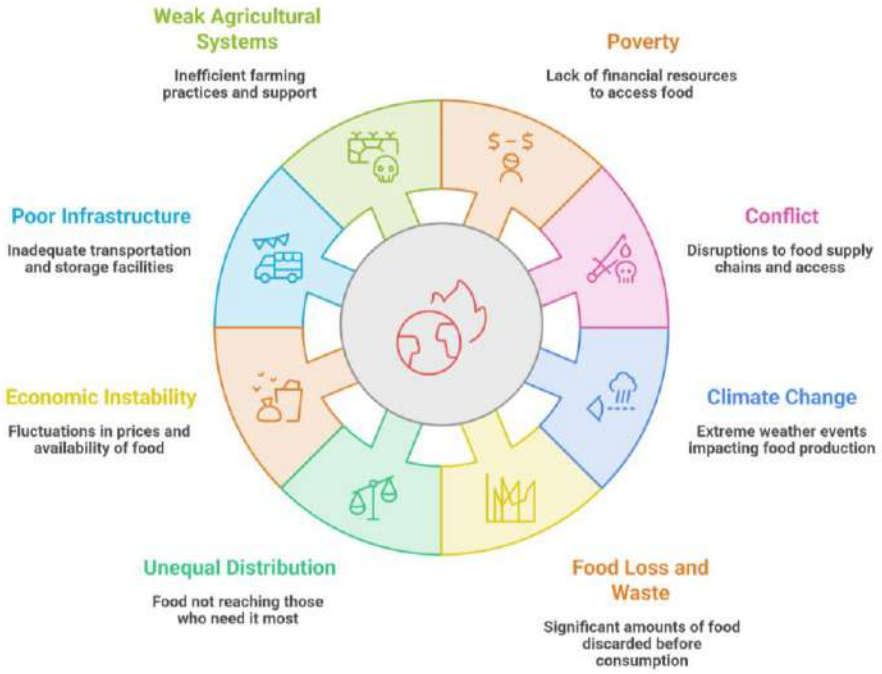


Figure 1. The major reasons for world hunger

Why is organic agriculture gaining global attention?

As the environmental impacts of intensive agriculture become increasingly visible, interest in organic agriculture has grown rapidly across the world. Consumers are becoming more conscious of the food they eat, while governments and researchers are searching for farming systems that protect natural resources without compromising future food production. Organic agriculture promotes healthy soil, and it supports beneficial microorganisms, improve water retention, and reduce erosion, making farms more resilient during droughts and heavy

rainfall. It also encourages biodiversity by providing habitats for pollinators, birds, and beneficial insects that naturally help control pests. Another reason for the growing popularity of organic farming is its reduced reliance on synthetic fertilizers and pesticides, which can contribute to environmental pollution when used excessively. Many consumers also associate organic food with safety, environmental responsibility, and sustainable production, leading to a steady increase in global demand for organic products. Although organic agriculture currently occupies only a small proportion of the world's farmland, its emphasis on ecological sustainability has made it an important part of discussions on the future of agriculture.

Can organic farming produce enough food?

This is perhaps the most debated question surrounding organic agriculture. Supporters argue that organic farming offers long-term environmental benefits, while critics question whether it can produce enough food to feed a growing global population. Organic farming strengthens soil health by increasing organic matter and improving soil structure. This also reduce dependence on synthetic fertilizers and pesticides by relying on locally available organic resources and natural pest management practices. These approaches contribute to cleaner water, healthier ecosystems, and improved biodiversity. The major advantage of organic agriculture is given below in figure 2.

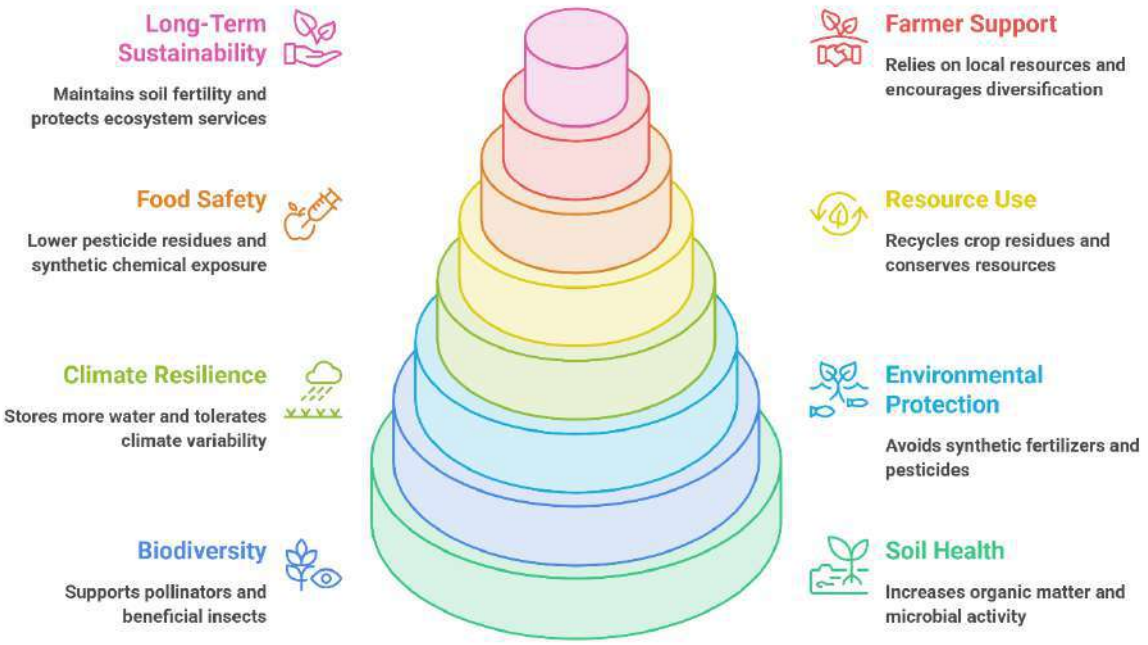


Figure 2. The major advantages of organic agriculture

However, organic farming also faces important challenges. Scientific studies have shown that yields of many crops under organic management are often lower than those under conventional farming, although the difference varies depending on the crop, location, and management practices. It requires more labour for weed management and compost preparation. Ensuring a continuous supply of organic nutrient sources such as farmyard manure and compost can also be difficult, particularly where livestock populations are limited. Pest and disease management may become more challenging under severe infestations, and farmers often experience a transition period before soil fertility improves and yields stabilize. So, organic agriculture should not be judged solely by crop yield. Its contribution to environmental sustainability, soil health, biodiversity conservation, and climate resilience must also be considered when evaluating its role in future food systems.

Can organic agriculture alone end world hunger?

The simple answer is no. Organic agriculture alone can't end world hunger because hunger is influenced by many interconnected social, economic, and political factors. Even if agricultural production increases, people may remain hungry if they cannot afford food or if food cannot reach them due to conflict, poor infrastructure, or economic inequality. Nevertheless, organic agriculture can make valuable contributions towards achieving global food security. By improving soil fertility, conserving biodiversity, reducing environmental degradation, and promoting sustainable use of natural resources. Rather than viewing organic agriculture as the only solution, it should be considered as one important component of a broader strategy for achieving sustainable food systems.

The Way Forward

Ending world hunger requires a combination of scientific innovation, sustainable farming, effective public policies, and social commitment. Improving food distribution systems, reducing post-harvest losses and food waste, supporting smallholder farmers, investing in agricultural research, and strengthening climate-resilient farming practices are all essential steps. Organic agriculture can complement these efforts by promoting healthier soils, conserving biodiversity, and reducing environmental impacts. At the same time, advances in plant breeding, precision agriculture, integrated nutrient management, and climate-smart farming can further improve productivity while protecting natural resources. The future of agriculture should not be viewed as a choice between organic and conventional farming. Instead, the focus should be on

adopting farming practices that are productive, environmentally sustainable, economically viable, and socially inclusive.

Conclusion

The question, **'*Can organic agriculture help end world hunger*?'**, does not have a simple yes-or-no answer. The world already produces sufficient food, yet millions continue to suffer from hunger because of poverty, inequality, conflict, climate change, and inefficient food systems. Organic agriculture alone cannot solve these complex challenges. However, its emphasis on healthy soils, biodiversity conservation, environmental sustainability, and resilience makes it an important part of the solution. When combined with scientific innovation, sound public policies, efficient food distribution, and reduced food waste, organic agriculture can contribute significantly to building a food-secure and sustainable future. The challenge before us is not merely to produce more food, but to ensure that everyone has access to nutritious food while protecting the natural resources on which future generations depend.

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ELECTROACTIVE BIOFILMS: A NEW FRONTIER IN AQUACULTURE WASTE MANAGEMENT

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Abstract

The rapid expansion of aquaculture has led to increased generation of organic wastes, excess nutrients, and deteriorating water quality, creating challenges for sustainable production. Electroactive biofilms, formed by microorganisms capable of transferring electrons to external surfaces through extracellular electron transfer, have emerged as a promising solution for aquaculture waste management. These living electrical networks can simultaneously degrade organic pollutants, facilitate nutrient removal, generate electricity, and function as biosensors for water quality monitoring. Their applications in wastewater treatment, sediment remediation, microbial fuel cells, and smart aquaculture systems highlight their potential to transform waste into valuable resources. As research advances, electroactive biofilms may become important components of future sustainable and energy-efficient aquaculture technologies.

Keywords: Electroactive biofilms; Electro microbiology; Extracellular electron transfer; Microbial fuel cells; Aquaculture; Wastewater treatment; Biosensors; Bio electrochemical systems.

1. Introduction

Microorganisms play essential roles in nutrient cycling, decomposition, and wastewater treatment. Traditionally, microbial respiration was believed to involve the transfer of electrons to soluble compounds such as oxygen, nitrate, or sulfate. However, recent discoveries have identified microorganisms capable of transferring electrons directly to external solid surfaces such as minerals, sediments, and electrodes. When these microorganisms colonize conductive materials and form structured communities, they create electroactive biofilms. Unlike conventional biofilms, electroactive biofilms function as living electrical networks through a process known as extracellular electron transfer (EET), allowing microorganisms to transfer electrons beyond the cell and effectively "breathe" conductive surfaces. This unique ability has revolutionized microbial ecology and enabled the development of bioelectrochemical technologies that combine wastewater treatment with electricity generation.

The technology holds particular promise for aquaculture, where intensive fish and shrimp farming generates large quantities of organic wastes and nitrogenous compounds that deteriorate water quality. By utilizing these wastes as substrates for microbial metabolism while simultaneously producing electrical current, electroactive biofilms offer a sustainable and energy-efficient approach to aquaculture waste management.

2. ELECTROACTIVE BIOFILMS: A NEW FORM OF MICROBIAL RESPIRATION

The defining feature of electroactive biofilms is their ability to perform extracellular electron transfer. During conventional microbial respiration, electrons produced during metabolism are transferred to soluble electron acceptors such as oxygen. In contrast, electroactive microorganisms transport electrons outside the cell to insoluble materials including iron oxides, sediments, and artificial electrodes. This adaptation enables microorganisms to survive in oxygen-limited environments such as pond sediments, wetlands, estuaries, and marine mudflats. As these microorganisms colonize conductive surfaces, they form electrically connected biofilms composed of microbial cells embedded in extracellular polymeric substances. Electron transfer within these biofilms is facilitated by outer membrane cytochromes, conductive pili known as microbial nanowires, and soluble electron shuttle molecules. Together, these components transform the biofilm into a biological electrical circuit capable of conducting electricity and supporting applications in wastewater treatment, biosensing, renewable energy production, and environmental biotechnology.

3. DISCOVERY OF ELECTROACTIVE MICROORGANISMS AND THE EMERGENCE OF ELECTROMICROBIOLOGY

The existence of electroactive microorganisms was first recognized during investigations of microbial processes occurring in aquatic sediments and subsurface environments. Scientists studying iron and manganese cycling observed that certain bacteria were capable of reducing insoluble metal oxides located outside the cell despite the apparent inability of these minerals to cross the microbial cell membrane. This raised an important question: how were electrons being transferred from microbial metabolism to solid minerals that were physically separated from the cell interior?

The answer emerged with the discovery of bacteria belonging to genera such as *Geobacter* and *Shewanella*, which were found to possess specialized mechanisms for transporting electrons beyond the cell surface. Unlike conventional microorganisms that rely on soluble compounds such as oxygen or nitrate as electron acceptors, these organisms could utilize insoluble iron oxides, manganese minerals, and even electrodes as respiratory partners.

This remarkable metabolic capability fundamentally altered long-standing concepts of microbial respiration and led to the development of an entirely new field known as electromicrobiology. The discipline focuses on understanding how microorganisms exchange electrons with their environment and how these interactions can be harnessed for practical applications such as wastewater treatment, renewable energy generation, bioremediation, and biosensing.

The discovery of microbial electricity generation also paved the way for the development of bioelectrochemical systems, particularly microbial fuel cells, in which microorganisms convert chemical energy stored in organic matter directly into electrical energy. Today, electromicrobiology represents one of the fastest-growing areas of environmental biotechnology and continues to reveal previously unknown interactions between microorganisms and their physical environment.

4. MECHANISMS OF EXTRACELLULAR ELECTRON TRANSFER

The defining feature of electroactive microorganisms is their ability to transfer electrons generated during metabolism to external solid surfaces through a process known as extracellular electron transfer (EET). This process enables microorganisms to utilize minerals, sediments, or

electrodes as terminal electron acceptors and forms the basis of electricity generation in electroactive biofilms.

4.1 Direct Electron Transfer

In direct electron transfer, microorganisms establish physical contact with conductive surfaces and transfer electrons through specialized proteins known as outer membrane cytochromes. These proteins act as biological conductors that shuttle electrons from the microbial electron transport chain directly to an external acceptor such as an iron oxide particle or electrode surface.

This mechanism is highly efficient because electrons move directly from the cell to the electron acceptor without requiring intermediate carriers. However, it requires intimate contact between the microorganism and the conductive surface, restricting electron transfer to cells located close to the electrode.

4.2 Microbial Nanowires

Many electroactive microorganisms overcome the limitations of direct contact by producing conductive filamentous appendages known as microbial nanowires. These structures, which are modified pili or extracellular cytochrome filaments, function as microscopic electrical cables that transport electrons over distances much greater than the dimensions of individual cells.

Microbial nanowires allow cells located deeper within a biofilm to participate in electron transfer even when they are not directly attached to the electrode surface. This creates electrically connected microbial communities in which electrons generated by one cell can be transported through the biofilm and ultimately reach the external electron acceptor.

The discovery of microbial nanowires revolutionized our understanding of biofilms by demonstrating that microbial communities can function as coordinated electrical networks rather than isolated collections of cells.

4.3 Electron Shuttle Molecules

Some electroactive microorganisms employ a third strategy known as mediated electron transfer. In this mechanism, microorganisms release soluble redox-active compounds such as flavins, phenazines, and quinones into their surroundings. These molecules act as electron shuttles, accepting electrons from microbial cells and transporting them to external electron acceptors before returning to repeat the cycle.

Unlike direct electron transfer, mediated transfer does not require physical contact between the microorganism and the conductive surface, allowing electron exchange to occur over greater distances. This mechanism is particularly important in thick biofilms and sediment environments where direct interactions with electrodes may be limited.

The coexistence of direct transfer, microbial nanowires, and electron shuttle molecules provides electroactive biofilms with remarkable flexibility and efficiency, enabling them to thrive in diverse aquatic environments and making them highly attractive for bioelectrochemical applications.

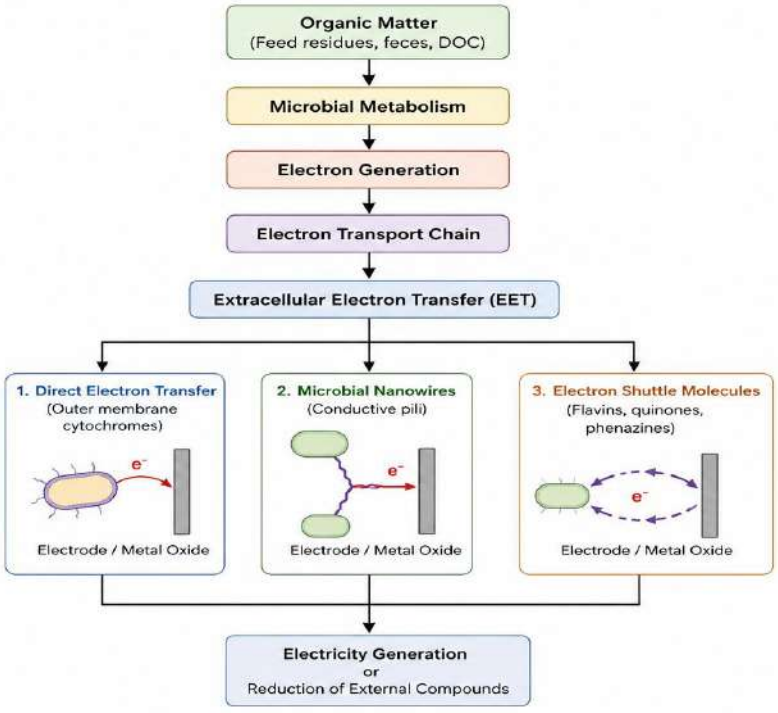


Figure 1. Mechanisms of extracellular electron transfer in electroactive biofilms.

5. ELECTROACTIVE MICROORGANISMS IN NATURAL AQUATIC ECOSYSTEMS

Electroactive Microorganism	Common Habitat	Primary Electron Acceptor	Ecological Role
Geobacter spp.	Freshwater sediments, wetlands, pond bottoms	Iron (Fe^{3+}) oxides, electrodes	Iron reduction, organic matter degradation, electricity generation
Shewanella spp.	Marine sediments, estuaries, coastal	Iron and manganese oxides,	Metal reduction and extracellular electron

	waters	electrodes	transfer
Desulfuromonas spp.	Marine sediments and anoxic environments	Sulfur compounds and iron oxides	Sulfur cycling and sediment biogeochemistry
Geothrix spp.	Wetlands and anaerobic soils	Iron oxides	Organic carbon oxidation and iron reduction
Rhodoferax spp.	Freshwater sediments and cold aquatic habitats	Iron oxides and electrodes	Carbon cycling and bioelectricity generation

6. WHY AQUACULTURE NEEDS ELECTROACTIVE BIOFILMS

- **Increased waste generation:** Intensive aquaculture produces large amounts of uneaten feed, fecal matter, and dissolved organic wastes.
- **Water quality deterioration:** Accumulation of organic matter increases nutrient loading and favors opportunistic pathogens.
- **Formation of toxic metabolites:** Anaerobic pond sediments can produce harmful compounds such as **ammonia, methane, and hydrogen sulfide**.
- **High operational costs:** Conventional treatment methods rely heavily on aeration, filtration, and water exchange.
- **Waste-to-energy approach:** Electroactive biofilms utilize aquaculture wastes as substrates for microbial metabolism.
- **Simultaneous treatment and energy recovery:** These systems remove pollutants while generating electrical current through extracellular electron transfer.
- **Supports sustainable aquaculture:** Electroactive biofilms convert waste into a resource, aligning with principles of the **circular bioeconomy** and resource-efficient production.

7. APPLICATIONS OF ELECTROACTIVE BIOFILMS IN AQUACULTURE

Application	How Electroactive Biofilms Work	Benefits in Aquaculture
Wastewater Treatment and Organic Matter Removal	Electroactive microorganisms utilize uneaten feed, fecal matter, and dissolved organic compounds as substrates and transfer the released	Reduces organic pollution, lowers biological oxygen demand (BOD), and improves water quality.

	electrons to conductive surfaces.	
Sediment Remediation in Ponds	Conductive materials placed in pond sediments serve as alternative electron acceptors, promoting oxidation of reduced compounds.	Minimizes the accumulation of ammonia, methane, and hydrogen sulfide while improving sediment health.
Nitrogen Removal and Ammonia Management	Bioelectrochemical systems stimulate nitrifying and denitrifying bacteria, enhancing nitrogen transformations.	Facilitates conversion of toxic ammonia and nitrate into harmless nitrogen gas and reduces water exchange requirements.
Microbial Fuel Cells (MFCs)	Electroactive biofilms growing on anodes oxidize organic wastes and transfer electrons through an external circuit to generate electricity.	Enables simultaneous wastewater treatment and recovery of energy from aquaculture wastes.
Self-Powered Biosensors	Variations in microbial activity produce measurable changes in electrical current generated by the biofilm.	Provides real-time monitoring of water quality parameters and early detection of environmental stress.
Integration with Recirculating Aquaculture Systems (RAS)	Electroactive reactors function alongside conventional biofilters to remove residual dissolved organic matter while producing electrical signals.	Enhances treatment efficiency and supports precision aquaculture and automated management systems.

8. CHALLENGES LIMITING COMMERCIAL APPLICATION

- **Low electrical output:** Current bioelectrochemical systems generate limited electricity, sufficient for sensors but inadequate for operating major equipment such as aerators and pumps.
- **High electrode costs:** Conductive materials such as graphite, carbon cloth, and carbon felt increase installation costs, particularly in large-scale pond systems.

- **Slow biofilm establishment:** Electroactive biofilms require time to develop stable and efficient microbial communities.
- **Environmental sensitivity:** Biofilm performance can be affected by changes in temperature, salinity, pH, and organic loading conditions.
- **Scale-up difficulties:** Technologies successful in laboratories often face challenges when applied under commercial farming conditions.
- **Limited ecological understanding:** Interactions between electroactive microorganisms and other beneficial microbial groups such as nitrifiers, denitrifiers, probiotics, and biofloc-associated bacteria remain poorly understood.

FUTURE PROSPECTS: TOWARDS SMART AQUACULTURE

The future of aquaculture will depend on technologies that improve productivity while simultaneously reducing environmental impacts and resource consumption. Electroactive biofilms offer a unique opportunity to achieve these objectives by transforming microbial communities from passive waste degraders into active components of farm management systems. One promising direction is the development of self-powered biosensors capable of continuously monitoring water quality parameters such as ammonia, organic loading, and toxic compounds in real time. Since electrical current production is directly linked to microbial activity, electroactive biofilms may provide early warning signals of deteriorating environmental conditions long before visible stress responses appear in cultured organisms.

Another exciting possibility involves integrating electroactive biofilms with existing sustainable technologies such as biofloc systems and recirculating aquaculture systems. In biofloc technology, microorganisms convert dissolved nitrogen into microbial biomass that can be consumed by cultured animals. Electroactive biofilms could complement this process by utilizing residual dissolved organic carbon and further improving water quality while generating electrical signals that reflect microbial activity within the system.The combination of bioelectrochemical systems, environmental sensors, automation, and artificial intelligence may eventually give rise to highly efficient precision aquaculture systems capable of self-regulation and predictive management.

Conclusion

Electroactive biofilms represent one of the most fascinating discoveries in modern environmental microbiology. Their ability to transfer electrons beyond the cell membrane

challenges traditional concepts of microbial respiration and demonstrates that microorganisms can establish direct electrical interactions with their environment. In aquaculture, these living electrical networks offer opportunities that extend far beyond conventional wastewater treatment. By simultaneously degrading organic wastes, improving water quality, supporting nutrient removal, generating electricity, and functioning as biosensors, electroactive biofilms have the potential to become key components of future sustainable farming systems.

Although significant technological and economic challenges remain, continued advances in electromicrobiology and bioelectrochemical engineering are rapidly expanding the practical applications of these systems. As aquaculture moves toward greater intensification and sustainability, electroactive biofilms may help transform waste from an environmental liability into a valuable resource, paving the way for smarter, cleaner, and more energy-efficient aquaculture production systems.

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MONSOON BREAK AND INDIAN AGRICULTURE: CHALLENGES, IMPACTS AND ADAPTATION STRATEGIES

Article ID: AG-V06-I07-164

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Abstract

The Southwest Monsoon provides nearly 70–80% of India's annual rainfall and is vital for agricultural production, particularly in rainfed regions. However, Monsoon Breaks—temporary dry spells during July and August caused by shifts in the monsoon trough and atmospheric circulation—disrupt rainfall distribution and adversely affect farming. These breaks reduce soil moisture, limit water availability, delay crop growth, and lower yields of major rainfed crops such as rice, maize, cotton, pulses, and oilseeds. Climate change is expected to increase the frequency and unpredictability of these dry spells, posing serious risks to agricultural sustainability and food security. Adaptation strategies, including drought-tolerant crop varieties, efficient irrigation, rainwater harvesting, conservation agriculture, crop diversification, and weather-based agro-advisory services, are essential for improving resilience and ensuring sustainable agricultural production under changing climatic conditions.

Keywords: Monsoon Breaks , Indian Agriculture, Climate Change, Rainfed Agriculture, Climate-Resilient Agriculture

Introduction

The Southwest Monsoon is the backbone of Indian agriculture, supplying nearly 70–80% of the country's annual rainfall and sustaining the cultivation of major food and cash crops. Since a large proportion of India's cultivated land is rainfed, agricultural productivity depends heavily on the timely onset, adequate distribution, and continuity of monsoon rainfall. However, the monsoon is characterized by considerable temporal and spatial variability, among which Monsoon Breaks represent one of the most significant weather anomalies. A monsoon break

refers to a temporary reduction or cessation of rainfall over the core monsoon region, typically occurring during July and August due to shifts in the monsoon trough and changes in atmospheric circulation. These dry spells reduce soil moisture, delay crop growth, lower water availability, and can significantly decrease yields, particularly in rainfed crops such as rice, maize, cotton, pulses, and oilseeds. Climate change is expected to increase the variability of the monsoon, making prolonged dry spells more frequent and unpredictable, thereby posing greater challenges to agricultural sustainability and food security. To minimize these impacts, farmers increasingly rely on climate-resilient adaptation strategies such as drought-tolerant crop varieties, efficient irrigation methods, rainwater harvesting, conservation agriculture, weather-based agro-advisory services, and crop diversification. Strengthening these measures is essential for enhancing the resilience of Indian agriculture against monsoon break conditions and ensuring sustainable agricultural production under a changing climate.

What is a Monsoon Break?

Monsoon Breaks are prolonged dry periods that occur during the Southwest Monsoon season, characterized by a marked decline in rainfall over large parts of India for several days or even weeks. These episodes generally develop during July and August due to the northward displacement of the monsoon trough and associated changes in atmospheric circulation. As a result, rainfall is substantially reduced over the core monsoon region, whereas the Himalayan foothills and northeastern states often experience enhanced precipitation. Such breaks have significant implications for agriculture, water resources, flood occurrence, hydropower production, and the overall economy of India.

Causes of Monsoon Break

A break in the monsoon is a temporary interruption or significant reduction in rainfall during the Southwest Monsoon, primarily caused by the oscillation of the monsoon trough and the associated Inter-Tropical Convergence Zone (ITCZ). During the monsoon season, the ITCZ shifts northward over the Indian subcontinent, creating favourable conditions for widespread rainfall. However, periodic movement of the ITCZ and the monsoon trough away from their normal position disrupts monsoon circulation, leading to dry spells. The monsoon trough, formed due to intense heating over northwestern India, normally extends from Sri Ganganagar to Kolkata. As the season progresses, it shifts eastward and oscillates between north and south. When the trough moves northward and aligns with the Himalayan foothills, rainfall becomes

concentrated over the Himalayan region and northeastern India, while the northern plains, central India, and parts of northwestern India experience a sharp decline in rainfall, resulting in a monsoon break. These breaks usually occur during July and August and last for one to two weeks. In northern India, they are often linked to the absence of monsoon depressions or low-pressure systems along the monsoon trough, whereas along the west coast, dry spells are associated with strong winds blowing parallel to the coastline that suppress moisture-laden air from rising and producing rainfall.

Agricultural Challenges

Monsoon: The Lifeline of Indian Agriculture

The Indian monsoon is the foundation of the country's agricultural economy, with nearly half of the cultivated land relying on rainfall. As Monsoon 2026 approaches, farmers must make timely decisions on crop selection, sowing, and water management. A well-distributed monsoon enhances crop yields, water availability, and farm income, while erratic rainfall can trigger droughts, floods, pest outbreaks, and yield losses. Contributing nearly 70% of India's annual rainfall, the southwest monsoon is vital for kharif crops, groundwater recharge, reservoir storage, and soil moisture. Timely weather information and contingency planning can help farmers reduce risks and improve resilience.

With the likelihood of below-normal monsoon rainfall, the Government has encouraged farmers to shift from water-intensive crops like sugarcane to short-duration pulses that require less water. Although pulses have relatively low water requirements, crops such as green gram benefit from a life-saving irrigation during pod formation when rainfall is insufficient. However, inadequate irrigation infrastructure leaves pulse cultivation vulnerable to climate variability. Farmers also emphasize that low market prices and rising input costs are more serious constraints than water availability. Therefore, improving irrigation facilities, ensuring remunerative prices, and reducing production costs are all essential for promoting sustainable pulse production (https://www.thehindu.com/news/national/monsoon-deficit-and-indias-agricultural-vulnerability/article71145767.ece).

Lower the score, higher the vulnerability to a poor monsoon (Source: CareEdge Ratings • The Index was built by CareEdge ratings as a composite measure based on six parameters: (i) Irrigation coverage, (ii) Share of agriculture in overall GVA; (iii)Share of non-crop activities in

agricultural GVA; (iv) Share of water-intensive crops (rice and sugarcane) in kharif output; (v) Average historical rainfall deviation from LPA; and (vi) Regional reservoir levels. The Hindu)

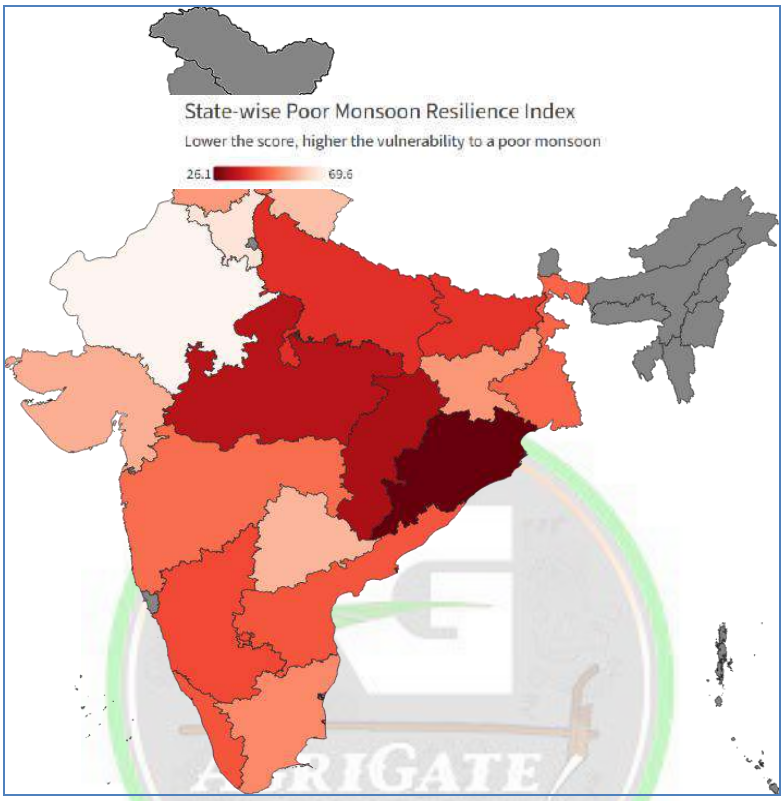


Fig. 1 State-wise Poor Monsoon Resilience Index

Crop-wise Impacts

Irregular monsoons disrupt the delicate calendar-bound planting and growing schedules of India's agricultural sector, with rainfed crops suffering the highest risk. Yields frequently drop as delayed rainfall forces late sowing, while uneven or excess bursts trigger soil erosion and waterlogging.

- **Rice (Paddy):** Requires continuous moisture; delayed monsoon or prolonged dry spells reduce growth and yield, while excessive rainfall causes waterlogging, root damage, and crop failure.
- **Pulses:** Rainfed crops such as tur, urad, and moong are highly vulnerable to delayed July rains, resulting in reduced sowing area, lower yields, and higher market prices.
- **Coarse Cereals:** Maize, bajra, and jowar are sensitive to soil moisture stress during early growth, leading to shortened crop duration, poor grain filling, and reduced yields.

- **Cotton:** Dry spells during sowing and seedling establishment hinder crop growth, while excessive rainfall adversely affects plant development and fibre quality.
- **Agrometeorological Support:** Seasonal monsoon forecasts and agro-advisory services issued by the India Meteorological Department help farmers optimize sowing schedules, irrigation, and crop management under variable monsoon conditions (https://www.downtoearth.org.in/climate-change/when-the-rains-miss-ashar-el-ni%C3%B1o-a-shifting-monsoon-and-the-smallholder-sowing-window).

Climate Change Perspective

Climate change is posing significant challenges to Indian agriculture, making farmers' understanding of changing weather patterns and their ability to adapt increasingly important for ensuring agricultural sustainability. A systematic review of studies from Scopus and Web of Science indicates that most Indian farmers have observed rising temperatures, declining and erratic rainfall, perceptions that closely align with meteorological records. In response, farmers have adopted a range of adaptation strategies, primarily involving incremental improvements in farming practices, while some have also implemented transformational changes such as altering cropping systems, land use, labour allocation, and livelihood patterns.

However, existing evidence does not conclusively establish that these adaptation measures are driven solely by farmers' perceptions of climate change. Factors such as access to climate information, timely credit, household income, farm size, gender, and resource availability play a crucial role in influencing adaptation decisions. The review emphasizes the need for greater investment in agriculture, strengthening farmers' adaptive capacity, and adopting integrated approaches that combine farmers' perceptions, adaptation practices, and their outcomes to support effective policymaking, long-term sustainability, food security, and improved farmer welfare (https://www.sciencedirect.com/science/article/pii/S2667010022001007).

Adaptation Strategies

I) SMART FARMING STRATEGIES FOR MONSOON :**WITH INCREASING CLIMATE VARIABILITY, CLIMATE-SMART AGRICULTURAL PRACTICES CAN HELP FARMERS REDUCE RISKS AND MAINTAIN CROP PRODUCTIVITY DURING MONSOON.**

ii) **Select climate-resilient crop varieties:** Choose drought-tolerant, short-duration, and disease-resistant cultivars to withstand erratic rainfall and reduce crop losses.

iii) **Adopt efficient water management:** Use drip irrigation, rainwater harvesting, farm ponds, and proper drainage to improve water-use efficiency and prevent waterlogging.

iv) **Conserve soil moisture through mulching:** Organic or plastic mulch conserves moisture, suppresses weeds, and reduces soil erosion.

v) **Maintain soil health:** Soil testing, balanced fertilization, and organic manures improve soil fertility and crop resilience.

vi) **Crop Planning and Weather-Based Decisions:**Timely sowing, crop diversification, intercropping, quality seeds, and weather-based advisories help minimize production risks and improve farm management.

vii) **Leveraging Modern Agricultural Technologies:** Weather forecasting apps, automated irrigation, satellite monitoring, and mobile advisory services support timely and efficient farming decisions.

viii) **Promoting Sustainable Agriculture:**Practices such as crop rotation, integrated pest management, organic farming, and water conservation improve productivity while protecting natural resources.

ix) **Government Support:**Crop insurance, micro-irrigation subsidies, Soil Health Card programmes, and extension services help farmers adopt resilient and sustainable farming practices.

Role of Weather Forecasting and Agro-advisories

Weather is a key factor influencing agriculture, affecting crop production from land preparation and sowing to irrigation, crop protection, and harvesting. With increasing climate variability and extreme weather events, accurate weather forecasting has become essential for improving farm productivity, reducing risks, and supporting climate-smart agriculture.

i) **Improving Farm Productivity:** Reliable weather forecasts help farmers plan field operations efficiently. Forecasts of rainfall, heatwaves, and strong winds assist in scheduling sowing, irrigation, fertilizer application, pesticide spraying, and harvesting, thereby reducing crop losses and improving the use of water, labour, machinery, and other farm inputs.

ii) **Better Crop Management:** Weather information on rainfall, temperature, humidity, soil moisture, and evapotranspiration helps farmers identify suitable sowing windows, schedule irrigation, and maintain favourable crop growth conditions. These forecasts improve resource-use efficiency while preventing moisture stress and over-irrigation**.**

iii) **Pest, Disease and Harvest Management:** Weather-based advisories enable early prediction of pest and disease outbreaks, allowing timely preventive measures and reducing unnecessary pesticide use. Forecasts of rainfall, frost, and strong winds also help farmers plan harvesting, drying, storage, and transportation, minimizing post-harvest losses and maintaining produce quality.

iv) **Towards Climate-Resilient Agriculture:** Integrating weather forecasting with improved agronomic practices and modern technologies strengthens farmers' resilience to climate variability. Weather-based advisory services support informed decision-making, efficient resource management, reduced production risks, and sustainable, profitable, and climate-resilient farming systems.

Case Examples from Indian Agriculture

Agrometeorological Advisory Services (AAS) provide weather-based recommendations for agricultural operations, including land preparation, sowing, irrigation, crop protection, and harvesting. Their primary objective is to enhance resource-use efficiency and reduce crop losses caused by adverse weather conditions. Based on accurate short- to medium-range weather forecasts (3–10 days), AAS enables farmers to plan and modify farm activities in advance according to expected weather conditions.

This helps optimize inputs, improve crop productivity, and minimize risks associated with weather variability and extreme climatic events. Studies have shown that AAS is an effective tool for communicating timely, location-specific weather forecasts and crop management recommendations, thereby increasing farmers' awareness and adoption of climate-resilient practices. Farmers who followed AAS advisories achieved better crop growth, higher yields, and greater profitability than non-users. In soybean, AAS users earned a net income of ₹56,042–58,278 ha^{-1} compared with ₹35,690 ha^{-1} for non-users, resulting in an additional economic benefit of 61–63% (https://www.agronomyjournals.com/archives/2024/vol7issue11S/PartC/S-7-7-114-936.pdf).

Key Messages for Farmers

Farmers need to focus on early preparation, crop resilience, soil and water management, and safety protocols to secure their livelihoods.

- **Adopt Weather-Based Advisories:** Utilize AI-based forecasts and early warning systems to guide planting decisions. Monitor updates provided via the India Meteorological Department to track rainfall trends and potential dry spells.
- **Focus on Climate-Resilient Crops:** Consider crop diversification by planting drought-resistant, short-duration varieties like millets and pulses instead of heavily water-intensive crops.
- **Protect Livestock and Equipment:** Relocate animals to well-grounded, sturdy shelters, and keep feed, fodder, and farm equipment dry to prevent mold and spoilage.
- **Prioritize Personal Safety:** Avoid open fields during thunderstorms and lightning. Stay away from downed electric poles and waterlogged areas that may contain live wires.
- **Leverage Government Schemes:** Protect against erratic monsoon losses by utilizing crop insurance schemes and consulting local agricultural extension offices for tailored contingency plans (https://www.pib.gov.in/).

Conclusion

Monsoon has a significant influence on India's agricultural production and farmers' livelihoods. Although climate uncertainty poses considerable challenges, adopting climate-smart farming practices, efficient water management, sustainable production systems, and modern technologies can enhance resilience and improve farm profitability. Careful planning, timely interventions, and effective use of available government support will enable farmers to make the best use of the monsoon season while ensuring sustainable agricultural growth.

Volume: 06 Issue No: 07

ROLE OF TRANSGENIC TECHNOLOGIES IN DEVELOPING INSECT-RESISTANT CROP PLANTS

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Abstract

Ensuring global food security is becoming increasingly challenging due to combined effects of climate change and rapid population growth. However, crop production continues to be affected by declining natural resources, environmental instability, and the emergence and spread of new insect pests. They attack nearly all major food, feed and fibre crops in all agro-ecological regions. The development of resistance to synthetic insecticides in many of these species has further complicated their management and highlighted the need to develop durable environment-friendly resistance traits in crop plants. The development of transgenic plants expressing insecticidal proteins from *Bacillus thuringiensis* (*Bt*) marked a major advance in crop protection. In addition to crystalline Cry toxins, *B. thuringiensis* and related bacteria produce vegetative insecticidal proteins during active growth. This chapter provides a comprehensive overview of the molecular mechanisms underlying transgenic insect resistance, summarizes major technological milestones and the current global adoption scenario, examines the challenges associated with resistance evolution and its management, and discusses emerging technologies that are likely to influence the future development of insect-resistant crops.

Introduction

The global population is expected to rise by approximately 2 billion over the next three decades, increasing from 7.7 billion to nearly 10 billion by 2050. This demographic expansion is

projected to increase food demand by about 56% relative to 2010 levels, thereby placing substantial pressure on agricultural systems to enhance crop productivity and minimize both pre- and post-harvest losses. Among the various biotic stresses affecting crops, insect infestations represent a major threat, accounting for an estimated 25–30% yield loss in several economically important crops. These losses directly affect food availability and farm profitability, emphasizing the need for sustainable and integrated strategies that combine effective pest management, climate-resilient crop improvement, and advanced biotechnological interventions. Since their first commercial cultivation in 1996, transgenic insect-resistant crops have undergone rapid global expansion, increasing from 1.72 million hectares in 1996 to 202.11 million hectares in 2022, representing an approximately 117-fold rise in cultivated area. Over the same period, insect-resistance technologies have progressed from the introduction of single *Bacillus thuringiensis* (*Bt*) toxin genes to more advanced approaches involving gene pyramiding, RNA interference (RNAi), and the deployment of diverse plant-derived defensive molecules.

Insect Pests and Their Impact on Crop Production

Historically, insect-related damage has been estimated to account for approximately 13% of global agricultural production losses. The major insect orders containing economically important crop pests include Lepidoptera, Coleoptera, Hemiptera, Orthoptera, and Diptera. Lepidopteran larvae are among the most destructive agricultural pests because of their extensive feeding on leaves, stems, reproductive structures, and developing seeds. Important examples include *Helicoverpa armigera*, *Spodoptera frugiperda* (fall armyworm), *Ostrinia nubilalis* (European corn borer), and *Pectinophora gossypiella* (pink bollworm), which cause substantial damage to cotton, maize, soybean, and several other crops. Sap-feeding hemipteran insects, including the whitefly *Bemisia tabaci*, pea aphid *Acyrthosiphon pisum*, and brown planthopper *Nilaparvata lugens*, reduce plant vigour through direct phloem feeding and also act as vectors of numerous economically important plant viruses.

Whiteflies alone are associated with the transmission of more than 150 plant viruses, resulting in considerable indirect crop losses. Similarly, the coleopteran pest *Diabrotica virgifera*, commonly known as the western corn rootworm, causes severe root injury in maize, leading to impaired water and nutrient uptake, lodging, and yield reduction. The widespread evolution of resistance to synthetic insecticides in many pest species has further complicated their management. In addition, excessive reliance on chemical control can adversely affect non-

target organisms, disrupt ecological balance, and increase production costs. These limitations underscore the need to develop durable, environmentally compatible, and crop-specific resistance mechanisms through integrated pest management and advanced crop-improvement strategies.

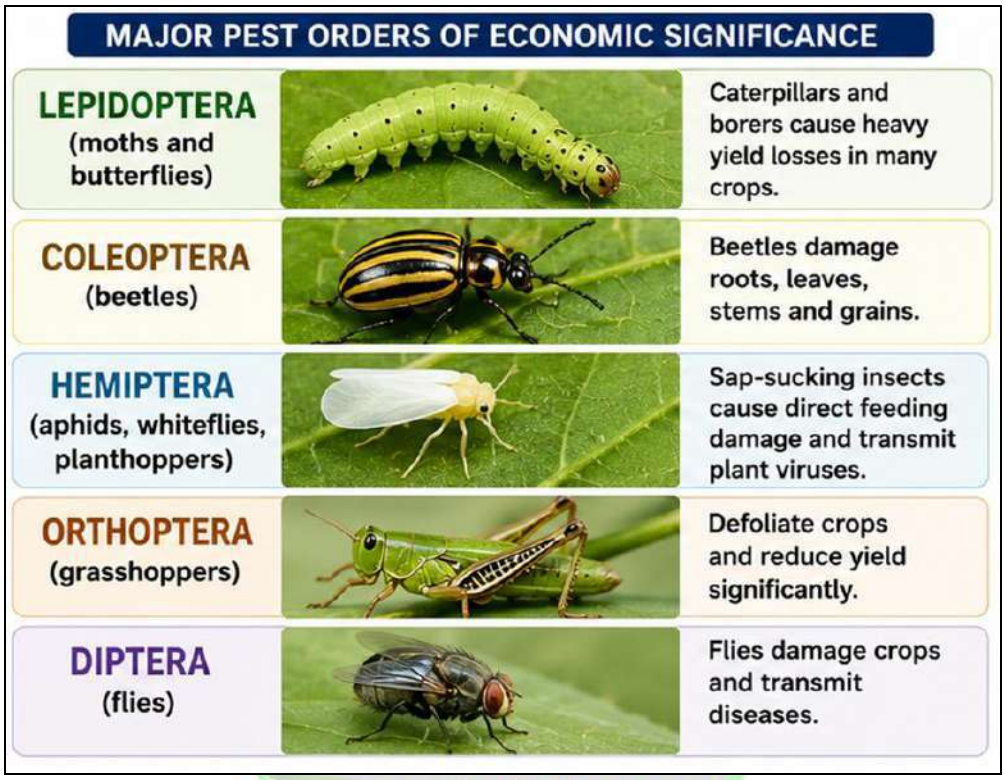


Fig. 1: Major Pest Order of Economic Significance

Transgenic Approaches for Insect Resistance in Crop Plants

Transgenic technology has transformed the way crops are protected from destructive insect pests by enabling plants to produce their own highly specific defense molecules. The best-known example is the use of insecticidal genes from the soil bacterium *Bacillus thuringiensis* (*Bt*). *Bt* crops produce Cry proteins that become toxic after ingestion by susceptible insects, damaging their gut and causing death. Different Cry proteins act against different pest groups; for example, Cry1 proteins are mainly effective against caterpillars, whereas Cry3 proteins target beetles. Vegetative insecticidal proteins, particularly Vip3A, provide an additional mode of action and can control some pests that are less sensitive to conventional Cry toxins. Modern *Bt* crops often contain two or more insecticidal genes, such as *Cry1Ac*, *Cry2Ab* and Vip3A, a strategy known as gene pyramiding. By exposing insects to proteins that act through different receptors, pyramiding broadens pest control and reduces the likelihood of rapid resistance

development. Researchers have also explored plant-derived defense molecules, including protease inhibitors, lectins, α-amylase inhibitors, defensins, chitinases and ribosome-inactivating proteins.

These compounds interfere with insect digestion, nutrient absorption, gut integrity or cellular metabolism and may be particularly useful against sap-feeding insects and storage pests that are not effectively controlled by conventional Bt proteins. Another promising approach is RNA interference, in which transgenic plants produce double-stranded RNA designed to silence genes essential for insect growth, digestion, reproduction or survival. Because RNA interference depends on close sequence matching, it can provide highly pest-specific protection when target sequences are carefully selected. Advances in protein engineering are also generating improved or novel insecticidal proteins with greater potency, broader activity and modified receptor specificity. The effectiveness of these traits can be enhanced through codon optimization, tissue-specific or inducible promoters and, in some crops, chloroplast transformation, which permits high levels of protein accumulation. However, insect-resistant transgenic crops cannot be regarded as permanent stand-alone solutions.

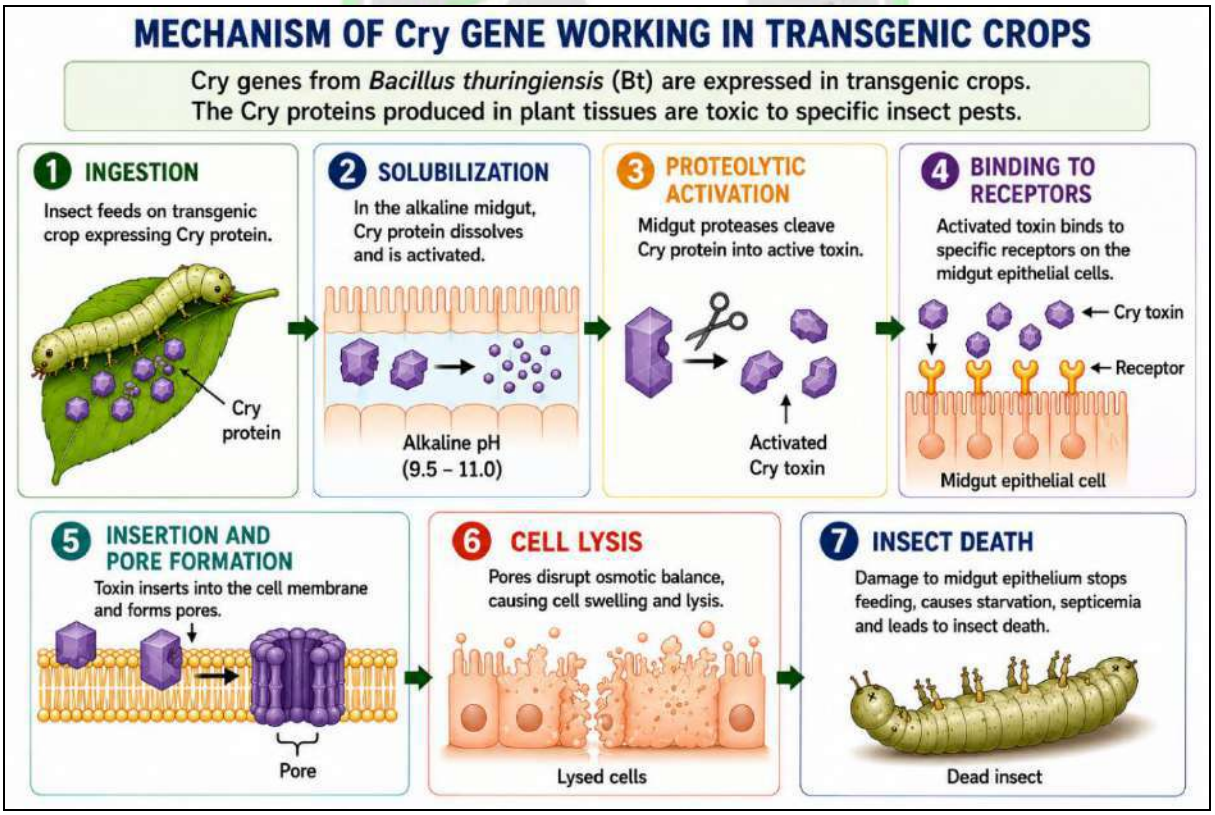


Fig. 2 Mechanism of *Cry* Gene Working in Transgenic Crop

Their long-term success depends on refuge cultivation, resistance monitoring, crop rotation, conservation of natural enemies and the use of multiple independent modes of action. Careful biosafety assessment is equally important to evaluate potential effects on pollinators, predators, parasitoids, soil organisms and food or feed safety. When combined with integrated pest management, transgenic technologies offer a powerful means of reducing crop losses, lowering dependence on broad-spectrum insecticides and developing more sustainable and productive agricultural systems.

Conclusion

Ever since their first commercial release in 1996, insect-resistant genetically modified crops have remarkably altered the scenario of crop protection across the globe. Apart from *cry* genes, plant-based approaches using protease inhibitors, lectins, and alpha-amylase inhibitors have added further variety to GM crops, especially when it comes to pests that cannot be controlled using *Bt* technology. Regulatory frameworks need to stay abreast, embracing tiered and science-based assessment procedures that safeguard human health and biodiversity while simultaneously allowing access to beneficial technologies. Continuing the advances in CRISPR-based editing, novel insecticidal proteins, and AI-augmented precision agriculture, are of utmost importance since they hold substantial promise for a transgenic insect-resistance future in crop plants that would contribute to a more secure and environmentally sustainable world.

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BLENDING BANANA PSEUDOSTEM AND POTATO PEEL WITH CONVENTIONAL PLASTICS: A SUSTAINABLE STRATEGY FOR IMPROVING PLASTIC DEGRADABILITY

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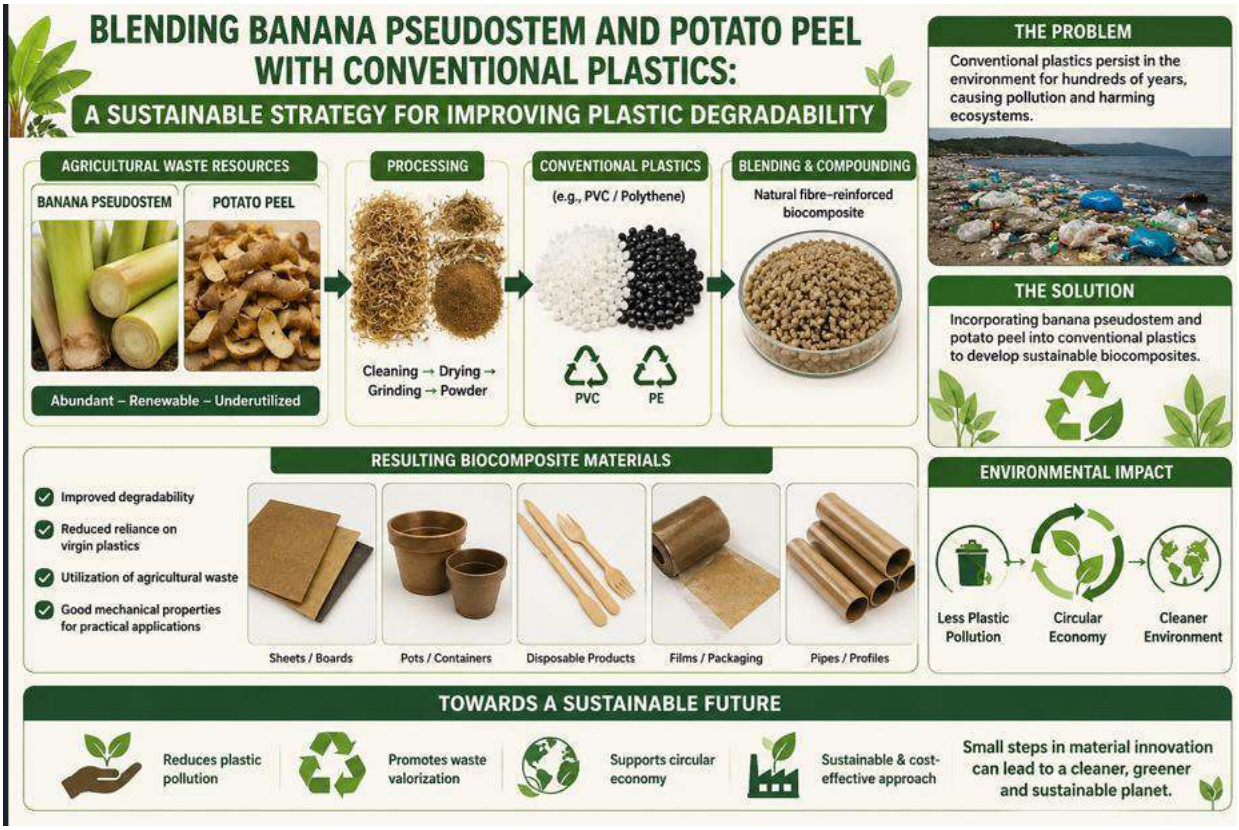
Abstract

Plastic pollution has become a major environmental concern because conventional plastics remain in the environment for hundreds of years. Although biodegradable plastics have been developed, replacing conventional plastics completely is difficult due to their high cost and the need for changes in existing manufacturing systems. This article explores the potential of agricultural waste as a sustainable alternative for improving the degradability of conventional plastics by incorporating banana pseudostem and potato peel into conventional plastics like PVC/Polythene. This approach represents a natural fibre – reinforced biocomposite system, where renewable agricultural residues improve the sustainability of plastic materials while maintaining their useful properties. Such an approach could reduce plastic pollution, promote the utilization of agricultural waste, and support the principles of a circular economy.

Introduction

Plastic is widely used across packaging, agriculture, healthcare, and construction due to its durability and low cost. However, conventional plastics PE, PP and PVC are petroleum – based and persist in the environment for centuries, that affects soil, water, and human health. Biocomposites are materials produced by combining a polymer matrix with natural fibres or

fillers. They have gained considerable attention because they are renewable, lightweight, environmentally friendly, and reduce dependence on petroleum – based materials. Rather than replacing the base polymer entirely, small quantities of agricultural wastes like banana pseudostem and potato peel can be blended during melt extrusion – the stage where plastic is melted and mixed before being shaped. This approach allows the plastic to retain its performance characteristics.



Improves stiffness and flexural strength of plastic composites. Reduces the consumption of petroleum-based polymers and utilizes agricultural waste effectively. It also lowers the carbon footprint compared to pure synthetic plastics.

Why banana pseudostem and potato peel?

Banana pseudostem and potato peel were selected because they are abundant agricultural wastes with unique properties that can improve the performance and sustainability of conventional plastics. Banana pseudostem is rich in cellulose, hemicellulose, and lignin, making it an excellent natural reinforcing material. On an average 200 – 220 tonnes of pseudostem waste generated per hectare each year. Studies have shown that adding approximately 5 – 10% banana fibre can improve the tensile strength, stiffness, and thermal

stability of the composite while also reducing water absorption. Potato peel is rich in starch. on an average 12 – 14 million tonnes of potato peel waste annually. It serves as a starch-based biodegradable additive, for attracting microbes.

A conceptual perspective

Banana pseudostem fibre and potato peel (starch) are proposed to be blended with molten plastic (conventional) during manufacturing. Since the natural components are hydrophilic and PVC/PE are hydrophobic, a compatibilizer (such as anhydride-grafted polymers) is added to form strong interfacial bonding by chemically linking the plastic matrix with the starch and cellulose. Before extrusion, the banana pseudostem fibres and potato peel should be thoroughly dried to remove moisture and to prevent steam bubbling or processing defects. Plasticizers such as glycerol, sorbitol, or epoxidized soybean oil are incorporated while manufacturing to improve flexibility and processability. In addition, the natural components are generally maintained at 10-20% of the total formulation, as higher proportions may significantly reduce the tensile strength and durability of the composite. When this plastic gets discarded, the cellulose particles may create tiny pathways or microchannels inside the plastic matrix. Since microorgansims readily consume starch, potato peel acts as a natural food source that attracts microbial activity. As microorganisms digest the starch, small pores may develop within the plastic, increasing its porosity and exposing a larger surface area to environmental conditions. Overall this combined effect may encourage faster degradation of conventional plastics after disposal while maintaining acceptable performance during normal use.

Challenges

Although banana pseudostem and potato peel is biodegradable, conventional plastics such as PE and PVC are not. During degradable , soil microorganisms break down the natural cellulose fibres and starch present in the banana pseudostem and potato peel, while the plastic matrix sssremains intact. As the natural fibres and starch decompose, the plastic structure weakens and fragments into tiny particles known as microplastics. These microplastics can persist in the environment for long periods. Strategies for Reducing Microplastic Pollution involves biological approaches that minimizing or eliminating the microplastics. Biological methods involve the use of enzymes such as laccases and peroxidases, along with microorganisms like bacillus spp. and pseudomonas spp., to promote further degradation of

plastic fragments. Although these approaches are still under active research, they offer promising eco – friendly solutions for managing microplastic pollution in the future.

Conclusion

Plastic pollution is a major environmental challenge, and completely replacing conventional plastics is not easy. This article suggests that incorporating banana pseudostem and potato peel into conventional plastics may improve their degradability while maintaining their useful properties. By developing a natural fibre – reinforced biocomposite, this approach combines the mechanical strength provided by banana pseudostem with the biodegradability promoted by potato peel starch. The use of these agricultural wastes can also reduce dependence on petroleum – based materials and promote the effective utilization of crop residues. In addition, this approach supports the principles of circular economy by converting agricultural waste into value – added products. Although further laboratory and field studies are needed, this concept offers a promising direction for developing more sustainable plastic materials in the future.

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EFFECTS OF EL NINO IN PLANTS AND ITS SOLUTION

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Abstract

In the current few days , the temperature of the country exceeds more than the normal temperature. By research , the scientists concluded that it is due to EL NINO effect. This increase in temperature cannot be tolerated by the humans as well as the plants. Since humans have many remedies and skin care products to avoid the sunrays , the plants are in the critical stage for their growth. So , here are some information about the EL NINO and it's effects for the plants and the practical ways to minimize the effect of the EL NINO for the plants .

Introduction

At first , EL NINO is the climate change which increases the temperature worldwide . It occurs due to the increase in the surface of the east and Central Pacific Ocean which causes the drought in the America and Asia . Focusing on India , the EL NINO causes the deficit in rainfall than the normal rainfall occurance . The kharif crops are well affected and the farmers facing losses in their farming. As we all know that India is a farming country , this effect plays a vital role in the economy and growth of the population in our country.

EL NINO

It is a climatic pattern by a unusual warming in the surface of the sea which causes extreme climate change in the world .The 2026 El Nino rapidly developed into a strong event across the

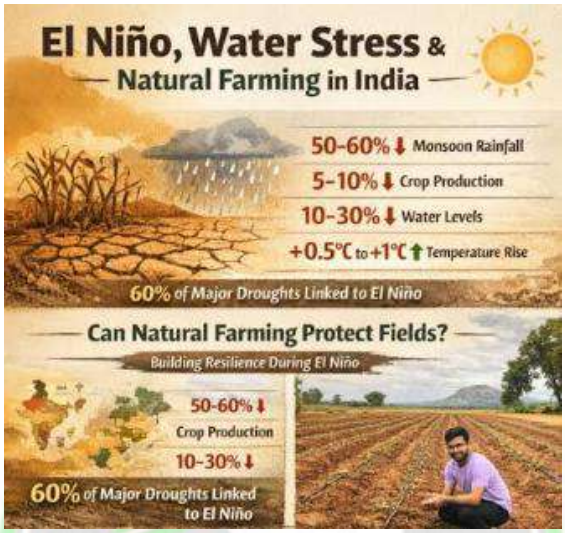
tropical Pacific, with sea surface temperatures in the Nino 3.4 region expected to exceed +2.0° C . Between June 1 and 22, half of India had received deficient rainfall (-20% to -59% below the expected normal), while nearly a quarter had recorded large deficient rainfall (-60% to -99% less than the expected normal), according to the categories used by the India Meteorological Department (IMD). Forecasters project this major climate pattern to peak in late 2026 or early 2027, bringing a high likelihood of extreme weather—including global heatwaves, heavy rainfall in some regions, and severe drought in others.



EFFECTS OF EL NINO IN PLANTS

The El Niño Southern Oscillation (ENSO) is a natural phenomenon that involves the interaction between the ocean and the atmosphere in the tropical Pacific Ocean. ENSO is characterized by irregular fluctuations in sea surface temperatures, atmospheric pressure, and winds in the equatorial Pacific region, which occur over a period of two to seven years. This change in ocean temperature and current affects atmospheric circulation and weather patterns globally. The impacts of ENSO can be significant and can have widespread effects on ecosystems, agriculture, and human activities. In states like Rajasthan, Gujarat, and Maharashtra, plants experienced severe water deficits. Without adequate groundwater, the plants closed their stomata to prevent moisture loss, abruptly halting photosynthesis and decreasing crop yields.India has identified 196 priority districts as officials assess crop risks, farmer alternatives and possible import needs. As India is a tropical country, the sudden increase in the temperature cannot be easily tolerated by the plants . The rainfed as well as kharif crops face

major difficulties to grow in the El Nino . El Nino changes weather patterns and can disrupt the usual planting season. Farmers may experience delays in planting crops, a reduction in planting area, or even crop failure.High temperatures and water shortages due to El Nino can cause a decrease in crop quality. Fruits and vegetables grown in less than ideal conditions tend to be smaller, taste less delicious, and have poor overall quality.



SOLUTIONS FOR THE EL NINO EFFECT

Recently, the Marine Cloud Brightening (MCB) MARINE CLOUD BRIGHTENING (MCB) COULD WEAKEN EL NIÑO EXTREMES

MCB sprays microscopic sea salt particles into lower atmosphere over the ocean.Acts as cloud condensation nuclei -forms numerous tiny droplets.Clouds become brighter & thicker, reflecting sunlight back to space.MCB cools key ocean temperatures & disrupts feedback loops that fuel El Niño intensification. Incorporate amino acids and seaweed extracts (like those with the Primactive Effect) into your watering schedule to help plants maintain cellular water balance and protect against oxidative stress. Next the development of Plants with thick cuticle can also reduce the absorption of sun rays , so that it can take the certai wavelength of the light.

Conclusion

As an agriculturalist, preparing for El Nino is not a choice but rather a necessity.It has been found that most of the El Nino years have either led to droughts or below normal rainfall and therefore it is clear that El Nino events adversely affect the mon-soon rain with few exceptions. However, El Nino is just one of the several factors that influence monsoon rainfall that it now can be easily reduced by the many technical solutions.

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EMPOWERING WOMEN FARMERS THROUGH GENDER-RESPONSIVE AGRICULTURAL EXTENSION SERVICES: A STUDY FROM SHIVAMOGGA, KARNATAKA

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Abstract

Women play a crucial role in Indian agriculture, contributing significantly to crop production, livestock management and household food security. However, they often face limited access to agricultural extension services due to social, institutional and gender-related barriers. Gender-responsive agricultural extension aims to address these challenges by providing inclusive, accessible and women-centred advisory services. This article highlights key insights from a field study conducted among 60 women farmers in Shivamogga district, Karnataka. The study found that women preferred extension services that provided information in a simple and understandable manner and actively participated in community-based platforms such as Self-Help Groups. Household responsibilities, lack of time and limited access to information were identified as major barriers to participation. Strengthening women-friendly extension approaches, increasing the number of female extension professionals and promoting community-based learning can significantly enhance women's participation in agriculture and contribute to sustainable rural development.

Keywords: Women farmers, Gender-responsive extension, Agricultural extension services, Women empowerment, Inclusive agriculture, Self-Help Groups.

Introduction

Agriculture is the backbone of India's economy, and women play a vital role in sustaining it. They are actively involved in land preparation, sowing, transplanting, weeding, harvesting,

livestock management and post-harvest activities. Despite their significant contribution, women farmers often remain under-recognized and have limited access to agricultural information, training, credit and extension services.

Agricultural extension services act as a bridge between research institutions and farming communities by providing farmers with improved technologies, technical guidance and information on government schemes. However, conventional extension systems have traditionally focused on male farmers, often overlooking the specific needs and challenges faced by women. As a result, women continue to face barriers such as household responsibilities, limited mobility, restricted access to resources and inadequate participation in decision-making, which reduce their opportunities to benefit from extension programmes.

To address these challenges, the concept of **gender-responsive agricultural extension** has gained importance. It emphasizes designing extension services that are inclusive and responsive to the needs of women farmers. This includes conducting training programmes at convenient times, using simple and locally understandable communication, increasing the involvement of female extension personnel, promoting women-friendly technologies and encouraging women's participation in agricultural decision-making.

As women increasingly contribute to agricultural production and rural livelihoods, strengthening gender-responsive extension services has become essential for achieving sustainable agriculture and gender equality. Extension systems that recognize women's roles and provide equal access to knowledge and resources can enhance farm productivity, improve household food security and empower rural women.

To understand the effectiveness of such approaches, a field study was conducted among **60 women farmers in Shivamogga district, Karnataka**. The study explored the responsiveness of agricultural extension services, women's participation in extension activities and the major challenges they face. The findings provide practical insights into developing more inclusive extension systems that support women farmers and contribute to sustainable rural development.

Building a More Inclusive Agricultural Extension System

Transforming agricultural extension into a truly gender-responsive system requires more than simply increasing the number of training programmes. It calls for a shift in perspective-from viewing women as helpers in agriculture to recognizing them as farmers, innovators, entrepreneurs and decision-makers.

One of the most effective ways to strengthen extension services is to make them **accessible**. Organizing training programmes at convenient times and within villages can significantly improve women's participation by reducing travel time and conflicts with household responsibilities. Extension activities should also adopt participatory approaches that encourage women to express their opinions, share experiences and contribute to decision-making. The recruitment and training of **female extension professionals** is another important step. Women extension workers often serve as role models and create a more comfortable environment for discussing technical and social issues related to farming. Their presence can improve communication, build trust, and increase women's confidence in accessing extension services.

Community institutions such as **Self-Help Groups (SHGs)**, Farmer Producer Organizations (FPOs), and women's cooperatives have tremendous potential to function as local extension platforms. These organizations provide opportunities for peer learning, leadership development, collective problem-solving and easier dissemination of agricultural information. Strengthening these community networks can expand the reach of extension services while ensuring that information is delivered through trusted local channels. Digital technologies also offer new opportunities for inclusive extension. Mobile applications, WhatsApp groups, interactive voice response systems and community radio can provide timely information on weather, pest management, market prices and government schemes. However, digital initiatives should be accompanied by efforts to improve digital literacy among rural women and ensure access to smartphones and internet connectivity.

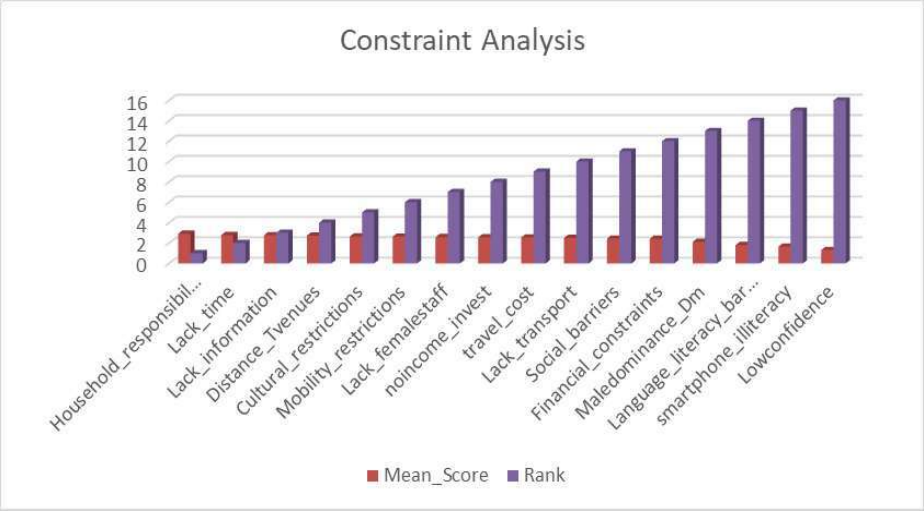


Fig.1 Constraint analysis of women farmers

A gender-responsive extension system should also integrate practical support measures such as childcare facilities during training programmes, women-friendly demonstration plots and communication materials developed in local languages. These seemingly small changes can make a significant difference in encouraging women's participation.

Ultimately, agricultural extension should not only transfer technologies but also empower women with knowledge, confidence, leadership skills and opportunities to participate equally in agricultural development.

The Road Ahead: Key Recommendations

Based on the findings of the study, several measures can help strengthen gender-responsive agricultural extension services:

- Recognize women as farmers and ensure their equal inclusion in all extension programmes.
- Conduct village-level training programmes at times that are convenient for women.
- Increase the recruitment and capacity building of female extension personnel.
- Strengthen Self-Help Groups as platforms for agricultural learning and innovation.
- Develop communication materials in simple language using locally relevant examples.
- Promote digital extension services while improving digital literacy among women farmers.
- Encourage women to participate in planning, implementation and evaluation of agricultural programmes.
- Improve coordination among agricultural departments, research institutions, non-governmental organizations and women's groups to deliver integrated extension services.
- Design policies that address gender-specific constraints such as mobility, time poverty and limited access to productive resources.
- Monitor and evaluate extension programmes using gender-sensitive indicators to ensure that women benefit equally from agricultural development initiatives.

These recommendations can contribute to building an agricultural extension system that is not only efficient but also equitable and inclusive.

Conclusion

Women farmers are indispensable to Indian agriculture. They sow seeds, nurture crops, manage livestock, preserve biodiversity and ensure household food security. Yet their

contributions often remain undervalued and their access to agricultural knowledge and services continues to be constrained by social and institutional barriers. The experiences of women farmers in Shivamogga district demonstrate that when extension services are designed to meet their specific needs, women actively participate, learn new skills and adopt improved agricultural practices. Clear communication, supportive community institutions and inclusive programme design can transform extension services into powerful tools for women's empowerment.

As agriculture faces emerging challenges such as climate change, labour shortages and food insecurity, empowering women farmers is no longer merely a matter of social justice-it is a strategic necessity for sustainable agricultural development. Gender-responsive agricultural extension offers a practical pathway toward achieving this goal by ensuring that no farmer is left behind. Creating an inclusive extension system is therefore not just an investment in women; it is an investment in resilient farming communities, stronger rural livelihoods and a more sustainable future for agriculture.

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HYDROGEL TECHNOLOGY IN AGRICULTURE

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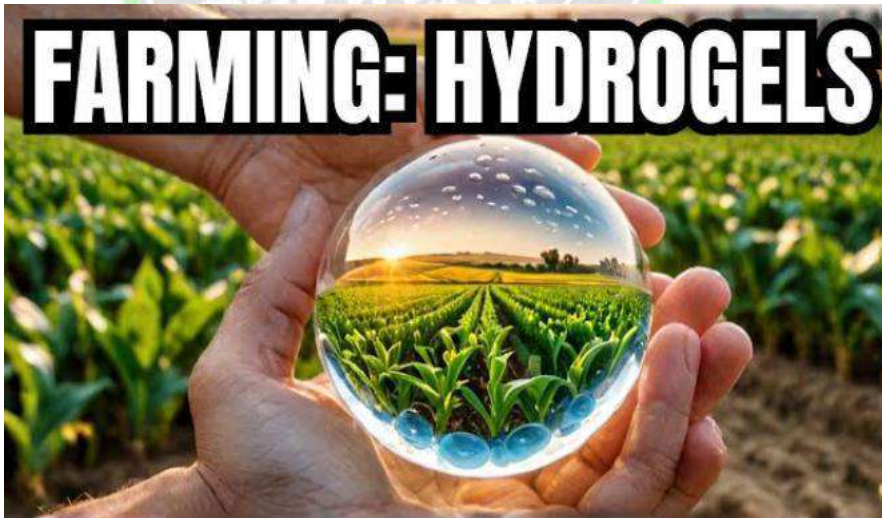
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Abstract

Hydrogel, as a typical representative of functional materials, constructs a three-dimensional network structure through physical or chemical cross-linking of hydrophilic polymer chains, which are rich in hydrophilic groups such as hydroxyl (-OH), carboxyl (-COOH), and amino (-NH2) on the molecular chain and exhibit excellent high water absorption (water absorption multiplication rate of 10–20 times and up to more than 500 times after nanocomposite modification). Studies have shown that the modified hydrogel removes more than 95 % of heavy metal ions (e.g., $Pb2^{+}$, $Cr3^{+}$) and possesses pH and temperature responsive swelling behaviour. In response to the pressing problems faced by global agriculture, such as water scarcity, low fertilizer utilization, and soil heavy metal pollution, hydrogels show great potential for application in precision controlled release of fertilizers, water and moisture conservation, and pollution remediation. In this paper, we systematically review the performance characteristics of hydrogel, optimization strategies, and preparation methods, focusing on its innovative applications in agriculture and mechanistic role based on the environmental response mechanism to achieve the synergistic management of nutrients, water, and pollutants, which provides significant technological support for the development of agriculture.

Introduction

1st century has witnessed a steady decline of irrigation water potential conjugated with the ever growing global population & enhanced economic activities among countries specially located in arid and semi-arid regions of the world. As these regions are ever facing water crisis due to uncertain and inadequate natural precipitation, the problem with water scarcity may possibly aggravate further. Global survey shows, the worst affected areas would be the semi-arid regions of Asia (India), the Middle East and Sub-Saharan Africa, all of which already face issues with heavy population growth and majority of them below the poverty line. It is estimated by 2025 water scarcity will be a major issue in India requiring immediate redressal. As per the Central Water Commission, the demand for water is growing at a steady rate but the availability of clean water in future is declining even faster. In the Indian scenario, Agricultural irrigation practices seem to be responsible for consumption of 80% of the available potable water. There is an increasing trend to this with the further intensification of Agriculture based industries. Due to the large geographical dimensions of the sub-continent and varied soil and farming practices, modern irrigation practices can still only cater to 40% of the grown crops. The remaining areas are far more susceptible to improper practices thus greatly lowering the effective and judicious use of available water for crops.



Desertification is a process in which fertile lands degrade into deserts due to natural causes, such as drought, or human activities associated with deforestation and improper agricultural practices. Rapid climate change has resulted in low annual rainfall, temperature variations, and increased drought frequency, collectively contributing to decreased agricultural

production. Many regions worldwide face desertification and global warming, significantly impacting crop yields. Hydrological drought, characterized by an abnormal reduction in water supply in rivers, lakes, streams, reservoirs, and groundwater, has seriously impacted crop yields. To tackle this problem, scientists have developed many strategies, including low-pressure micro-sprinklers and drip irrigation systems. These techniques require a high operational budget, so they are mostly implemented on high-value crops.

Major drawbacks with irrigation practices:

The predominant irrigation practice is surface draining i.e. direct application of water to crops from surface. It's a problematic and flawed system as the crops can utilize only 50% of the provided water while the remaining is lost in conveyance, as runoff and by evaporation. Modern methods like drip irrigation and use of sprinklers can effectively reduce the wastage of irrigation water but high initial costs, inadequate government subsidy and cooperation, lack of technical input and after sales service, faulty equipment, damage due to pests and high costs of spares prohibits the farmers from opting these techniques. It is worth mentioning that 98 million of the total 120 million farm holdings are small and marginal farmers thus net income from small farms makes farmers reluctant to adopt such water management practices in agriculture. Spatial diversification in soil characteristics, shortage of large land holdings and underprivileged conditions discourage farmers from adopting advantageous and economical application of water conserving irrigation techniques, even in arid zones with distinct scarcity of water. The stress on sustainable development practices even in the agricultural sector has laid emphasis on further judicious, economic and optimum utilization of land, water and plant resources with the major goal to maximize land and water productivity without threatening the environment and available natural resources.

Hydrogels technology in agriculture:

Hydrogel agriculture technology involves gel forming polymers that are insoluble water absorbing polymers designed exclusively for agricultural use.

They were developed to improve physical properties of soil to:

1)Increase water holding capacity.

2)Increase water use efficiency.

3)Enhance soil permeability and infiltration rate.

4)Reduce irrigation frequency.

5)Reduce compaction tendency.

6)Stop soil erosion, farm run-off & surface leaching.

7)Increase plant performance, particularly in structure-less soils stressed with drought condition.

Hydrogels as they are commonly called are cross-linked three-dimensional networked water absorbent polymers.

Three main types of Hydrogels have so far been found appropriate for agricultural use:

i)Starch-graft copolymers

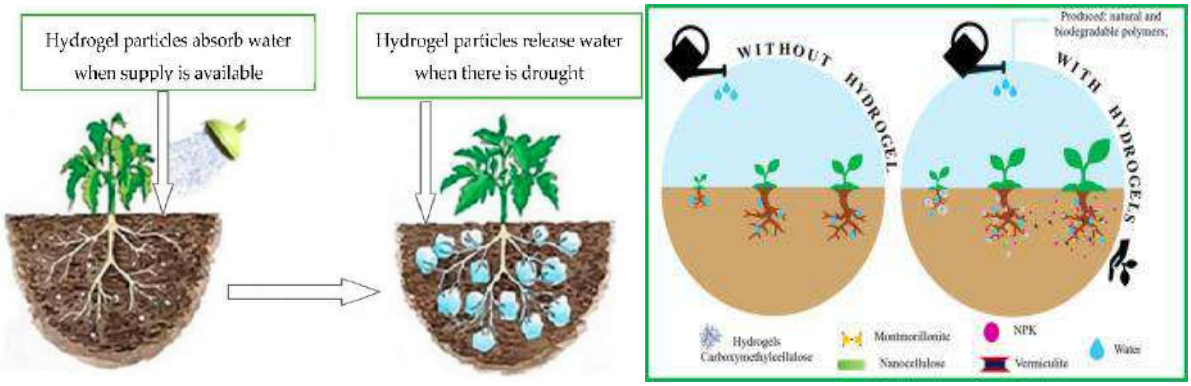
ii)Cross-linked Polyacrylates

iii)Cross-linked Polyacrylamides & Acrylamide-acrylate copolymers

Potassium Polyacrylate is the principal material used in SAP industry and marketed as hydrogel for agricultural use because of its longer retention and high efficiency in soil with nil toxicity issues. They are prepared by polymerizing acrylic acid with a cross linker. Cross-linked polymers can hold water 400 times their own weight and release 95% of that to growing plants. Use of Hydrogel leads to increased water use efficiency by preventing leaching and increasing frequency for irrigation.

Mechanism of Action of Hydrogels:

Releasing Water and Nutrients in Soil Polymeric networks in hydrogels differ and have been classified as homo-polymeric hydrogels (cross-linking one type of polymer) and co-polymeric hydrogels (cross-linking two different types of polymers).The cross-linking density and the number of hydrophilic groups influence the water-holding capacity of hydrogels. Water is considered a solvent because of its innate polarity and ability to form hydrogen bonds. Furthermore, an increased water temperature enhances molecular motion, increasing its solubility. Although water molecules tend to dissolve the hydrogel by cleaving the strong covalent bonds that are cross-linked, it only enables the cleavage of hydrogen bonds. The alteration in hydrogen bonding promotes the restriction of water molecules within the pores of the hydrogel's network structure, a process known as swelling. Osmotically active mobile polar molecules promote swelling. When water is exposed to land, it gets trapped within the soil granules. When soil is moist, the hydrogel uses osmosis to absorb water molecules within its network. However, when the soil is dry, it quickly releases water into the environment from its internal polymer network. Therefore, as required, water is released from a hydrogel network and returned to the soil.



Agriculture specific applications of Hydrogel:

Hydrogel application in agriculture in terms of proposed practices and their advantages is summarized herein.

1) Conservation in Agricultural Lands:

Addition of hydrogel polymer can increase water retention capacity of soil by 50-70% with proper amendment with various dosages of soil to hydrogel ratio. Consecutively soil bulk density can reduce by 8-10%. There is an upward trend in saturated water volumetric content of soil with increasing dose of hydrogel showing clear signs of increase in agricultural water use efficiency in arid and semi-arid regions. This has positive impact on the net plant yield. Hydrogel directly influences soil permeability, density, structure, texture, evaporation and infiltration rates of water. Irrigation frequency, compaction tendency and run-offs decrease while aeration & microbial activity is promoted. Water stress due to scarcity of moisture around root zones is often associated with premature leaf shedding, decreasing chlorophyll content, reduced seed yield, less fruit and flower yield per plant. Use of hydrogel can help moderate these impacts caused by deficit irrigation. Being a water retaining agent greatly increase irrigation period of cultivation, enhancing irrigation efficiency particularly in arid & semi-arid belts.

2) Drought Stress Reduction:

Drought stress can lead to production of Oxygen radicals that result in increased lipid peroxidation and oxidative stress in the plants. Visible effects include stunned height, decrease in leaf area and foliar matrix damage etc. Hydrogel can reduce drought impact on plants leading to reduced stress and oxygen radical formation. This in turn provides scope for better growth and yield even in unfavourable climatic conditions.

3) Enhanced Fertilizer Efficiency:

Irrigation technology has major constraints in the fields of application of fertilizers, herbicides and germicides. Studies suggest the use of synthetic fertilizers can be greatly reduced when hydrogel agriculture is practiced without hindering with crop yield and nutritional value. It would indeed be a more appropriate practice for sustainable agriculture in arid and semi-arid conditions and regions with similar ecological constrains. Moreover, potassium polyacrylate is safe and non-toxic thus prevents pollution of agro ecosystems.

4) Biodegradability of Hydrogel:

Polymer studies have confirmed that hydrogel is sensitive to the action of UV rays and degrades into oligomers. The Polyacrylate becomes much more sensitive to aerobic and anaerobic microbiological degradation and can degrade at rates of 10-15% per year into water, carbon dioxide and nitrogen compounds. The hydrogel molecules are too voluminous to be absorbed into plant tissue and have zero bioaccumulation potential.

Sustainable Agricultural Innovations in 2025 using hydrogel:

In hydrogel-fertilizer formulations, nutrients are released gradually in the soil. This results in reduced fertilizer leaching, higher crop yield, and lower fertilizer requirements. It has been estimated that fertilizers loaded into hydrogel are released into the environment via a diffusion mechanism at a rate half that of conventional fertilizer treatments. The diffusion mechanism initiates a deswelling process, in which water molecules from the hydrogel are diffused and carry fertilizer through the porous network into the surrounding environment.

ALSTA HYDROGEL: Super Absorbent Polymer for Agriculture

ALSTA HYDROGEL is a potassium polyacrylate based super absorbent polymer manufactured by Chemtex Speciality Ltd. for agricultural sector. The granular polymer has a capacity to absorb water 300-500 times its own weight and release it gradually directly to the plant roots over a period. It is effective at reducing irrigation frequency, maintaining soil texture and permeability while ensuring proper and healthy growth of the plants themselves. It can be used conveniently with de-ionized and de-mineralized water to retain soil moisture as well as reduce use of synthetic NPK fertilizers. It finds large scale applications in Open Field & Protective Cultivation, Terrace Farming, Vertical Farming, Domestic Gardens, Arboriculture, Bare Root Dripping, Hydro Seeding, Hydroponics etc.

Rate of application of hydrogel:

Particulars	Recommended dose of hydrogel
Arid and semi-arid regions	4-6 g/kg soil
For all level of water stress treatment and improved irrigation period	2.30-3.0 g/kg soil
To delay PWP in sandy soils	0.2-0.4 g/kg soil or 0.8% of soil
To improve relative water content and leaf water use efficiency	0.5-2.0 g/pot
To reduce irrigation water by up to 50% in loams	2-4 g/plant pit
To reduce drought stress	0.2-0.4% of soil
To decrease water stress	3% weight basis
To prohibit drought stress totally	250-300 kg/ha

Conclusion

Hydrogels are gaining popularity in agricultural practices due to the global water shortage crisis, the increased frequency of droughts, soil degradation, and the need for higher agricultural production through sustainable strategies. Hydrogel application promotes sustainable agriculture by promoting efficient use of water resources by lowering water loss from evaporation and runoff. Coating hydrogel formulations in plant roots provides the plant with access to water, thereby protecting it from drought or insufficient water resources. This approach enhances crop resilience to drought and maintains crop yields even in unfavourable conditions. Furthermore, an increase in the soil water-holding capacity stabilizes soil surfaces and decreases erosion. Therefore, the application of hydrogels combats soil deterioration and safeguards arable land. Hydrogel engineering facilitates the controlled release of nutrients, providing a steady supply of essential elements for plant growth. Therefore, increasing hydrogel formulations in agriculture could improve the microclimate for plant growth and serve as a protective barrier against biotic and abiotic stresses.

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ENHANCING ANTIOXIDANT ENZYME ACTIVITY IN RICE THROUGH NANO COMPOSITES UNDER COASTAL STRESS CONDITIONS

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Abstract

Excellent antioxidant capacity has been observed in almost all plant species, making many of them important for therapeutic and nutritional purposes. In food crops, antioxidants protect plant cells from deterioration under stress conditions. The harmful effects of free radicals can be minimized by the activity of antioxidant enzymes such as catalase, reduced glutathione, protein carbonyl, and glutathione peroxidase. Coastal soils present several constraints such as salinization, low water and nutrient retention capacity, high pH and electrical conductivity (EC), low base saturation, and low organic matter content. These conditions reduce crop productivity and also affect the antioxidant enzyme levels in rice grains, including catalase, glutathione activity, protein carbonyl, and glutathione peroxidase. Therefore, to study the influence of Zn and Fe nano-based Zn and Fe composites on antioxidant enzyme activity in rice, a field experiment was conducted at North Pichavaram, Cuddalore District, Tamil Nadu. , The following treatments namely, T_1 - Control (NPK @ recommended level), T_2 - NPK + $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha^{-1}, T_3 - NPK+ nano Zn + nano Fe foliar each @ 500 ppm, T_4 - NPK + nano zeolite composite @ 2 t ha^{-1} , T_5 - NPK + nano biochar composite @ 2 t ha^{-1} , T_6 - NPK +

nano zeolite composites+ nano Zn and Fe foliar each @ 500 ppm, T_7 -NPK + nano biochar composites + nano Zn and Fe foliar each @500 ppm were studied in Randomized Block Design in three replications with rice variety ADT 43. Among the treatments, nano biochar composites @ 2 t ha^{-1} + nano Zn and Fe foliar each @ 500 ppm excelled all other treatments. This treatment registered a Catalase and Reduced Glutathione activity of 3.21 units/ml and 0.163 µl/mg in rice grain as against 2.09 units/ml and 0.122 µl/mg in the treatment that received NPK alone and Protein carbonyl and Glutathione peroxidase (GPx) showed a significant increase with the treatment T7, nano biochar composites @ 2 t ha^{-1} + nano foliar 500 ppm by recording 61.1 n mol $mg^{-1}$and 0.032 unit mg^{-1} in rice grain respectively.

Key Words: Nano Zn and Fe, Antioxidant enzyme activity, Coastal soil.

Introduction

Rice is a major staple crop in India and constitutes a primary source of nutrition for nearly 75% of the global population. In India's coastal regions, however, rice cultivation is increasingly constrained by soil degradation associated with salinity, high pH, low organic carbon, and reduced cation exchange capacity. These unfavorable soil conditions impose severe abiotic stress on rice plants, triggering osmotic imbalance and ionic toxicity that lead to excessive production of reactive oxygen species (ROS), including superoxide radicals and hydrogen peroxide (Gill and Tuteja, 2011; Yu et al., 2025). Elevated ROS levels cause oxidative damage to lipids, proteins, and nucleic acids, thereby disrupting cellular integrity, physiological processes, and grain quality in rice (Zhang et al., 2024; Singh et al., 2025).To counteract ROS-induced damage, rice plants rely on a well-coordinated antioxidant defense system comprising enzymatic antioxidants such as superoxide dismutase, catalase, peroxidases, ascorbate peroxidase, and glutathione peroxidase, together with non-enzymatic antioxidants including glutathione, ascorbate, and phenolic compounds (Gill et al., 2022; do Carmo Santos et al., 2025).

Nevertheless, under prolonged or intense salinity stress, the endogenous antioxidant capacity of rice is often insufficient to maintain redox balance, resulting in oxidative stress and impaired plant performance (Yu et al., 2025).Recent research indicates that nano-based soil amendments and nutrient formulations can effectively enhance antioxidant defense mechanisms in rice grown under saline conditions. Micronutrients such as zinc and iron play crucial roles in regulating antioxidant enzyme activity and maintaining cellular redox homeostasis. Zinc contributes to membrane stability and modulates ROS-scavenging enzymes, whereas iron

participates in redox reactions and electron transport systems essential for antioxidant metabolism (Das et al., 2016; Khalid et al., 2022). Application of ZnO and FeO nanoparticles has been shown to stimulate catalase, peroxidase, and glutathione-dependent enzyme activities, thereby reducing ROS accumulation and lipid peroxidation in salt-stressed rice plants (Rui et al., 2016; Wang et al., 2018; Singh et al., 2025).

In addition, nano-biochar and nano-zeolite-based amendments have emerged as effective tools for mitigating oxidative stress in crops. Nano-biochar, due to its high surface area and strong adsorption capacity, enhances nutrient availability and root–soil interactions, leading to increased antioxidant enzyme activity and reduced accumulation of oxidative stress markers such as hydrogen peroxide and malondialdehyde in rice under salinity stress (Lateef et al., 2016; Sun et al., 2016; Zhang et al., 2025). Similarly, nano-zeolites, characterized by high cation exchange capacity and water-holding ability, provide a slow and sustained nutrient release that supports prolonged antioxidant activity and improves stress tolerance in rice plants (Mumpton, 1999; Sheta et al., 2003; Roklamasiningsih et al., 2020).

Overall, accumulating evidence from recent studies suggests that integrating nano-biochar and nano-zeolite composites with micronutrient nanoparticles offers a promising strategy to enhance antioxidant capacity, regulate ROS homeostasis, and alleviate salt-induced oxidative stress in rice cultivated in coastal saline soils (Singh et al., 2025; Zhang et al., 2025).

Materials and Methods

To evaluate the effect of nano-fertilizer-based amendments on antioxidant activity and oxidative stress regulation in rice grown under coastal saline conditions, a field experiment was conducted at a farmers' field in Vadakku Pichavaram. The experiment was carried out using the rice variety ADT-43 and laid out in a randomized block design with seven treatments and three replications. The treatments included: T1 – Control (NPK at recommended dose); T2 – NPK + $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha^{-1}; T3 – NPK + nano Zn and nano Fe as foliar spray each @ 500 ppm; T4 – NPK + nano zeolite composite @ 2 t ha^{-1}; T5 – NPK + nano biochar composite @ 2 t ha^{-1}; T6 – NPK + nano zeolite composite @ 2 t ha^{-1} + nano Zn and nano Fe foliar spray each @ 500 ppm; and T7 – NPK + nano biochar composite @ 2 t ha^{-1} + nano Zn and nano Fe foliar spray each @ 500 ppm. The experimental soil was characterized by alkaline pH (8.27) and electrical conductivity of 2.53 dS m^{-1}, indicating moderate salinity stress. These conditions were

conducive for evaluating the role of nano-based amendments in enhancing antioxidant defense mechanisms and mitigating oxidative stress in rice.

Nano-zeolite composite

Natural zeolite was processed to nanoscale dimensions using high-energy ball milling at a rotational speed of 600 rpm for 6 h. A calculated quantity of nano-sized zinc and iron (each equivalent to 5 kg ha^{-1}) was subsequently incorporated into the zeolite matrix and further milled for an additional 6 h. This process facilitated particle size reduction while preserving the crystalline structure of zeolite, resulting in the formation of a nano-zeolite composite (Subramanian and Sharmila Rahale, 2012; Sivashankari et al., 2019).

Nano-biochar composite

Biochar was produced using a low-cost portable drum (kiln) method developed by ICAR. Paddy straw was chopped into pieces shorter than 12 inches, sun-dried, and subjected to slow pyrolysis at 450 °C for 1.2 h to obtain biochar.

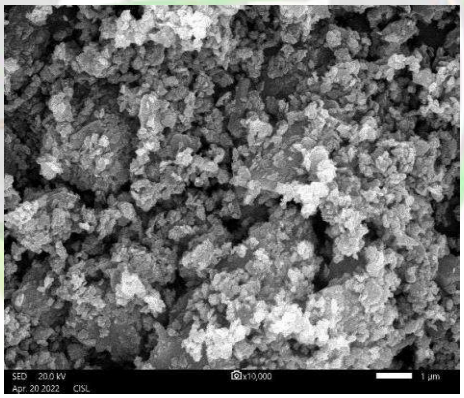


Fig 1. SEM image of nano Zn

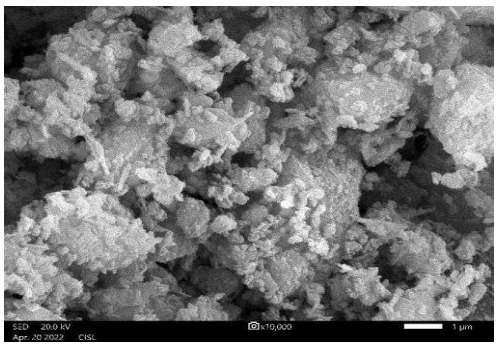


Fig 2. SEM image of nano FeO

The resulting biochar was then oven-dried at 110 °C for 24 h to remove residual moisture (Shaon Kumar Das et al., 2018). Subsequently, a calculated amount of nano-sized zinc and iron (each equivalent to 5 kg ha^{-1}) was added to the biochar and subjected to high-energy ball milling for 6 h at a controlled milling speed to obtain a homogeneous nano-biochar composite (Subramanian and Sharmila Rahale, 2012; Sivashankari et al., 2019).

Sample preparation

Rice grain samples were oven-dried at 60 °C to constant weight and finely ground. A known quantity of powdered sample was homogenized in chilled extraction buffer (usually 50 mM phosphate buffer, pH 7.0–7.8) using a mortar and pestle under cold conditions. The homogenate was centrifuged at 10,000–15,000 rpm for 15–20 min at 4 °C, and the supernatant was used for biochemical analyses.

Catalase (CAT) activity

Catalase activity was determined following the method of Aebi (1984). The reaction mixture consisted of phosphate buffer and hydrogen peroxide (H_2O_2). The decrease in absorbance due to the decomposition of H_2O_2 was recorded at 240 nm using a UV–visible spectrophotometer. Enzyme activity was calculated based on the rate of decline in absorbance and expressed as units mL^{-1} extract.

Reduced glutathione (GSH)

Reduced glutathione content was estimated using the method described by Ellman (1959). The assay is based on the reaction of reduced glutathione with 5,5′-dithiobis-2-nitrobenzoic acid (DTNB), forming a yellow-colored complex. Absorbance was measured at 412 nm, and GSH concentration was calculated using a standard curve prepared with known concentrations of glutathione. Results were expressed as µmol g^{-1} fresh or dry weight.

Protein carbonyl content

Protein carbonyl content, an indicator of oxidative protein damage, was estimated following the method of Levine et al. (1990). Protein extracts were reacted with 2,4-dinitrophenylhydrazine (DNPH), forming hydrazone derivatives. After precipitation and washing steps, absorbance was measured at 370 nm. Protein carbonyl concentration was calculated using the molar extinction coefficient and expressed as nmol carbonyl mg^{-1} protein.

Glutathione peroxidase (GPx) activity

Glutathione peroxidase activity was determined using the method of Paglia and Valentine

(1967). The assay involves the oxidation of reduced glutathione by GPx in the presence of hydrogen peroxide, coupled with the reduction of oxidized glutathione by glutathione reductase using NADPH. The decrease in absorbance due to NADPH oxidation was measured at 340 nm. Enzyme activity was expressed as units mg^{-1} protein.

Result and Discussion

An antioxidant protection system, which include nonenzymatic antioxidants, such as glutathione and enzymatic antioxidants, such as Catalase, reduced glutathione, protein carbonyl and glutathione peroxidase regulates a potential harmful effect of reactive oxygen species (ROS) (Alhasnawi *et al.,* 2016) accumulated under stress conditions. Nevertheless, when plants are exposed to salt stress, oxidative damage can occur due to imbalance between ROS accumulation and detoxification.

There are several mechanisms of antioxidative defences in the cells such as prevention of radical formation, elimination of damaged molecules and prevention of mutations which are controlled by both antioxidant enzymes and non-enzymatic antioxidant compounds. Catalase and Glutathione Px are enzymes that use to remove the peroxides and play an important role in protecting oxidative stress. These antioxidant enzymes play interconnected functions and their insufficient synthesis and activities leading to the accumulation of ROS and an increased oxidative stress in the cells (Alhasnawi *et al.,* 2016).

In our study, significantly higher Catalase and Reduced Glutathione enzyme activity was registered in the treatment T7, nano biochar composites @ 2 t ha^{-1} + nano foliar 500 ppm. This treatment registered a Catalase (3.21 units/ml) and Reduced Glutathione (0.163 µl/mg) enzyme activity in rice grain as against 2.09 units/ml and 0.122 µl/mg in the treatment that received NPK alone. Application of (T5) nano biochar composites alone @ 2 t ha^{-1} also increased Catalase and Reduced Glutathione of rice and this followed by T6 - nano zeolite composites + nano foliar @ 500 ppm which registered a Catalase activity of 2.94 units/ml and Reduced Glutathione activity of 0.153 µl/mg.

The effect due to the application of nano zeolite and biochar composites in significantly enhancing the other antioxidant enzymes namely Protein carbonyl and Glutathione peroxidase (GPx) by rice was also significant. Of all the treatments, Protein carbonyl and Glutathione peroxidase showed a significant increase with the treatment T7, nano biochar composites @ 2 t ha^{-1} + nano foliar 500 ppm by recording 61.1 and 0.032 in

rice grain respectively and was found onpar with T5, nano biochar composites alone by recording (59.8 n mol mg^{-1}) and (0.030 units mg^{-1}) in rice grain.

Table 1. Effect of nano Zn and Fe composites on the Catalase and Reduced Glutathione of rice

Treatments	Catalase (units/ml)	Reduced Glutathione (µl/mg)
T1 - NPK (Control)	2.09	0.122
T2 - NPK + ZnSO4 + FeSO4 each @ 25 kg ha^{-1}	2.26	0.129
T3 - NPK + nano Zn + nano Fe foliar each @ 500 ppm	2.42	0.143
T4 - NPK + nano zeolite composites @ 2 t ha^{-1}	2.86	0.150
T5 - NPK + nano biochar composites @ 2 t ha^{-1}	3.12	0.161
T6 - NPK + nano zeolite composites + nano Zn and Fe foliar each @ 500 ppm	2.94	0.153
T7 - NPK + nano biochar composites + nano Zn and Fe foliar each @ 500 ppm	3.21	0.163
Sed	**0.07**	**0.010**
CD (p=0.05)	**0.14**	**0.040**

The increasing antioxidant activity is closely associated with the phenolic content in rice grains, suggesting that enhanced phenolic synthesis contributes to the activation of antioxidant enzymes. These enzymes interact with substrates and expose free hydroxyl groups on phenolic structures, thereby increasing the antioxidant potential due to the availability of free phenolic compounds (Bhanja et al., 2009).

Antioxidant activity was found to be higher in nano-biochar-treated samples compared to the control. The incorporation of nano-biochar composites reduced reactive oxygen species (ROS) formation and minimized cell membrane peroxidation, while also enhancing the ascorbate pool in food crops (Quartacci et al., 2017). Oxidative stress in plants can be alleviated by increasing the activity of key enzymatic antioxidants such as catalase, reduced glutathione,

protein carbonyl, and glutathione peroxidase under abiotic stress conditions (Gill and Tuteja, 2011; Zhang et al., 2016; Singh et al., 2025).

Plants subjected to stress conditions tend to produce secondary metabolites along with ROS as by-products of altered metabolism. The accumulation of ROS can be effectively regulated by amendments such as zeolite, which enhance antioxidant activity and stimulate antioxidative enzyme systems (Roklamasiningsih et al., 2020). Zinc, being an essential micronutrient, plays a crucial role in modulating abiotic stress responses in plants by regulating ROS metabolism and antioxidant enzyme activity (Das et al., 2016). Furthermore, ZnO nanoparticles in rice have been reported to directly enhance peroxidase activity, facilitating the removal of active oxygen species and thereby improving stress tolerance (Wang et al., 2018; Li et al., 2017).

Recent studies further demonstrate that nanoparticle applications significantly enhance both enzymatic (catalase, peroxidase, glutathione peroxidase) and non-enzymatic antioxidant systems, improving ROS scavenging and reducing oxidative damage under salinity stress (Singh et al., 2025; Zia-Ur-Rehman et al., 2023; Chandrashekar et al., 2023; Kumari et al., 2024; Cao et al., 2025; Abou El-Nasr et al., 2025; Kılınç and Kuru, 2025). Nano-biochar formulations have also been shown to improve antioxidative defense and physiological resilience in rice under abiotic stress conditions (Das et al., 2018).

Table 2. Effect of nano Zn and Fe composites on the Protein carbonyl and Glutathione peroxidase (GPx) of rice

Treatments	Protein carbonyl (n mol mg $^{-1}$)	Glutathione peroxidase (unit/mg)
T1 - NPK (Control)	34.3	0.012
T2 - NPK + ZnSO4 + FeSO4 each @ 25 kg ha^{-1}	39.4	0.015
T3 - NPK + nano Zn + nano Fe foliar each @ 500 ppm	48.2	0.022
T4 - NPK + nano zeolite composites @ 2 t ha^{-1}	53.5	0.026

T5 - NPK + nano biochar composites @ 2 t ha^{-1}	59.8	0.030
T6 - NPK + nano zeolite composites + nano Zn and Fe foliar each @ 500 ppm	55.3	0.027
T7 - NPK + nano biochar composites + nano Zn and Fe foliar each @ 500 ppm	61.1	0.032
Sed	**1.8**	**0.007**
CD (p=0.05)	**3.6**	**0.016**

Conclusion

The application of nano-fertilizer-based amendments, particularly nano-biochar and nano-zeolite composites combined with foliar nano Zn and Fe, significantly enhanced the antioxidant defense system of rice grown under coastal saline conditions. Among all treatments, T7 (nano-biochar composite @ 2 t ha^{-1} + nano Zn and Fe foliar @ 500 ppm) consistently recorded the highest activities of Catalase (3.21 units/mL), Reduced Glutathione (0.163 µL/mg), Protein Carbonyl (61.1 nmol mg^{-1}), and Glutathione Peroxidase (0.032 units mg^{-1}), indicating superior ROS scavenging and protection against oxidative stress compared to conventional NPK fertilization. Treatments with nano-biochar alone (T5) or in combination with nano-foliar sprays (T7) outperformed nano-zeolite composites in boosting antioxidant enzyme activities. The observed increase in enzymatic antioxidants was positively correlated with phenolic content, suggesting that nano-based amendments not only provide essential micronutrients but also stimulate the plant's intrinsic antioxidant metabolism. Overall, the study demonstrates that integrating nano-biochar and nano-zeolite composites with micronutrient foliar sprays is an effective strategy to mitigate oxidative stress, enhance antioxidant capacity, and improve the stress resilience of rice under saline conditions.

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POTENTIAL OF FENUGREEK (TRIGONELLA FOENUM-GRAECUM L.) AS A PHYTOGENIC FEED ADDITIVE IN CARP AQUACULTURE: CURRENT KNOWLEDGE AND FUTURE RESEARCH PERSPECTIVES

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Abstract

Carp aquaculture, particularly the culture of Indian major carps such as LABEO ROHITA, CATLA CATLA, and CIRRHINUS MRIGALA, contributes substantially to freshwater fish production and food security in many Asian countries. However, intensive farming practices have increased the occurrence of disease outbreaks, environmental stress, and reliance on antibiotics, highlighting the need for sustainable and eco-friendly feed additives. Fenugreek (TRIGONELLA FOENUM-GRAECUM L.) has emerged as a promising phytogenic feed additive due to the presence of various bioactive compounds, including saponins, flavonoids, alkaloids, and polyphenols. Previous studies have reported that dietary supplementation of fenugreek improves growth performance, feed utilization, hematological parameters, antioxidant status, and immune responses in several fish species, including carps. Moreover, its antimicrobial and immunostimulatory properties may enhance disease resistance and reduce dependence on chemotherapeutic agents in aquaculture. Despite these promising findings, information regarding the optimum dietary inclusion levels, long-term effects, and mechanisms of action of fenugreek in Indian major carps remains limited. Therefore, further research is necessary to establish standardized recommendations and evaluate the potential of fenugreek as a sustainable feed additive for enhancing health and productivity in carp aquaculture systems.

Keywords: Fenugreek, *Trigonella foenum-graecum*, Indian major carps, *Labeo rohita*, phytogenic feed additive, immunity, sustainable aquaculture.

Introduction

Aquaculture has emerged as one of the fastest-growing food production sectors

worldwide and plays a crucial role in ensuring global food and nutritional security. According to the Food and Agriculture Organization (FAO), global fisheries and aquaculture production reached approximately 235 million tonnes in 2024, with aquaculture contributing around 103 million tonnes of aquatic animal production, highlighting its increasing importance in meeting the nutritional requirements of the growing population (FAO, 2026).

Among freshwater aquaculture species, carps occupy a dominant position, particularly in Asian countries, due to their rapid growth, adaptability to diverse environmental conditions, consumer acceptance, and economic importance. Indian major carps, namely LABEO ROHITA (rohu), CATLA CATLA (catla), and CIRRHINUS MRIGALA (mrigal), are the major components of carp polyculture systems and contribute significantly to freshwater fish production in South Asia (FAO, 2022).

However, the rapid intensification of carp farming has resulted in several challenges, including disease outbreaks, environmental stress, poor water quality, and reduced production efficiency. To overcome these constraints, antibiotics and chemotherapeutic agents have frequently been used in aquaculture. Nevertheless, indiscriminate use of such compounds has raised concerns regarding antimicrobial resistance, environmental contamination, and food safety, thereby necessitating the development of sustainable and eco-friendly alternatives.

In recent years, phytogenic feed additives derived from medicinal plants have gained considerable attention due to their potential to improve growth performance, enhance immunity, and increase disease resistance in cultured fish species. Among these medicinal plants, fenugreek (*Trigonella foenum-graecum* L.) has emerged as a promising functional feed additive owing to its rich composition of bioactive compounds, including saponins, flavonoids, alkaloids, and polyphenols (Wani & Kumar, 2018).

. Previous studies have demonstrated that dietary supplementation of fenugreek can positively influence growth performance, feed utilization, hematological parameters, immune responses, and stress resistance in fish species such as common carp (*Cyprinus carpio*) (Roohi et al., 2017; Kumar et al., 2017).

Despite these encouraging findings, information regarding the application of fenugreek in Indian major carps remains limited. Furthermore, the optimum dietary inclusion levels, long-term effects, and underlying mechanisms responsible for its beneficial effects are still inadequately understood. Therefore, the present review aims to compile and critically evaluate

the available information on fenugreek supplementation in carp aquaculture and to identify existing research gaps and future research prospects for its effective utilization in sustainable aquaculture systems.

Importance of fenugreek in Aquaculture

Fenugreek (TRIGONELLA FOENUM-GRAECUM L.) is considered a valuable phytogenic feed additive in aquaculture due to its rich nutritional and bioactive profile. The seeds contain approximately 20–30% protein, 45–50% carbohydrates, 5–10% lipids, substantial amounts of dietary fiber, and essential minerals such as iron, calcium, phosphorus, magnesium, and zinc. They also contain vitamins and several bioactive constituents, including saponins, flavonoids, polyphenols, galactomannans, and alkaloids such as trigonelline. Supplementation of fenugreek in fish diets may enhance feed palatability and digestive efficiency by stimulating digestive enzyme secretion and improving nutrient absorption (Awad & Awaad, 2017).. Its antioxidant constituents help mitigate oxidative stress induced by intensive culture conditions, poor water quality, and environmental fluctuations. Additionally, the antimicrobial and immunomodulatory properties of fenugreek may strengthen innate immune responses and increase resistance against bacterial and parasitic infections.

Fenugreek has also attracted attention due to its potential prebiotic effects, as its galactomannan-rich fiber may support beneficial gut microbiota, thereby improving intestinal health and nutrient utilization. Furthermore, the use of fenugreek aligns with the principles of sustainable aquaculture by reducing dependence on antibiotics and synthetic growth promoters, which are associated with antimicrobial resistance and environmental concerns. Because fenugreek is inexpensive, widely available, biodegradable, and generally regarded as safe, it represents a promising phytogenic candidate for improving fish growth, health status, stress tolerance, and overall production efficiency in carp aquaculture.

Effects of Fenugreek on Growth and Immunity of Fish

Dietary supplementation of fenugreek (TRIGONELLA FOENUM-GRAECUM L.) has attracted considerable attention in aquaculture owing to its potential growth-promoting and immunomodulatory properties. The beneficial effects of fenugreek are primarily attributed to its rich nutritional composition and diverse bioactive compounds, including saponins, flavonoids, alkaloids, polyphenols, and galactomannans. These constituents may enhance feed palatability, stimulate digestive enzyme secretion, improve nutrient digestibility, and consequently increase

growth performance and feed utilization efficiency in fish (Awad & Awaad, 2017; Wani & Kumar, 2018).

Several studies have reported improvements in growth indicators such as weight gain, specific growth rate (SGR), and feed conversion ratio (FCR) following dietary inclusion of fenugreek or its extracts. The presence of essential amino acids and bioactive compounds may contribute to enhanced protein utilization and metabolic efficiency. Furthermore, the prebiotic properties of galactomannan-rich polysaccharides may positively influence intestinal morphology and gut microbial balance, thereby improving nutrient absorption and overall fish performance.

In addition to growth enhancement, fenugreek exhibits considerable immunomodulatory potential. Bioactive compounds such as saponins and polyphenols may stimulate innate immune responses by enhancing lysozyme activity, phagocytic activity, respiratory burst activity, complement activity, and leukocyte proliferation (Harikrishnan et al., 2011; Van Hai, 2015). Furthermore, the antioxidant properties of flavonoids and phenolic compounds may increase the activities of antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), thereby protecting fish from oxidative stress and improving resistance against pathogens and environmental stressors (Reverter et al., 2014; Dawood et al., 2018).

Despite these promising findings, the underlying molecular mechanisms responsible for growth enhancement and immune modulation remain inadequately understood, particularly in carp species. Further investigations integrating nutritional, immunological, and microbiome approaches are therefore required to establish optimum inclusion levels and elucidate the precise mode of action of fenugreek in aquaculture.

Dietary Inclusion Levels of Fenugreek in Aquaculture Species

The efficacy of fenugreek (TRIGONELLA FOENUM-GRAECUM L.) as a phytogenic feed additive is largely influenced by its dietary inclusion level, form of supplementation, fish species, and duration of feeding. Previous studies have employed varying concentrations of fenugreek seed powder, extracts, and fermented products in aquafeeds, with the objective of improving growth performance, feed utilization, immune response, antioxidant capacity, and disease resistance. However, the reported inclusion levels differ considerably among studies, making direct comparisons difficult. Low to moderate dietary supplementation levels have generally

been associated with beneficial effects on fish growth and health, primarily due to the presence of bioactive compounds such as saponins, flavonoids, alkaloids, and galactomannans (Reverter et al., 2014; Awad & Awaad, 2017). These compounds may enhance digestive enzyme activity, improve nutrient absorption, modulate immune responses, and positively influence intestinal health. Conversely, excessive inclusion levels may reduce feed palatability, interfere with nutrient utilization, or exert antinutritional effects because fenugreek seeds also contain certain antinutritional factors, including tannins, phytic acid, and high levels of fiber.

The substantial variation in dietary inclusion rates reported in the literature may be attributed to differences in fish species, developmental stages, culture conditions, processing methods, and the form of fenugreek used. Therefore, establishing species-specific optimum inclusion levels through well-designed dose-response studies is essential before recommending fenugreek as a standardized functional feed additive in aquaculture. Comparative investigations evaluating different forms of fenugreek supplementation and their interactions with growth, immunity, antioxidant status, and gut microbiota are also required to elucidate its precise mode of action and maximize its application potential in carp aquaculture.

Research Gaps and Future Perspectives

Despite the growing interest in fenugreek (TRIGONELLA FOENUM-GRAECUM L.) as a phytogenic feed additive in aquaculture, several knowledge gaps remain, particularly in carp species.

1. Standardization of dietary inclusion levels

Previous studies have employed widely varying inclusion levels of fenugreek in aquafeeds, ranging from low to relatively high concentrations depending on fish species, developmental stage, and form of supplementation. Such variability makes direct comparison among studies difficult and limits the establishment of species-specific recommendations. Therefore, future studies should focus on conducting well-designed dose-response experiments to determine the optimum dietary inclusion level of fenugreek for maximizing growth, feed utilization, immune responses, and health performance in carp aquaculture.

2. Effects on reproductive performance in Indian major carps

Most investigations concerning fenugreek supplementation have primarily focused on growth promotion and immunomodulation, whereas its effects on reproductive physiology remain largely unexplored, particularly in Indian major carps such as rohu (LABEO ROHITA),

catla (CATLA CATLA), and mrigal (CIRRHINUS MRIGALA). However, compared with growth and immunity studies, investigations on the reproductive effects of fenugreek supplementation in Indian major carps remain limited. Future studies should therefore investigate the potential role of fenugreek in enhancing reproductive performance and seed quality in Indian major carp breeding programmes.

3. Interaction between fenugreek supplementation and gut microbiota

Emerging evidence suggests that gut microbiota plays a crucial role in regulating nutrient utilization, immune competence, and disease resistance in fish(Gómez & Balcázar, 2008).However, information regarding the effects of fenugreek on the intestinal microbial composition of carp species is extremely limited. In particular, the correlation between microbiota alterations and improvements in growth performance, immune responses, antioxidant status, and resistance against pathogenic infections remains poorly understood. Future studies integrating microbiome analysis, particularly high-throughput sequencing approaches such as 16S rRNA sequencing, with physiological and immunological assessments may provide valuable insights into the mechanisms underlying the beneficial effects of fenugreek in aquaculture.

Overall, future multidisciplinary investigations integrating nutrition, reproductive biology, immunology, and microbiome research are essential to fully exploit the potential of fenugreek as a sustainable phytogenic feed additive in carp aquaculture.

Conclusion

Fenugreek (TRIGONELLA FOENUM-GRAECUM L.) has emerged as a promising phytogenic feed additive in aquaculture due to its rich nutritional profile and diverse bioactive compounds, including saponins, flavonoids, alkaloids, and galactomannans. Available evidence indicates that dietary supplementation of fenugreek may enhance growth performance, feed utilization, antioxidant capacity, immune responses, and overall health status of cultured fish. Furthermore, its plant origin and potential to reduce dependence on synthetic chemicals and antibiotics make it a valuable candidate for sustainable aquaculture practices.

Despite these encouraging findings, several aspects concerning its application in carp aquaculture remain inadequately understood. Future research should focus on establishing species-specific optimum dietary inclusion levels, particularly for Indian major carps, through comprehensive dose-response studies. Furthermore, investigations on the potential role of fenugreek in reproductive performance, including gonadal development, fecundity, egg quality,

and larval survival, are required. Particular emphasis should also be placed on elucidating the interactions between fenugreek supplementation and gut microbiota and understanding how microbiome alterations influence growth, immune competence, and disease resistance.

The future application of fenugreek in aquaculture will depend on a better understanding of its mechanisms of action and the development of scientifically validated feeding strategies. Further studies integrating nutritional, physiological, immunological, and microbiological approaches are necessary to optimize its use in carp culture. Special emphasis should be placed on long-term feeding trials, species-specific responses, and the development of standardized recommendations for dietary supplementation. Such investigations will contribute to the effective utilization of fenugreek and other phytogenic feed additives as sustainable alternatives to synthetic growth promoters and antibiotics, thereby supporting environmentally responsible and economically viable aquaculture practices.

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SOCIAL COMMUNICATION IN HONEY BEE (*APIS MELLIFERA*)

Article ID: AG-VO6-I07-172

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Abstract

Honey bees (primarily the western honey bee, *Apis mellifera*) are social flying insects in the genus *Apis* within the family Apidae. They are among the most familiar and economically valuable insects to humans due to their production of honey, beeswax, and especially their role as pollinators. Bees do not have a spoken language. When food source within a 100-meter radius of the hive the bee perform Circular Dance (Round Dance), and if the food source is more than 100 meters away, the tail-wagging dance (Figure Eight "8" Dance) is perform.

Introduction

Honey bees play a vital role in global agriculture. Understanding the movement of a queen bee within a hive box is essential for advancing both biological research and practical apiculture (Wang *et al*., 2026). The queen bee plays a central role in maintaining the stability and productivity of a honey bee colony. Her primary role is to maintain colony growth by laying 2,000–3,000 eggs per day. Bees do not have a spoken language. Honey bees have the most advanced communication language among the living creatures in the animal kingdom (Gadagk ar, 1996). In honeybees, dance language is described as a silent and complex form of animal communication used to inform nest mates about food sources or the specific location of new nest sites (Brockmann and Robinson, 2007).

BEE DANCES: The dances performed by bees are based on cooperation between individuals living in bee colonies, which is an important element of social life (Liang *et al*., 2012). *Apis mellifera* bees indicate the location of attractive nectar sources by performing communication dances.

1. Circular Dance (Round Dance): When foraging bees find food sources close to the hive, they come to the hive and perform a circular dance (Kirchiner *et al*., 1988). The circular dance is a dance performed by bees with very rapid and sudden movements to indicate the location of a food source **within a 100-meter radius of the hive** (Dyer, 2002). It dances by rapidly rotating clockwise and counter clockwise, drawing one or two poles in each direction. In the circular dance, the foraging bee begins to rotate in a small circle within a section of the honeycomb, constantly changing direction and turning from side to side. Through this dance, the foraging bee communicates the distance to the nest's food source to other bees.

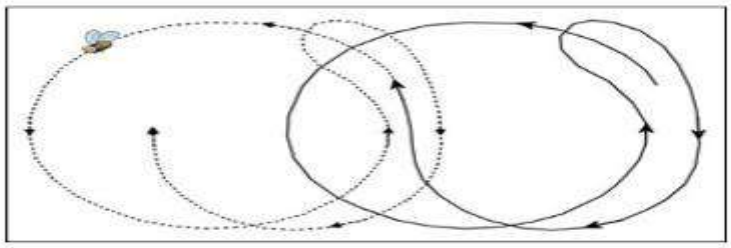


Figure 1. Circular dance (von Frisch, 1967)

2. Wagging Dance (Figure Eight "8" Dance, Tail Wagging Dance): The wagging dance of honey bees (*Apis mellifera*) is one of the best-known communication behaviours in the animal world, performed by a foraging bee on the honeycombs inside the hive to indicate the location of rich food sources to other bees in the hive (Von Frisch, 1967). If the food source is **more than 100 meters** away, the tail-wagging dance is performed (Dyer, 2002). In the wagging dance, the dance movement takes the shape of a figure eight because the dance moves in alternating straight lines (wagging run) and back circles between turns to the right and left (Michelsen, 2003).

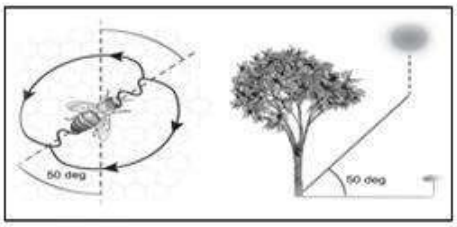


Figure 2. Diagram of the tail-wagging dance of Apis mellifera (von Frisch, 1967)

A wobble dance consists of several wobble runs. The direction of each wobble run relative to gravity indicates the direction of the food source relative to the sun. An interesting feature of the dance is that the directional information for the nearby food source is remarkably inaccurate.

Conclusion

Honey bees (*Apis mellifera*) play a fundamental ecological role in pollination. Bees do not have a spoken language. When food source within a 100-meter radius of the hive the bee perform Circular Dance (Round Dance), and if the food source is more than 100 meters away, the tail-wagging dance (Figure Eight "8" Dance) is perform.

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MICROPLASTIC POLLUTION IN AGRICULTURAL SOILS: SOURCES, DISTRIBUTION, AND ENVIRONMENTAL IMPLICATIONS

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Abstract

Microplastic pollution has become an emerging environmental concern affecting both aquatic and terrestrial ecosystems. Although oceans have traditionally received greater attention, agricultural soils are now recognized as significant reservoirs of microplastics due to the widespread use of plastics in modern farming practices. Microplastics, defined as plastic particles smaller than 5 mm, enter agricultural soils through various pathways, including plastic mulching, sewage sludge application, compost, wastewater irrigation, atmospheric deposition, and the degradation of agricultural plastic products. Once present in the soil, these particles persist for long periods because of their resistance to natural degradation. Their accumulation alters soil physical, chemical, and biological properties, affecting soil structure, nutrient cycling, microbial diversity, water retention, and crop productivity. Microplastics also act as carriers for heavy metals, pesticides, and other pollutants, increasing their mobility and environmental persistence. Furthermore, recent studies suggest that microplastics may enter plants through root uptake, posing potential risks to food safety and human health. Despite increasing research, many uncertainties remain regarding the long-term ecological impacts and effective mitigation strategies. This review discusses the major sources, distribution patterns, environmental behaviour, and ecological consequences of microplastics in agricultural soils. It also highlights current analytical techniques for their detection and outlines sustainable management practices to reduce soil contamination. Understanding the interactions between microplastics and soil ecosystems is essential for protecting soil health, ensuring sustainable agricultural production, and safeguarding environmental quality.

Keywords: Microplastics, Agricultural soils, Soil pollution, Soil health

1. Introduction

Soil is one of the most valuable natural resources on Earth and serves as the foundation for agricultural production, environmental sustainability, and ecosystem functioning. It provides essential nutrients and water to plants, supports diverse biological communities, regulates the movement of water, stores carbon, and plays a key role in maintaining ecological balance. Healthy soils are fundamental for achieving food security and sustainable agricultural development. However, increasing industrialization, urbanization, and intensive farming practices have introduced numerous pollutants into soil ecosystems, threatening their productivity and long-term health.

Traditionally, soil pollution research has focused on contaminants such as heavy metals, pesticides, excessive fertilizers, petroleum hydrocarbons, and industrial chemicals. In recent years, however, microplastics have emerged as a new class of environmental contaminants that has attracted significant scientific attention. While plastic pollution was initially considered a problem mainly affecting oceans and freshwater ecosystems, growing evidence indicates that terrestrial environments, particularly agricultural soils, may contain even larger quantities of plastic debris.

Microplastics are plastic particles smaller than 5 mm in size. They are generally classified into **primary microplastics**, which are intentionally manufactured in microscopic sizes for industrial and commercial applications, and **secondary microplastics**, which are produced through the fragmentation of larger plastic materials exposed to sunlight, temperature fluctuations, mechanical stress, and biological activity. Because conventional plastics degrade very slowly under natural conditions, microplastics remain in the environment for decades, continuously accumulating in soil.

The increasing use of plastics in agriculture has greatly contributed to soil contamination. Plastic mulch films, greenhouse covers, irrigation pipes, seedling trays, fertilizer bags, silage wraps, and packaging materials have become essential components of modern farming systems. Plastic mulch, in particular, is widely used to conserve soil moisture, regulate soil temperature, suppress weeds, and improve crop yields. However, prolonged exposure to environmental conditions causes these materials to crack and fragment, producing large numbers of microplastic particles that remain in the soil even after the visible plastic has been removed.

Apart from agricultural plastics, several other pathways contribute to the accumulation of microplastics in farmland. Sewage sludge generated during wastewater treatment contains large quantities of microplastics that are trapped during the treatment process. Since treated sludge is commonly used as an organic fertilizer because of its nutrient content, significant amounts of microplastics are unintentionally added to agricultural fields. Similarly, compost produced from municipal solid waste may contain plastic fragments if waste segregation is inadequate. Irrigation using treated or untreated wastewater also introduces synthetic fibers and plastic particles into agricultural soils.

Atmospheric deposition has emerged as another important source of soil microplastics. Tiny plastic fibers released from synthetic textiles, vehicle tyre wear, industrial emissions, and urban dust can be transported over long distances by wind before settling on agricultural land. Consequently, even remote agricultural regions with limited direct plastic usage may gradually accumulate microplastics from the atmosphere.

Once introduced into the soil, microplastics interact with soil minerals, organic matter, microorganisms, plant roots, and soil fauna. Their environmental behavior depends on characteristics such as particle size, shape, density, surface area, and polymer composition. Common polymers detected in agricultural soils include polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and polyurethane (PU). These polymers differ in their chemical stability, degradation rates, and capacity to adsorb environmental contaminants.

Microplastics have been shown to influence several important soil properties. They may modify soil structure, aggregate stability, bulk density, porosity, water infiltration, and water-holding capacity. Such changes affect root growth, water availability, and nutrient movement, ultimately influencing crop productivity. In addition, the large surface area of microplastic particles allows them to adsorb heavy metals, pesticides, antibiotics, and persistent organic pollutants, thereby increasing the transport and persistence of these contaminants within soil ecosystems.

This review provides an overview of the major sources of microplastic contamination in agricultural soils, their distribution and transport mechanisms, their effects on soil health and crop production, and the environmental implications associated with their accumulation. It also

discusses current detection methods and management strategies aimed at protecting soil resources and promoting sustainable agriculture.

2. Microplastics: Definition and Classification

Microplastics are synthetic polymer particles measuring less than **5 mm** in diameter. Based on their origin, they are classified into **primary microplastics**, which are intentionally manufactured in small sizes for products such as cosmetics, industrial abrasives, and plastic pellets, and **secondary microplastics**, which are produced through the breakdown of larger plastic items. Secondary microplastics are the dominant form found in agricultural soils because they originate from degraded mulch films, irrigation pipes, packaging materials, greenhouse covers, and other agricultural plastics.

Microplastics are also classified according to their shape, including **fibers, fragments, films, foams, pellets, and beads**. Fibers commonly originate from synthetic textiles, fragments result from the breakdown of larger plastic materials, while films mainly originate from degraded agricultural mulch. The most common polymer types found in agricultural soils include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), and polyethylene terephthalate (PET). Each polymer exhibits different physical and chemical properties that influence its persistence, degradation, and interaction with soil components.

3. Sources of Microplastic Pollution in Agricultural Soils

Microplastics enter agricultural soils through a variety of natural and human-induced pathways. The increasing use of plastic materials in agriculture, coupled with inadequate waste management and the reuse of waste products, has accelerated the accumulation of microplastics in farmland. Unlike many conventional pollutants, microplastics persist in the environment for long periods because they are highly resistant to biological degradation. Their continuous input from multiple sources makes agricultural soils one of the largest reservoirs of plastic pollution.

3.1 Agricultural Plastic Mulching

Plastic mulch films are among the most important sources of microplastics in agricultural soils. Polyethylene mulch is widely used to conserve soil moisture, regulate soil temperature, suppress weed growth, reduce evaporation, and improve crop yield. These films are particularly common in vegetable cultivation, fruit orchards, and horticultural farming.

Over time, exposure to sunlight, ultraviolet (UV) radiation, rainfall, wind, cultivation practices, and temperature fluctuations causes mulch films to become brittle and fragment into

smaller pieces. Even after the visible plastic is removed following harvest, numerous tiny fragments remain embedded in the soil. Continuous use of plastic mulch over several growing seasons results in the gradual accumulation of microplastics, making agricultural mulching one of the largest contributors to soil plastic pollution worldwide.

3.2 Sewage Sludge Application

Sewage sludge is another significant source of microplastics in farmland. Wastewater treatment plants efficiently remove most microplastics from wastewater by trapping them in sludge during the treatment process. Since treated sewage sludge contains valuable nutrients such as nitrogen, phosphorus, and organic matter, it is commonly applied to agricultural fields as an organic fertilizer.

However, along with these nutrients, large numbers of microplastic particles are also introduced into the soil. Synthetic textile fibers released during household laundry are among the most abundant microplastics found in sewage sludge. Repeated application of sludge over many years can substantially increase microplastic concentrations in agricultural soils.

3.3 Compost and Organic Amendments

Compost prepared from municipal solid waste can also contribute to microplastic contamination. Inadequate segregation of biodegradable and plastic waste allows small plastic fragments to enter composting facilities. During the composting process, plastics do not decompose but instead break into smaller particles through mechanical handling and environmental weathering.

When contaminated compost is applied to agricultural fields to improve soil fertility, these microplastics become incorporated into the soil. Although compost provides valuable organic matter and nutrients, poor-quality compost may unintentionally become a source of plastic pollution.

3.4 Wastewater Irrigation

Water scarcity has encouraged many countries to reuse treated wastewater for irrigation. While wastewater irrigation conserves freshwater resources and supplies nutrients to crops, it also introduces microplastics into agricultural soils.

Wastewater often contains synthetic fibers from clothing, plastic fragments from household products, industrial discharges, and personal care products. Although wastewater treatment removes a considerable proportion of these particles, many microplastics remain in

treated effluent and are transported to farmland during irrigation. Repeated irrigation over several years can result in the gradual accumulation of plastic particles in the soil profile.

3.5 Atmospheric Deposition

Recent studies have shown that the atmosphere serves as an important transport pathway for microplastics. Lightweight plastic fibers and fragments released from urban areas, industrial activities, construction sites, vehicle tyre wear, and synthetic textiles become airborne and can travel hundreds of kilometers before settling on the land surface.

As a result, agricultural fields located far from cities or industrial centers may still receive significant quantities of airborne microplastics. Wind, rainfall, and dust storms further redistribute these particles across agricultural landscapes, making atmospheric deposition an increasingly recognized source of soil contamination.

3.6 Agricultural Machinery and Farm Activities

Modern agricultural operations themselves contribute to microplastic generation. Mechanical cultivation, harvesting, and transportation cause wear and tear of plastic materials used on farms. Irrigation pipes, greenhouse covers, fertilizer bags, seedling trays, silage wraps, and plastic ropes gradually deteriorate due to repeated use and environmental exposure.

Farm machinery may also mechanically fragment plastic residues left in fields, accelerating the formation of microplastics. Consequently, routine farming operations can indirectly increase the amount of plastic particles present in soil.

3.7 Improper Disposal of Plastic Waste

Improper management of agricultural plastic waste is another major source of contamination. Burning, burying, or abandoning plastic materials in fields allows them to gradually degrade under environmental conditions. Weathering processes continuously generate smaller plastic fragments that eventually become microplastics.

Poor recycling infrastructure and limited awareness among farmers often contribute to the accumulation of plastic residues in agricultural landscapes.

5. Factors Influencing the Distribution of Microplastics

The distribution of microplastics in agricultural soils is influenced by several environmental and management-related factors.

Particle Size

Small microplastics and nanoplastics move more easily through soil pores and are more

likely to be absorbed by plant roots than larger particles.

Particle Shape

Fibers tend to become entangled within soil aggregates, whereas spherical particles move more freely through pore spaces. Film fragments often remain near the soil surface because of their flat shape.

Polymer Type

Different polymers possess different densities and degradation rates. Low-density plastics such as polyethylene and polypropylene remain near the soil surface for longer periods, while denser polymers may gradually migrate into deeper soil layers.

Soil Texture

Sandy soils generally allow faster movement of microplastics because of their larger pore spaces. Clay-rich soils retain more particles due to their smaller pores and stronger adsorption capacity.

Climate

Temperature, rainfall, solar radiation, and wind influence the weathering, fragmentation, and transport of plastic materials. Warm climates with intense sunlight accelerate plastic degradation, whereas heavy rainfall enhances particle movement through runoff and infiltration.

Agricultural Practices

Tillage, irrigation methods, fertilizer application, crop rotation, and plastic mulch usage strongly influence the accumulation and redistribution of microplastics within agricultural fields. Overall, the spatial distribution of microplastics is highly variable and depends on the interaction between environmental conditions and farming activities.

6. Effects of Microplastics on Soil Physical Properties

Microplastics influence several physical properties of soil that determine its ability to support plant growth. Because plastic particles differ greatly from natural soil minerals in size, shape, and density, their accumulation alters soil structure and changes the movement of air, water, and nutrients.

One of the most noticeable effects is on **soil aggregation**. Soil aggregates are groups of mineral particles bound together by organic matter, microbial secretions, and fungal hyphae. Stable aggregates improve water infiltration, reduce erosion, and provide suitable conditions for root development. Microplastics can interfere with aggregate formation by disrupting the natural

binding between soil particles. Film- and fiber-shaped microplastics often reduce aggregate stability, making soil more vulnerable to erosion by wind and water.

Microplastics also affect **soil bulk density** and **porosity**. Because most plastics are less dense than mineral particles, increasing microplastic concentrations may reduce soil bulk density. While this may improve aeration in some soils, excessive accumulation can create irregular pore spaces that restrict root penetration and alter water movement. The magnitude of these changes depends on soil texture, polymer type, and the amount of plastic present.

The **water-holding capacity** of soil is another important property influenced by microplastics. Fibers can increase water retention by creating additional pore spaces that hold moisture, whereas plastic films may block natural water flow and reduce infiltration. Consequently, different microplastic types produce contrasting effects on soil moisture availability.

Hydraulic conductivity and infiltration rates are also modified. Changes in soil pore connectivity influence the movement of irrigation water and rainfall through the soil profile. Poor water movement may increase surface runoff, reduce groundwater recharge, and affect crop performance during drought.

Another consequence is the increased susceptibility of soils to erosion. As aggregate stability decreases and soil structure deteriorates, topsoil becomes more vulnerable to removal by rainfall and wind. Loss of fertile topsoil reduces agricultural productivity and increases sediment transport into nearby water bodies.

7. Effects on Soil Chemical Properties

Microplastics also alter the chemical environment of soils through interactions with nutrients, pollutants, and organic matter.

One important characteristic of microplastics is their **large surface area**, which allows them to adsorb contaminants from the surrounding environment. Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn) readily attach to plastic surfaces. Similarly, pesticides, antibiotics, polycyclic aromatic hydrocarbons (PAHs), and persistent organic pollutants can accumulate on microplastic particles. As these particles move through soil, they transport adsorbed contaminants to new locations, increasing their environmental persistence and mobility.

Plastics also contain chemical additives introduced during manufacturing. Plasticizers, stabilizers, pigments, flame retardants, antioxidants, and ultraviolet stabilizers may gradually leach into soil during weathering. Some of these compounds exhibit toxic or endocrine-disrupting properties, posing additional environmental risks.

Microplastics may also influence **soil pH**, **cation exchange capacity**, and **nutrient availability**. Alterations in soil chemistry affect nutrient cycling and fertilizer efficiency. Some studies report reduced availability of nitrogen and phosphorus because changes in microbial activity influence mineralization processes.

The interaction between microplastics and soil organic matter is complex. Organic matter may either promote the retention of microplastics through adsorption or facilitate their movement depending on soil conditions. These interactions affect long-term carbon storage and nutrient cycling within agricultural ecosystems.

8. Environmental Implications

The consequences of microplastic pollution extend beyond agricultural fields.

Microplastics contribute to the movement of contaminants into groundwater through leaching and surface runoff. Rivers and lakes receiving agricultural drainage become secondary sinks for plastic particles.

Plastic particles also act as carriers of heavy metals, pesticides, and pathogenic microorganisms. Combined contamination often produces greater ecological risks than individual pollutants because contaminants interact synergistically.

Changes in microbial activity may influence greenhouse gas emissions from soil by affecting carbon and nitrogen cycling. Alterations in methane, nitrous oxide, and carbon dioxide production have been reported under experimental conditions, although long-term field data remain limited.

Because microplastics are extremely persistent, they accumulate continuously over time. Their long residence period makes prevention far more effective than remediation.

Conclusion

Microplastic pollution has become one of the most important emerging threats to agricultural soils worldwide. Modern farming practices, including plastic mulching, wastewater irrigation, sewage sludge application, compost use, and extensive plastic-based materials, have significantly increased the accumulation of microplastics in farmland. Due to their persistence

and resistance to degradation, these particles remain in soils for extended periods and interact with soil minerals, organic matter, microorganisms, plants, and other contaminants.

The presence of microplastics alters soil physical, chemical, and biological properties by affecting aggregate stability, porosity, water movement, nutrient cycling, microbial diversity, and enzyme activity. Their ability to adsorb heavy metals and organic pollutants further increases environmental risks. Emerging evidence also suggests that very small plastic particles may enter plants, raising concerns about food safety and human health.

Although considerable progress has been made in understanding the occurrence and impacts of microplastics, important knowledge gaps remain regarding their long-term behavior under field conditions, interactions with other contaminants, and effective remediation techniques. Standardized sampling methods, long-term monitoring, and multidisciplinary research are essential for improving risk assessment.

Protecting agricultural soils from microplastic pollution requires preventive measures rather than relying solely on remediation. Reducing plastic consumption, improving waste management, adopting biodegradable alternatives, enhancing wastewater treatment, and strengthening environmental policies are essential for minimizing future contamination. Through sustainable management practices and continued scientific research, it is possible to reduce the environmental impacts of microplastics while preserving soil health, agricultural productivity, and food security for future generations.

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FROST MANAGEMENT IN ARID ZONE FRUIT PLANTS

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Introduction

Frost is a thin layer of ice crystals that forms when water vapour in the air transitions directly into a solid. It occurs on clear, calm nights when the surface temperature of plants, soil, or objects drops below the freezing point of 32°F (0°C).

Types of Frost

Hoar (White) Frost: The most common type, featuring visible, needle-like ice crystals that build up on leaves and stems.

Black Frost: Occurs in highly dry air when temperatures drop below freezing, but no visible ice forms. It causes plant tissues to instantly freeze, blacken, and die internally.

Radiation Frost: Forms on calm, clear nights as ground heat radiates rapidly up into the sky, trapping a layer of freezing air at canopy level.

Advection Frost: Driven by cold, windy weather fronts that transport freezing air masses into an area, affecting plants uniformly.

Effects of Frost on Plants

Cellular Rupture: Water inside plant cells expands as it freezes, puncturing and destroying cell walls.

Wilting and Necrosis: Upon thawing, damaged leaves lose structure, turning limp, water-soaked, brown, or completely black.

Blossom and Fruit Drop: Frost destroys delicate flower tissues and young fruits, stopping

pollination and wiping out seasonal harvests.

Physiological Stress: It severely stunts growth, inhibits chlorophyll synthesis, and reduces general nutrient uptake.

Frost control methods

Frost Control Methods for Arid zone fruit trees (such as ber, pomegranate, date palm, fig, and citrus) are highly susceptible to winter radiation frosts. Management is split into two primary approaches:

Passive Control (Preventative)

Site Selection: Planting on higher slopes or elevated terrain allows cold air to drain naturally into lower valley floors, avoiding frost pockets.

Nutritional Management: Applying potassium and phosphorus fertilizers enhances the crop's internal cold hardiness, while avoiding late-nitrogen applications prevents vulnerable, tender new growth.

Orchard Floor Care: Keeping the ground bare, moist, and free of long grass or weeds maximizes the soil's capacity to absorb daytime heat and radiate it back upward during freezing nights.

Active Control (During Frost Events)

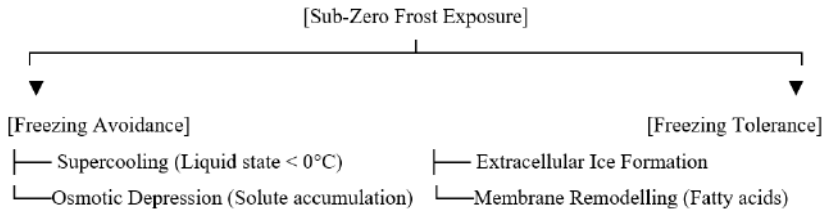
Strategic Irrigation: Flood or sprinkler irrigation the evening before an expected freeze releases latent heat as the water cools, stabilizing the boundary air temperature.

Wind Machines: Large orchard fans mix the lower, freezing air layer with the warmer air mass trapped higher up in the inversion layer.

Thermal Barriers: Covering small or high-density trees with breathable commercial fabrics or Frost Protection Blankets traps rising ground heat. Small brush fires or smudge pots are also used in low-lying areas to actively generate smoke and localized warmth.

Biological Mechanisms of Frost Tolerance

Arid zone fruits adapt to cold stress using specialized cellular and biochemical survival strategies:



Supercooling (Freezing Avoidance): Plant tissues maintain cell water in a liquid state well below 0°C (32°F) by preventing the initiation of ice crystals. This relies heavily on a high concentration of active, non-nucleating sap.

Osmotic Adjustment: Under cold acclimation, trees accumulate cryoprotective osmolytes such as soluble sugars (sucrose, glucose), proline, and sugar alcohols. These solutes depress the freezing point of the cytoplasm, acting like natural antifreeze.

Controlled Extracellular Freezing: Ice is safely guided to form in the intercellular gaps (apoplast) rather than inside the cells. As ice grows outside, it gently draws water out of the cell, causing a controlled dehydration that protects the delicate intracellular structures from being physically punctured by ice shards.

Membrane Remodelling: Plants increase the proportion of unsaturated fatty acids within their plasma membrane lipids. This modification maintains structural flexibility and prevents the membrane from fracturing or leaking during cell desiccation.

How to Protect Plants from Frost

Cover Beds at Dusk: Drape breathable fabrics like old bed sheets, burlap sacks, or specialized Frost Blankets over your plants. Anchor the edges to the ground to trap soil heat, and use stakes to keep the material from touching the wet leaves directly. Avoid using bare plastic.

Hydrate the Soil: Thoroughly water your garden soil during midday. Wet soil absorbs maximum sunlight and retains heat far better than dry soil, radiating warmth upward through the night.

Apply Thick Mulch: Insulate root zones with a thick layer of straw, wood chips, or fallen leaves to keep the ground from freezing.

Relocate Potted Plants: Bring mobile containers indoors into a garage, basement, or shed before nighttime temperatures plummet.

Use Temporary Shields: Invert large plastic buckets, milk jugs, or cardboard boxes over small individual plants to create a protective micro-greenhouse. Remove these covers first thing in the morning.

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STATUS OF ARID ZONE FRUIT TREES

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Introduction

Arid zone fruit plants are tough trees and shrubs that survive on very little water and handle hot weather well. The key plants for dry areas include Ber (*Ziziphus mauritiana*), Pomegranate (*Punica granatum*), and Date Palm (*Phoenix dactylifera*).

Major Arid Fruit Trees

Ber / Indian Jujube (*Ziziphus mauritiana*): Deep roots make it very hardy; bears sweet vitamin-rich fruits.

Pomegranate (*Punica granatum*): Thrives in dry soil with low water needs; yields nutritious red fruit.

Date Palm (*Phoenix dactylifera*): Loves intense heat and sunshine; needs minimal water once grown.

Aonla / Indian Gooseberry (*Emblica officinalis*): Very tough tree; produces tart fruit loaded with vitamin C.

Bael (*Aegle marmelos*): Strong native tree that tolerates poor dry soil and hot winds.

Native and Underutilized Arid Shrubs

Ker (*Capparis decidua*): A leafless desert shrub providing edible pickled buds and small fruits.

Lasora / Lasoda (*Cordia myxa*): Small tree yielding sticky edible fruits used in pickles.

Jal / Pilu (*Salvadora oleoides*): Desert shrub/tree producing small sweet edible berries in summer.

Hingota (*Balanites aegyptiaca*): Wild desert tree surviving harsh dry spells with oily, edible fruit pulp

The source of origin for key arid zone fruit plants

The source of origin for key arid zone fruit plants spans several distinct global phytogeographical regions, notably the Indo-Malayan/Hindustan center, Central Asia, and the Near East. Native institutions like the Central Institute for Arid Horticulture oversee regional conservation of these diverse species.

Major Arid Fruits and Their Native Regions

Hindustan / Indian Subcontinent Center:

Ber (*Ziziphus mauritiana*): Indo-China and India

Ker (*Capparis decidua*): Thar Desert and arid tracts of India

Aonla (*Emblica officinalis*): India

Bael (*Aegle marmelos*): India

Lasora (*Cordia myxa / Cordia dichotoma*): Indian subcontinent

Pilu (*Salvadora oleoides*): Thar Desert and dry regions of India

Near Eastern & Mediterranean Centers:

Pomegranate (*Punica granatum*): Iran, Afghanistan, and the Near East

Date Palm (*Phoenix dactylifera*): Mesopotamia (modern-day Iraq/Persian Gulf region)

African Center:

Tamarind (*Tamarindus indica*): Tropical Africa

Desert Date (*Balanites aegyptiaca*): Dry regions of Africa

Importance of Arid Zone Fruit Trees

Arid zone fruit plants provide critical nutritional security, ecological stability, and economic resilience in harsh dry regions. Key species like **ber** (*Ziziphus mauritiana*), **pomegranate** (*Punica granatum*), and **aonla** (*Emblica officinalis*) thrive under extreme temperatures and low rainfall.

Nutritional and Livelihood Security

High Nutrients: Fruits like ber are rich sources of Vitamin C, protein, calcium, and carotene, often surpassing common fruits like apples.

Famine Food: Native shrubs and trees (*Capparis decidua* / Ker, *Cordia myxa* / Lasora, and *Salvadora oleoides* / Pilu) act as vital survival food reserves during severe droughts.

Income Generation: Hardy crops diversify farm income and provide stable yields in marginal lands where traditional crops fail.

Environmental and Ecological Benefits

Drought Adaptation: Deep root systems and low moisture requirements allow these perennial plants to survive high evaporation rates and poor sandy soils.

Soil Conservation: Vegetation cover helps bind light-textured desert soils, reducing wind erosion and stabilizing fragile arid ecosystems.

Nutritional Status of Arid Zone Fruit Trees

Arid zone fruit plants possess exceptional nutritional profiles, high climate resilience, and dense concentrations of proteins, dietary fibers, vitamins (particularly Vitamin C and A), and essential minerals. Key plants representing this group include *Ziziphus mauritiana* (ber), *Capparis decidua* (ker), and *Emblica officinalis* (aonla).

Major Arid Fruit Nutrients

Ber (Ziziphus mauritiana): Richer in protein, phosphorus, calcium, carotene, and Vitamin C than standard temperate fruits like apples.

Ker (Capparis decidua): High density of crude protein, fiber, carbohydrates, and antioxidant-rich Vitamin C and A.

Aonla (Emblica officinalis): Exceptional source of bio-assimilable Vitamin C (up to 700 mg/100g) alongside essential iron, calcium, and polyphenols.

Chemical Composition of Arid Zone Fruit Trees: Arid zone fruit plants like Ber (Indian Jujube), Ker, and Pilu feature high concentrations of carbohydrates, organic acids, essential minerals (calcium, phosphorus, potassium, iron), and protective bioactive phytochemicals like flavonoids, tannins, and Vitamin C.

Proximate and Nutritional Profiles

Carbohydrates: Dominated by natural sugars (glucose, fructose, and sucrose) serving as primary energy reserves.

Proteins and Fats: Noticeably higher in underutilized wild pods and seeds (e.g., *Capparis decidua* / Ker and *Salvadora oleoides* / Pilu seeds) compared to conventional juicy fruits.

Fiber: Abundant dietary and mucilaginous fiber aiding moisture retention and digestive health.

Vitamin and Mineral Composition

Ascorbic Acid (Vitamin C): Exceptionally high in fruits like ber and aonla, surpassing common

orchard fruits.

Macrominerals: Rich storehouses of **potassium (K)** for cellular balance, **calcium (Ca)** for structural integrity, and **phosphorus (P)**.

Micronutrients: Significant baseline concentrations of bioavailable **iron (Fe)** and magnesium (Mg).

Bioactive Phytochemicals

Polyphenols & Flavonoids: Potent antioxidants protecting plant cells against extreme UV radiation and oxidative stress.

Tannins & Alkaloids: Confer distinct astringency, defense mechanisms, and strong traditional medicinal properties.

Role of Arid Zone Fruit Trees in Indian Economy

Arid zone fruit plants support the Indian economy by providing **livelihood security**, **drought-resistant commercial farming**, and **nutritional stability** in fragile dry regions. Key crops like ber, pomegranate, and aonla transform dry lands into profitable zones.

Economic Contributions

Income stability: Drought-hardy crops like ber and pomegranate yield steady farm revenue when traditional seasonal crops fail due to low rain.

Job creation: Cultivating, harvesting, and processing fruits like aonla and date palm create local jobs in rural desert communities.

Land value: Perennial fruit trees improve barren and sandy soils, preventing soil erosion and adding long-term value to dry wasteland.

Food and Resource Security

Low water use: These plants need very little water, saving precious groundwater resources in states like Rajasthan and Gujarat.

Extra value: Plants like ber provide fruit for humans plus valuable fodder for farm animals.

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TINY ENGINEERS OF THE OCEAN-ROLE OF ZOOPLANKTON IN MARINE SNOW FORMATION AND CARBON SEQUESTRATION

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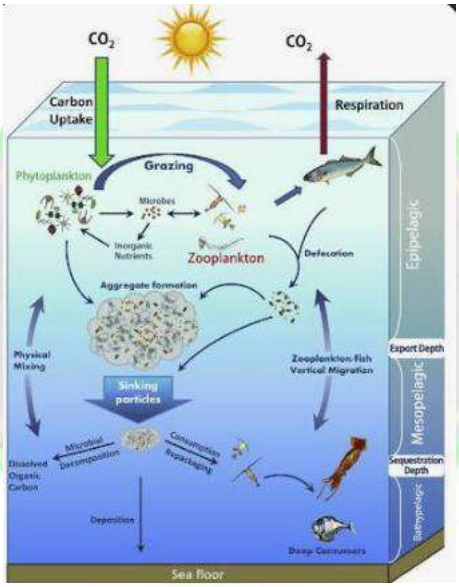
Absract

Marine snow which plays an important role in the sequestration and transportation of the carbon by the continuous shower of organic particles from the surface of the ocean to the deep ocean surface Phytoplankton were recognized for capturing the atmospheric carbon dioxide through photosynthesis as like, zooplankton which plays a crucial role in the formation of the marine snow. Zooplankton including, copepods, appendicularians, salps and also the jellyfish, these organisms which influence the marine snow formation through the following process which includes fecal pellet formation grazing mucus secretion discarded feeding structure, and the post-mortem sinking events. These process which enhances the particle aggregation, increases sinking rates, and facilitate the transfer of organic carbon from the upper ocean to the deep sea and could be stored for the longer period of time. Marine snow not only contributes to the carbon sequestration but also gives important sources to the deep sea organisms. This article which depicts about the significance of zooplankton in the marine snow formation and also examines its contribution to the carbon export, and also for the deep sea food webs.

Introduction

Marine snow which is said to be macroscopic organic aggregates often larger than the 500micro meter in diameter. It powers the oceans biological pump and also sustains the deep sea

ecosystems. As microhabitants, marine snow aggregates contain enriched microbial communities and chemical gradients within which the process of photosynthesis,decomposition, and nutrient regeneration occur at highly elevated levels.it can also be produced either de novo by living plants and animals especially as mucus feeding webs of zooplankton, or by the biologically enhanced physical aggregation of smaller particles. By the later pathway, microaggregates, phytoplankton, fecal pellets, organic debris and clay mineral particals collide by differential settlement or physical shear and adhere by the various actions, biologically generated, organic compounds. The greatest challenge to the study of marine snow at present is the development of appropriate technology to measure the abundance and the characteristics of aggregrates insitu. This article which explains the fascinating relationship between zooplankton and marine snow.



MARINE SNOW:

It is a continuous shower of organic detritus such as dead plankton , fecal pellets, and mucus falling from the upper ocean to the deep sea.it serves as the primary food source for deep sea organisms and acts as a crit-ical biological pump for the carbon sequestration. Marine snow composed of:

1.Dead phytoplankton cells

2.Zooplankton fecal pellets

3.Mucus secretion

4. Discarded appendicularian houses

5.Bacteria and microbial aggregates

6. Detritus from marine organisms

7.Dead zooplankton and fish larvae

8. Mineral particles and dust

The size of the marine snow particles varies from micrometers to centimeters. As these particles sink, they undergo physical, chemical, and biological, transformations.

ZOOPLANKTON

The marine zooplankton community which includes many different species of animals, ranging in size from microscopic protozoans to animals of several meters in dimension. The holoplanktonic species spend their entire lives in the pelagic environment, meroplanktonic forms are temporary members of the plankton, and include the eggs and the larvae stages of many benthic invertibrates and fish.

Direct observation of zooplankton using scuba techniques, ROVs, or submersibles have great increased our knowledge of fragile and fast swim-ming species. As light from the sun diminishes with depth, bioluminescent light produced by the organisms become increasingly important form of communication.

APPENDICULARIANS

.size will be less than 5mm, adopted for living in the oligotrophic waters. The small tunicates constructs intricate mucus structures called houses.The houses called as filtration devices that capture tiny particles from the surrounding water. Discarded houses sink rapidly, dropping up to several hundred meters per day, which prevents the carbon from being broken down by bacteria near the surface.

Appendicularians (larvaceans) are free-swimming tunicates that construct intricate mucus "houses" to filter-feed. By continually discarding these clogged houses, they generate large volumes of fast-sinking marine snow. This rapidly transports atmospheric carbon sequestered by phytoplankton into the deep ocean, bypassing surface remineralizationThese structure which are rich in the organic carbon and often trapped phytoplankton, bacteria, detritus, and microplastics. It contribute significantly to the carbon export.

COPEPODS:

They are the most important contributors of the marine snow. Cope-pods are small, shrimp like crustaceans that live in both marine and fresh.water environments. Measuring 0.5-2

millimeters, they are virtually invisble without magnification -yet their ecological importance is unmatched.

They consume excess algae, bacteria and organic debris -essentially functioning as a natural biofilters. The ecological significance of copepods fecal pellets lies in their ability to transport carbon efficiently.Helps in long term sequestration of carbon.

SALPS:

Salps are gelatinous, mostly transparent, cylindrically shaped. They ranged the size from few millimeters at birth to around 10cm as they grow, some also grow in meters.Salps fecal pellets are particularly important because of their size, density, and high carbon content .Salps feed by pumping a large volume of seawater through the mucous filter.

JELLYFISH AND JELLYFALLS:

Jelly fish are the ancient, free swimming marine invertebrates characterized by the gelatinous, umbrella -shaped bells and trailing venomous tentacles.Composed of roughly 95% of water, they lack brains, blood, or bones and drift primarily with the ocean currents

Jellyfalls is the deep sea equivalent of a "whale fall". It is a marine carbon cycling event where massive swarms or blooms of dead gelatinous zooplankton. Jelly derived particles support deep sea scavengers and microbial communities while contributing to carbon sequestration.

MUCUS:

Zooplankton which releases the mucus into the surrounding water.This mucus acts as a biological adhesive that binds smaller particles together.

MARINE SNOW - used a For deep sea food webs

It provides food for

- Bacteria
- Protozoans
- Zooplankton
- Deep sea fishes
- Crustaceans

ZOOPLANKTON AND THE BIOLOGICAL CARBON PUMP :

Zooplankton drive the ocean's biological carbon pump by consuming carbon rich phytoplankton at the surface and transporting it to the deep sea. They package this carbon into

dense, fast -sinking fecal pellets and actively carry it downward during the daily twilight commuted known as diel vertical migration.

The biological carbon pump is natural mechanism that transfers carbon from a atmosphere and the surface ocean to the deep sea. The process begin when phytoplankton absorb carbon dioxide during photosynthesis. The captured carbon enters marine food webs through grazing by zooplankton. Without zooplankton, the efficiency of the biological carbon pump would be significantly reduced.

Conclusion

Though the zooplankton are underappreciated organisms in nature But it still contributes to lot of benefical roles which include the transform the microscopic particles into marine snow that sinks toward the deep ocean through the process of their feeding, digestion, mucus production, and life-cycle process, they transform microscopic particles into marine snow that sinks towards the deep ocean. These zooplankton also plays a major in the climate regulation, carbon sequestration, and the maintenance of deep sea ecosystems. As these organisms are tiny, they play a vital role in the earth carbon cycle. Thus it was understood that they were the hidden engineers of the ocean, but quietly helps to regulate the climate change and helps to maintain the ecosystem widely.

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INVISIBLE PLASTICS, VISIBLE DAMAGE: THE HIDDEN THREAT OF NANOPLASTICS IN AQUATIC ENVIRONMENTS

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Abstract

Nanoplastics are emerging as one of the most serious yet least visible forms of plastic pollution in aquatic environments. This article highlights how larger plastic waste gradually breaks down into microscopic particles that spread through rivers, lakes, and oceans. It explains the sources, unique properties, and movement of nanoplastics through aquatic food webs, as well as their harmful effects on plankton, fish, shellfish, corals, and overall biodiversity. The article also discusses the potential risks to human health through seafood consumption and emphasizes the environmental, economic, and fisheries-related consequences of this hidden pollutant. Current research, real-world examples, and practical solutions, including reducing plastic use, improving waste management, promoting innovation, and strengthening environmental policies, are presented to increase public awareness. The article concludes that collective action and sustainable lifestyle choices are essential to reduce nanoplastic pollution and protect aquatic ecosystems for future generations.

Keywords: Nanoplastics; Aquatic Environment; Plastic Pollution; Food Chain; Biodiversity; Marine Ecosystems

Introduction

Imagine a world where pollution exists but cannot be seen with the naked eye. Hidden beneath the surface of rivers, lakes, and oceans are nanoplastics—tiny plastic particles so small that they are invisible, yet they pose a serious threat to aquatic ecosystems. Unlike floating

plastic bottles or bags, these particles silently spread through water, making them one of the most challenging forms of pollution today. Plastic pollution has become a global environmental issue, but as larger plastics break down over time, they form nanoplastics that can easily enter the bodies of plankton, fish, shellfish, and other aquatic organisms. These particles can move through the food chain and may eventually reach humans through seafood and drinking water. Understanding nanoplastics is important because their effects are often hidden but long-lasting. By learning about this invisible pollutant, we can better protect our aquatic environment, conserve biodiversity, and promote a cleaner and healthier future for both aquatic life and people.

Evolution : How Did We Get Here?

Plastic has become an essential part of our daily life because it is cheap, lightweight, and durable. It is used in shopping bags, bottles, food packaging, fishing nets, and many other products. However, a large amount of plastic waste is not disposed of properly and often ends up in rivers, lakes, and oceans. Unlike natural materials, plastic does not decompose easily. Instead, it slowly breaks into smaller and smaller pieces through exposure to sunlight (UV rays), heat, waves, wind, and physical wear.

Plastic is widely used because it is inexpensive, lightweight, and durable. However, improper disposal causes large amounts of plastic waste to enter rivers, lakes, and oceans. Over time, sunlight, heat, waves, and physical wear break plastics into smaller particles.

The evolution of plastic pollution occurs in three stages:

- Plastic Waste (Macroplastics): Large items such as bottles, bags, and fishing nets enter aquatic environments.
- Microplastics: These plastics break into particles smaller than 5 mm, or originate from synthetic fibers, tyre wear, and cosmetics.
- Nanoplastics: Microplastics further degrade into particles smaller than 1 µm, which are invisible to the naked eye. These tiny particles can enter aquatic organisms and move through the food chain, posing serious risks to ecosystems and human health

Meet the Invisible Pollutant: The Journey of an Invisible Traveller

What if the biggest pollution problem was too small to see? - Nanoplastics are tiny plastic particles, generally smaller than 1 micrometer (1000 nanometers), formed when discarded plastics break down through sunlight, heat, wind, and waves or are released from synthetic

clothing, vehicle tires, industrial activities, and household products. Invisible to the naked eye, they travel through oceans, rivers, air, and soil, carrying toxic pollutants and entering tiny aquatic organisms. They then move through the food chain to fish, larger marine animals, and eventually humans, making nanoplastics one of the most serious and widespread threats to aquatic ecosystems.

Table 1 : Types of nanoplastics and their impacts in particular species

Type of Nanoplastic	**Common Polymer**	**Source**	**Aquatic Species Studied**	**Observed Impact**	**Mechanism of Toxicity**
Polystyrene Nanoplastics (PS-NPs)	Polystyrene (PS)	Food containers, disposable cups, packaging foam	**Zebrafish (*Danio rerio*)**	Reduced growth, developmental abnormalities, impaired swimming, oxidative stress	ROS generation, inflammation, neurotoxicity
Polyethylene Nanoplastics (PE-NPs)	Polyethylene	Packaging films	**Common Carp (*Cyprinus carpio*)**	Reduced growth, intestinal damage, altered gut microbiota	Physical abrasion and oxidative stress
Polypropylene Nanoplastics (PP-NPs)	Polypropylene (PP)	Bottle caps, ropes, fishing nets	**Japanese Medaka (*Oryzias latipes*)**	Reduced embryo survival, developmental toxicity	Cellular stress and apoptosis
Polyvinyl Chloride Nanoplastics (PVC-NPs)	Polyvinyl Chloride (PVC)	Pipes, cables, construction materials	**Rainbow Trout (*Oncorhynchus mykiss*)**	Gill lesions, respiratory stress, altered blood parameters	Membrane damage and oxidative stress

Polyamide (Nylon) Nanoplastics	Polyamide (PA)	Fishing nets, synthetic textiles	**Whiteleg Shrimp (*Litopenaeus vannamei*)**	Reduced growth, intestinal injury, immune suppression	Gut inflammation and oxidative stress

While microplastics usually stop at the digestive tract, nanoplastics are far more insidious—they breach physical barriers entirely. They behave like microscopic cellular hackers, bypassing biological membranes and overtaking essential biological systems..Here is how this invisible war is playing out inside different marine residents, from the smallest organisms to entire ecosystems.

Life Under Threat: Cellular Hijackers: The Microscopic War Inside Marine Life

1.Plankton: The Tiny Powerhouses Running on Empty

Plankton form the base of the ocean food web and produce much of Earth's oxygen. Nanoplastics can enter their cells, disrupt energy production, and make them feel full without nutrients. When plankton decline, the entire marine food chain suffers.

2.Fish: The Drunken Swimmers (Neurological Hijack)

3.Shellfish: Oysters and Mussels on a Toxic Diet.

Nanoplastics can pass through fish gills into the bloodstream and even reach the brain. There, they disrupt behavior, causing disorientation, sluggishness, erratic movement, and poor predator response

Oysters, clams, and mussels filter water and can concentrate nanoplastics along with heavy metals and pesticides. This can cause inflammation, reproductive problems, and weakened shells.

4.Corals: The Starving Cities of the Sea

Corals depend on algae inside their tissues for food. Nanoplastics can block light and stress corals, causing them to expel their algae in coral bleaching. Without them, reefs starve and die.

5.Aquatic Biodiversity: The Slow-Motion System Crash

Because ocean life is interconnected, damage to plankton, corals, and shellfish spreads through the whole ecosystem. Long-term exposure to nanoplastics can cause cellular stress, DNA damage, and immune failure, contributing to a slow collapse of aquatic biodiversity.

From Ocean to Our Dinner Plate

Food Chain: Nanoplastics enter the ocean through polluted water and are first consumed by tiny organisms like plankton. Small fish eat the plankton, larger fish eat the smaller fish, and these particles move up the food chain. At every step, nanoplastics travel silently from one organism to another.

Bioaccumulation: Unlike food that is digested, nanoplastics can remain inside the body of marine animals. Over time, these particles build up in tissues and organs, making it difficult for the animals to remove them. This gradual buildup is known as bioaccumulation.

Human Exposure: When people eat seafood such as fish, shellfish, or crabs, they may also consume the nanoplastics present in these animals. Although scientists are still studying the long-term health effects, reducing plastic pollution today is essential for protecting future generations.

When the Invisible Becomes Impossible to Ignore

Nanoplastics are spreading through oceans, rivers, and coastal waters, reducing water quality and disrupting aquatic ecosystems. Their tiny size allows them to reach areas inaccessible to larger plastic debris, affecting the growth, survival, and reproduction of aquatic organisms. This threatens fisheries, food security, and the livelihoods of coastal communities while reducing seafood quality, increasing cleanup costs, and impacting tourism. By damaging marine ecosystems, nanoplastics also weaken vital ecosystem services such as food production, climate regulation, oxygen generation, and biodiversity conservation.

Turning the Tide: Can We Reclaim Our Invisible Oceans?

Reducing plastic waste at its source is the most effective way to prevent nanoplastics from polluting rivers and oceans. Using reusable products, improving waste management, recycling, and wastewater treatment can limit their formation.



Figure 1 : Aquatic Pollution By Nanoplastics

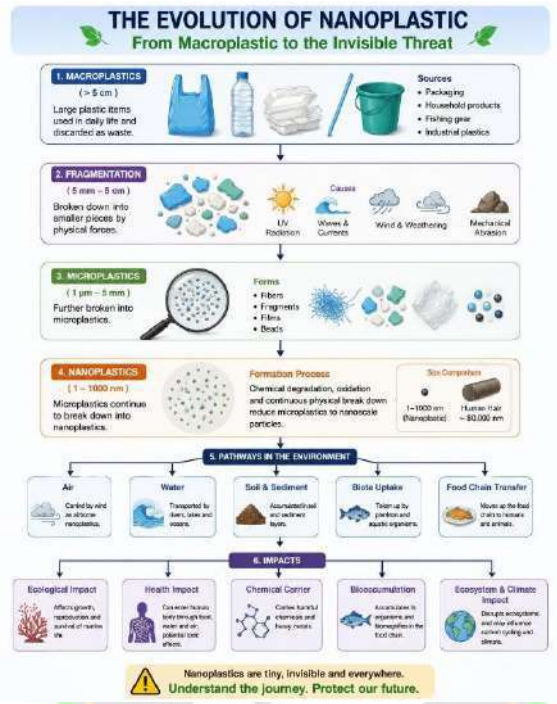


Figure 2 : The Evolution Of Nanoplastics And Their Impacts

At the same time, scientists are developing advanced filtration technologies, biodegradable materials, and better detection methods, while governments and industries are strengthening policies to reduce plastic pollution. Every small action—refusing single-use plastics, recycling responsibly, joining clean-up drives, and spreading awareness—can help restore healthier oceans and protect marine life for future generations.

Conclusion

Nanoplastics may be invisible, but their impact is becoming impossible to ignore. The choices we make today will shape the health of our oceans tomorrow. By reducing plastic waste, protecting marine ecosystems, and inspiring others to act, we can ensure cleaner waters and healthier marine life for future generations. "**The ocean has always cared for us—providing food, oxygen, and life. Now, it's our turn to care for the ocean. Together, let's keep our blue planet clean, healthy, and full of life".**

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DECOMPOSITION OF CARDAMOM PRICE TREND

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Abstract

Cardamom, exhibits highly volatile auction-prices. On 4th January 2020, a premium lot sold at a Kerala auction for nearly Rs.7,000, the highest recorded nearly silver's price by weight. Earlier the same lot was traded Rs.1,000. This paper applies a peak-trough decomposition of prices from 2015-2026 to identify the cyclical structure behind this volatility. Two complete cycles are identified i.e. a trough of Rs.950 (January 2018) followed by peak of Rs. 2,950 (October 2019), and subsequent trough of Rs. 905 (July 2022) followed by a peak Rs. 2,640 (May 2025). Each cycle spans roughly over 21 to 34 months but retrace only a third of gains over the following two to three years. This pattern reflects a lagged supply response, driven by rainfall-constraint short-run supply and the multi-year gestation lag of newly planted or rejuvenated cardamom. The next trough is projected between late 2027-2028, with implications for price risk management.

Key words: Cardamom, Cyclical trends, Cardamom markets, Auction prices

Introduction

Cardamom (*Elettaria cardamomum*), among the India's most valuable perennial planation crops grown in the hill regions of Kerala. Tamil Nadu, and Karnataka. For farmers who grow this crop, prices are most important. Cardamom prices are discovered mainly through open e-auctions rather than futures contacts (Vijayakumar (2022)), One month a kilogram of cardamom may sell for a few hundred rupees and year later, the same quality may fetch several thousand.

The paper will address such extreme swings. When we look at cardamom prices over a long period of time in this case from 2015 to 2026 a clear and repeating pattern emerges. On this basis, the paper projects the next cyclical trough to fall in future, while noting that weather, export demand, and policy shifts could alter this trend. The findings carry implications for price-risk management by growers, traders, and policy makers in perennial spice markets. Currently cardamom prices have climbed across all the markets reporting above average of Rs.2500 per kg and above due to low rainfall in major producing regions has reduced production, strong export demand has kept the prices high.

The cardamom prices have not risen overnight. Prices have been increasing gradually from months before the peak price occurs. Daily cardamom prices bounce around constantly from an auctioneer to auctioneer, although cardamom prices fluctuate from day to day, the long-term trend reveals clear cyclical trends. The major turning points occurred in January 2018, when prices fell to around Rs.950 per kg, and in October 2019, when they reached about Rs.2,950 per kg. Prices declined again to around Rs.905 per kg in July 2022 before rising to approximately Rs.2640 per kg in May 2025.



Source: Spices Board of India (n.d.).

The Cardamom price: 2015 to 2026

Cardamom prices vary day to day at auctions. But bigger picture tells a different story. Over the past decade, price have clear cyclical movements from the period of rapid rise followed by long, slow declines. Two complete cycles can be seen in the data so far taken.

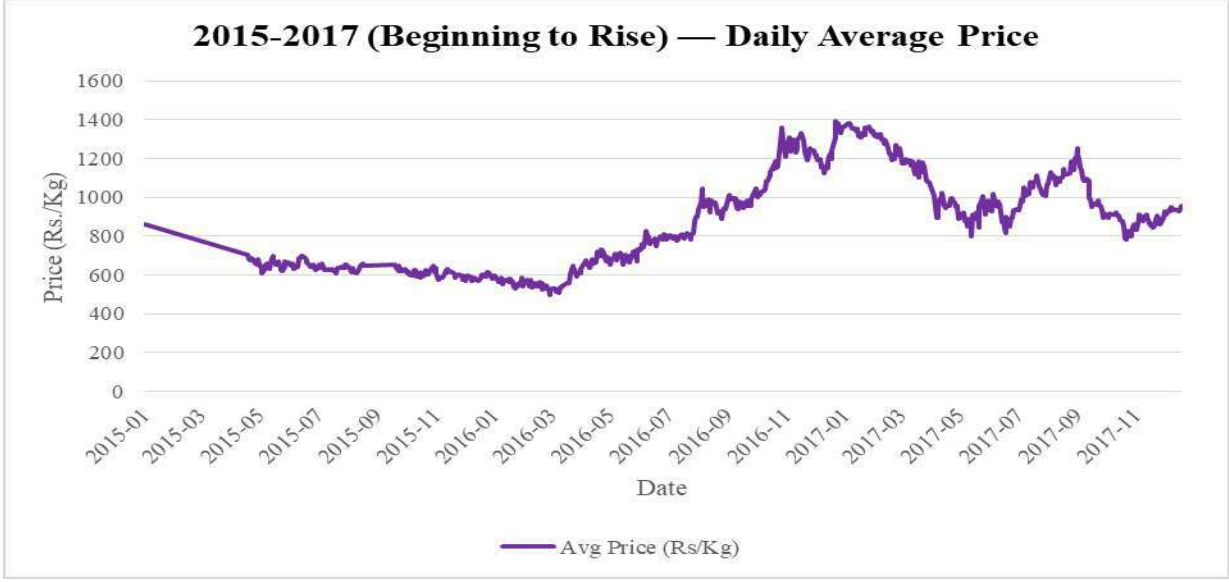
Cycle	Low price (Trough)	High price (Peak)	Time Taken to Rise
1st cycle	Rs.950/kg (Jan 2018)	Rs.2.950/kg (Oct 2019)	21 months
2nd cycle	Rs.905/kg (Jul 2022)	Rs.2,640/kg (May 2025)	34 months

Note: At the peak of first cycle in 2020, 7,000/kg was recorded. (Spices Board of India (n.d.)).

1st cycle, prices rose from a low of Rs.950 per kg in January 2018 to a high of Rs.2,950 per kg in October 2019. Almost tripled in less then 2 years. But the fall that followed took much longer. A new low of Rs.905 per kg reached in July 2022, and even then only about a third of ground recovered.

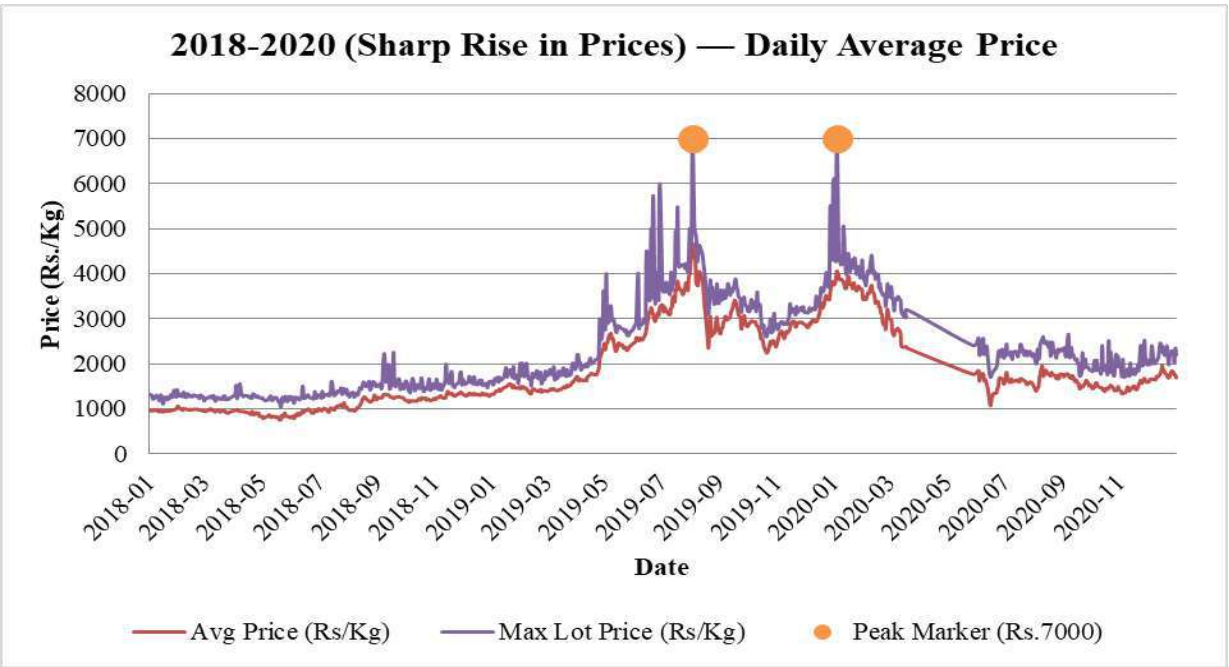
2nd cycle followed the same pattern. From the July 2022 low, prices climbed steadily for almost three years, reaching Rs.2,640 per kg by May 2025 a rise strikingly similar to the first cycle in both speed and scale. In 2025, the average cardamom price for year had reached Rs.2,549 per kg, a difference of nearly 74% compared to 2023. If the pattern observed in previous years continues, cardamom prices may rise further before beginning to decline.

2015-2017 (Beginning to rise)



The decade began with its lowest point. Prices rose gradually through 2016 and into early 2017 before declining slightly. Soon after, the market entered a much stronger period of price growth.

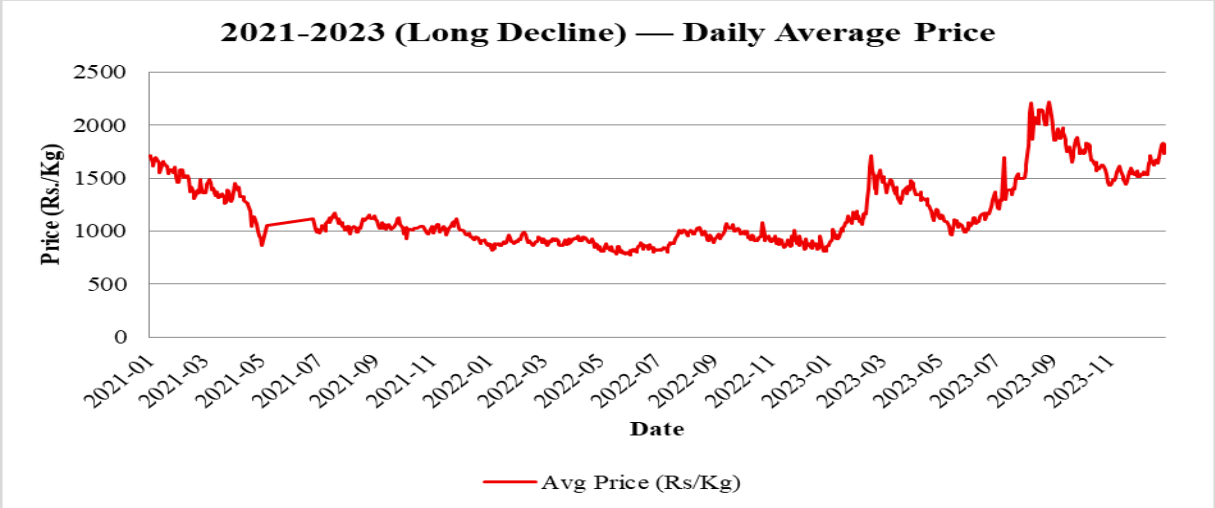
2018-2020 (Sharpe rise in prices) (peak price = Rs.7000 per kg)



Peak Marker (Rs.7000) (Source: Spices Board of India (n.d.)).

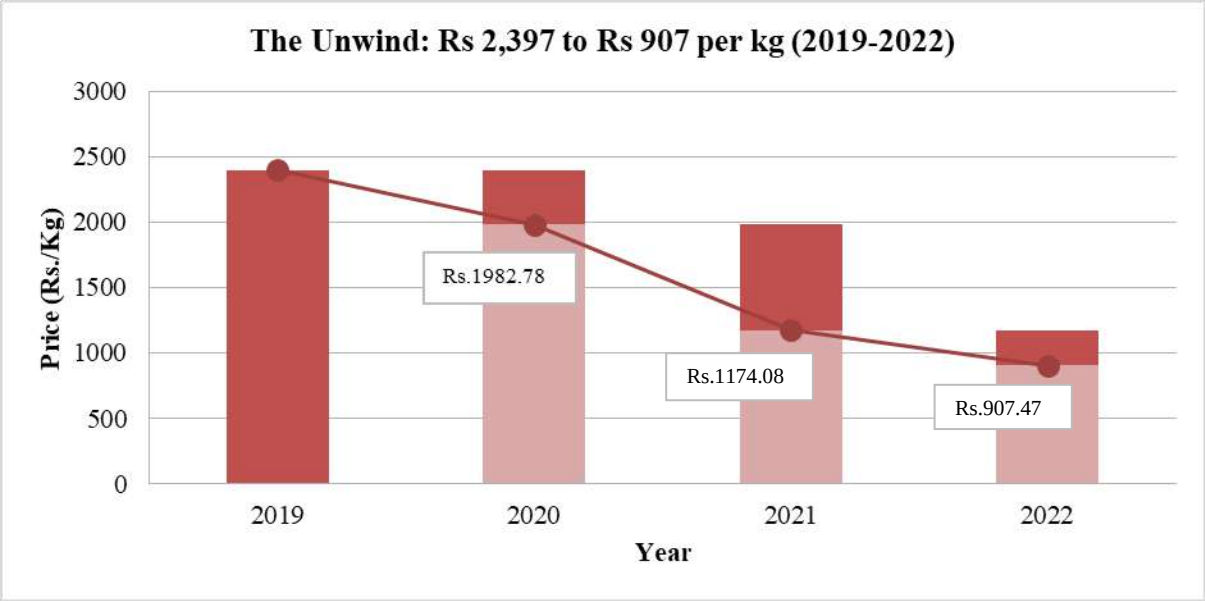
The most significant price increase after the low in January 2018. Over the next 21 months, cardamom prices nearly tripled, reaching a peak in October 2019. During this period, single lot achieved a record auction price of nearly Rs.7000 per kg in January 2020. However, the upward trend of prices began to decline during 2020.

2021-2023 (long decline)

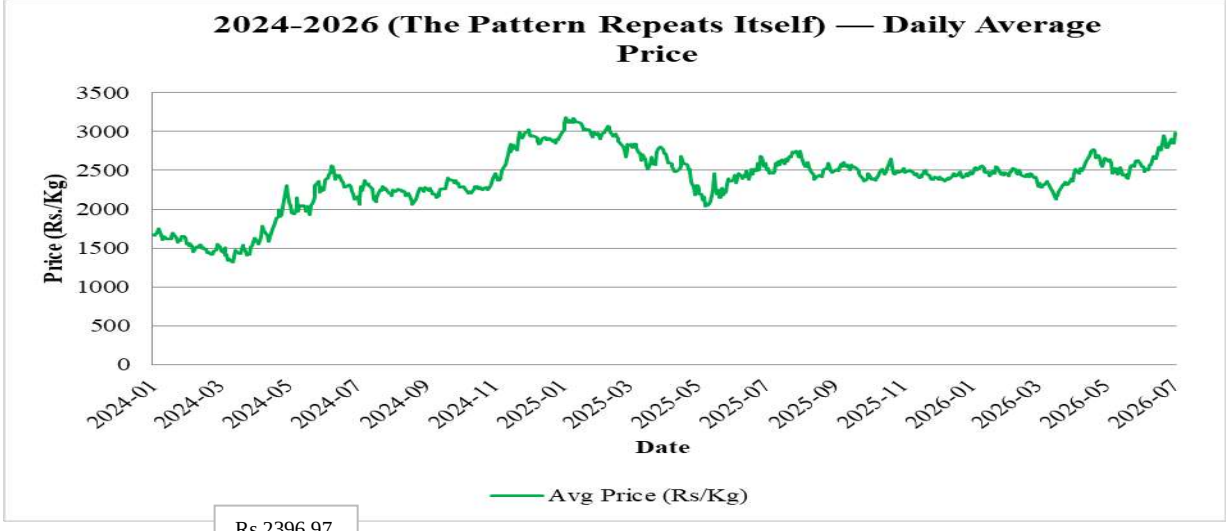


One important feature of the cardamom market is that prices fall more slowly than they rise. After a spike in October 2019, prices decline gradually over nearly three years before reaching

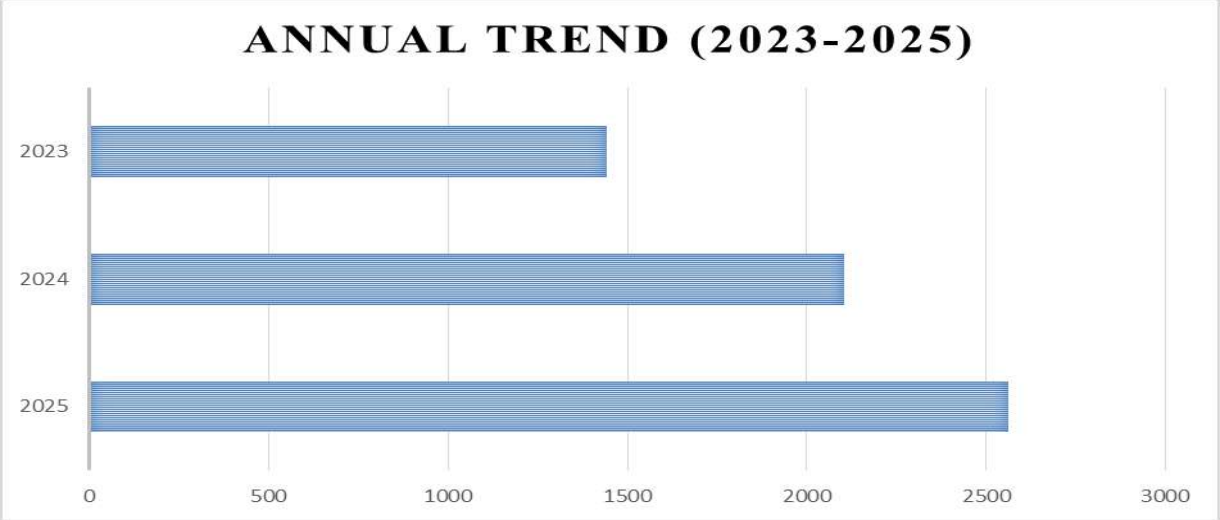
their next low in July 2022. By then, nearly 69% of the gains achieved during the earlier price increase had been lost.



2024-2026 (the pattern repeats itself - began to rise)



The pattern repeated after July 2022. From the low reached in July 2022, cardamom prices increased steadily for 34 months and peaked in May 2025. The rise following a pattern similar to 2018-2019 price cycle. In early 2026 prices showed the usual seasonal fluctuations, but the overall pattern remained unchanged.



Source: Spices Board of India (n.d.).

The last three years show a strong and steady increase in cardamom prices. Each year, the average price was higher than the previous year, with no clear sign reflecting upward trend.

What does this pattern tell us?

When the four price cycles are compared, a clear pattern emerges. Cardamom prices rise rapidly but decline more gradually. This pattern helps factors driving the market.

The rapid increase in prices usually occurs when poor monsoon conditions reduce production. At the same time, demand consumers, food manufactures, and export markets remains strong. As a result, limited supply and steady demand push prices up quickly. Intensive cardamom has altered local microclimate conditions in India's cardamom hills, increasing pest and disease pressure (Murugan et al. (2022)).

The decline in prices is much slower because production takes to recover. Newly planted cardamom takes several years to become productive, and full production cannot be restored immediately. As supply gradually increases, prices also decline gradually. Cost of cultivation is especially complex to estimation for cardamom due to its long gestation period as a perennial crop (Varghese (2007)).

What does the pattern suggest for the future?

The price data show that each complete cardamom price cycle has lasted about 4.5 years, from one low point to the next. In both cycles, prices nearly tripled before gradually declining. If a similar pattern continues, the market could reach its next low continues between late 2027 and 2028.

However, this is only an indication based on past trends, not a certainty. Changes in weather, Production, exports, or market demand could alter the price cycle.

What this means for farmers and Traders

Understanding the cycle can help farmers, traders, exporters, extension workers and policy makers in the cardamom trade make better decisions.

Traders interest in Indian cardamom futures has been declining due to stricter quality norms and higher margin requirements (Vijayakumar (2023)).

Conclusion

Cardamom prices are not random. They follow a recurring pattern shaped by changes in supply and demand. Poor harvests can cause prices to rise rapidly, while production recovery takes longer, leading to a gradual decline in prices. Over the past decade, this cycle has repeated roughly every 4.5years. Understanding this pattern can help farmers, traders, and consumers better anticipate of future market movements.

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FROM SUPPORT TO SUSTAINABILITY: GOVERNMENT SCHEMES TRANSFORMING INDIAN AGRICULTURE

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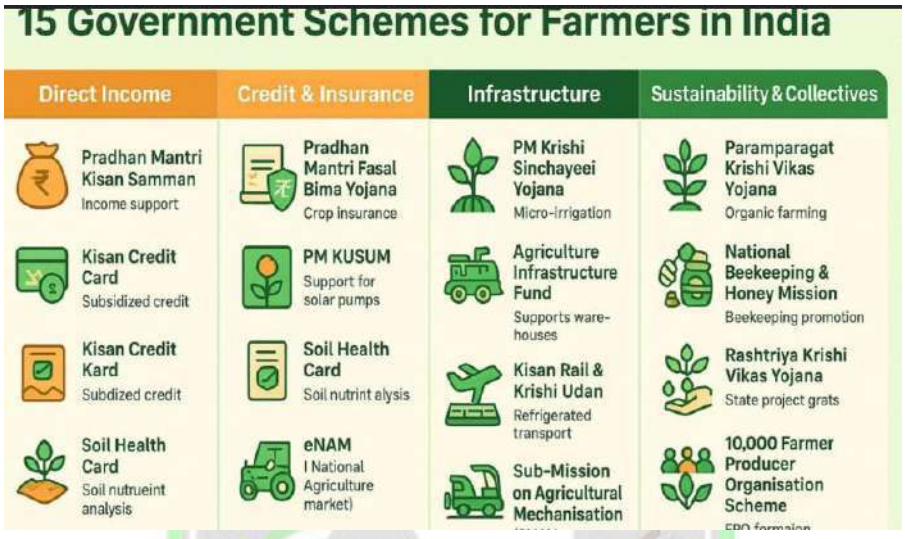
Abstract

Agriculture remains the backbone of India's economy, supporting nearly half of the population while ensuring national food security. However, farmers continue to face multiple challenges such as low income, climate uncertainties, and market fluctuations. To address these issues, the Government of India has introduced a wide range of welfare schemes aimed at strengthening farmers' livelihoods. Initiatives like the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) provide direct income support, while the Pradhan Mantri Fasal Bima Yojana (PMFBY) safeguards farmers against crop losses due to natural calamities. The Kisan Credit Card (KCC) scheme ensures timely access to affordable institutional credit, reducing dependence on informal sources. Programs such as the Soil Health Card Scheme promote balanced fertilizer use and sustainable farming practices. Additionally, the Pradhan Mantri Krishi Sinchai Yojana (PMKSY) focuses on expanding irrigation facilities and improving water-use efficiency. Organic farming is encouraged through schemes like Paramparagat Krishi Vikas Yojana (PKVY), promoting eco-friendly agricultural methods. These initiatives collectively aim to enhance productivity, reduce risks, and improve farmers' income. Furthermore, they contribute to the modernization and resilience of the agricultural sector. Overall, these schemes play a crucial role in ensuring inclusive growth and long-term sustainability in Indian agriculture.

Introduction

"The future of India lies in the prosperity of its farmers." This idea is deeply rooted in the country's development vision, as agriculture continues to employ nearly 45–50% of the population while contributing around 1 6–1

8% to GDP. Despite this significance, Indian farmers—especially small and marginal ones—have long struggled with low income, climate uncertainties, fragmented landholdings, and limited access to modern technology.To address these multifaceted challenges, the Government of India has introduced a comprehensive framework of farmer welfare schemes that collectively aim at income support, risk protection, credit access, and sustainable agricultural growth.



Pradhan Mantri Kisan Samman Nidhi

PM- KISAN is a central sector scheme launched on 24th February 201 9 to supplement financial needs of land holding farmers, subject to exclusions. Under the scheme, financial benefit of Rs. 6000/- per year is transferred in three equal four-monthly installments into the aadhar linked bank accounts of farmers' families across the country, through Direct Benefit Transfer (DBT) mode. Till now, Rs.2.81 lakh crores have been transferred through Direct Benefit Transfer (DBT) to more than 1 1 crores beneficiaries (Farmers) through various installments.

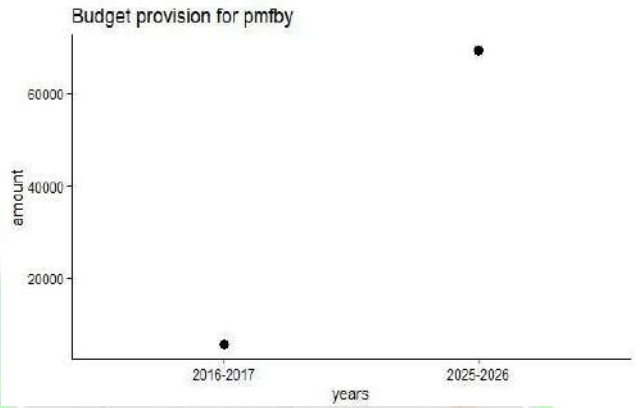
Pradhan Mantri Fasal Bima Yojana (PMFBY)

PMFBY was launched in 201 6 in order to provide a simple and affordable crop insurance product to ensure comprehensive risk cover for crops to farmers against all non-preventable natural risks from pre-sowing to post-

harvest and to provide adequate claim amount. Farmers pay a capped share -2% for kharif ,1 .5% for rabi and 5% for commercial crops.

Risk Covered

Yield losses that fall under the non –preventable risks Cases may arise where most of the farmers (insured) of notified areas may want to plant or sow. In such cases, they have to bear the expenditure for that cause and are restricted from planting or sowing insured crops because of unfavourable weather conditions. These farmers will then become eligible for the indemnity claims of up to a maximum of 25% of the sum insured The Government offers coverage of up to 1 4 days (maximum) from harvesting for crops that are stored in "cut and spread" condition.



The scheme is demand driven and available for all farmers A total of 5549.40 lakh farmer applications were insured under the scheme since 201 6-1 7 and Rs 1 50589.1 0 crore has been paid as claim. Witnessing the success and potential of the scheme, the Union Cabinet in January 2025 approved the continuation of Pradhan Mantri Fasal Bima Yojana and Restructured Weather Based Crop Insurance Scheme till 2025-26 with a total budget of ₹69,51 5.71 crore.



Restructured Weather Based Crop Insurance Scheme: is a weather index-based scheme, which was introduced along with PMFBY. The basic difference between the PMFBY and RWBCIS is in its methodology for calculation of admissible claims to the farmers.

Modified Interest Subvention Scheme (MISS)

The Union Cabinet chaired by the Prime Minister Shri Narendra Modi approved the continuation of the Interest Subvention (IS) component under the Modified Interest Subvention Scheme (MISS) for the financial year 2025-26, and approved required fund arrangements.MISS is a Central Sector Scheme aimed at ensuring the availability of short-term credit to farmers at an affordable interest rate through Kisan Credit card (KCC).

- Farmers received short-term loans of up to Rs.3 lakh through Kisan Credit Cards (KCC) at a subsidized interest rate of 7%, with 1.5% interest subvention provided to eligible lending institutions.
- Additionally, farmers repaying loans promptly are eligible for an incentive of up to 3% as Prompt Repayment Incentive (PRI) effectively reducing their interest rate on KCC loans to 4%.
- For loans taken exclusively for animal husbandry or fisheries, the interest benefit is applicable up to Rs.2 lakh.
- No changes have been proposed in the structure or other components of the scheme. There are more than 7.75 crores of KCC accounts in the country. The continuation of this support is critical to sustaining the flow of institutional credit to agriculture, which is vital for enhancing productivity and ensuring financial inclusion for small and marginal farmers.

Key highlights of Agriculture Credit:

Institutional credit disbursement through KCC increased from Rs.4.26 lakh crore in 2014 to Rs. 10.05 lakh crore by December 2024. Overall agricultural credit flow also rose from Rs.7.3 lakh crore in FY 2013-14 to Rs.25.49 lakh crore in FY 2023-24. Digital reforms such as the launch of the Kisan Rin Portal (KRP) in August 2023 have enhanced transparency and efficiency in claim processing.

Kisan Credit Card (KCC) scheme

The Kisan Credit Card (KCC) scheme is a credit scheme introduced in august 1998 by Indian public sector banks ,facilitates farmers to get easy access to short-term credit facilities to conduct agricultural operations, including crop production, purchase of farm equipment, and other related operations like animal husbandry, poultry farming, and fisheries. The scheme is intended to provide credits at reduced interest so that farmers do not have to incur the high cost of borrowing money to support their financial requirements.This scheme gives farmers an easy way of accessing farm loans with a flexible repayment plan. Loan repayment is even associated with the agricultural

cycle, and hence, farmers can find it easy to settle their loans after harvesting.In addition, the government provides a 1 .5% interest subvention on short-term KCC loans up to ₹3 lakh (now extended to ₹5 lakh per Budget 2025), making the base rate 7% before incentives. The prompt repayment incentive is 3%, for an effective 4% rate.



Sub-Mission on Agricultural Mechanisation

Agricultural machines take an important role to increase productivity with timely and precise fieldwork. To promote the usage of farm mechanization and increase the ratio of farm power to cultivable unit area up to 2.5 kW/ha, the scheme will be implemented in all the Indian states.The SMAM scheme has both centrally sponsored and central sector scheme components. In the centrally sponsored scheme components, the Government of India funds 60% of the cost and the states' share is 40% in all states except north-eastern and Himalayan states where the ratio is 90:1 0 wherein GOI funds 90%. In UTs, the central share is 1 00%. It is being implemented w.e.f April, 201 4 which aims at catalyzing an accelerated but inclusive growth of agricultural mechanization in India with the objectives of Increasing the reach of farm mechanization to small and marginal farmers and to the regions where availability of farm power is low, promoting 'Custom Hiring Centres' to offset the adverse economies of scale arising due to small landholding and high cost of individual ownership, creating hubs for hi-tech& high value farm equipments,.Till date Rs. 6748.78 Crore have been released to State Governments, distributed more than 1 5,75,71 9 agricultural machinery & equipment's including Tractors, Power Tillers, Self-Propelled Machineries and Plant Protection Equipment and established 23472 nos of Custom Hiring Centres, 504 nos of Hi-Tech Hubs and 20597 nos. of Farm Machinery Banks.

Promotion of Drone Technology under SMAM:

Looking into the unique advantages of Drone technologies in agriculture, a Standard Crop Specific Operating Procedures (SOPs) released the for use of drones in pesticide and nutrient application in public domain on 20.04.2023, which provides concise instructions for effective and safe operations of drones.From within the funds of SMAM, so far an amount of Rs.1 38.82 crores have been released

towards Kisan drone promotion, which include purchase of 31 7 Drones for their demonstration in 79070 hectares of land and supply of 461 drones to the farmers on subsidy and also supply of 1 595 drones to the CHCs for providing drone services to the farmers on rental basis.

Soil health card

Soil health card provides information to farmers on nutrient status of their soil along with recommendation on appropriate dosage of nutrients to be applied for improving soil health and its fertility. The indicators are typically based on farmers' practical experience and knowledge of local natural resources. The card lists soil health indicators that can be assessed without the aid of technical or laboratory equipment. The Scheme rolls out a decentralized system of soil testing which will help in developing a nationwide soil fertility map on a GIS platform that can easily be integrated with the real time decision support systems being developed. In order to develop the soil fertility map, Government of India has decided to conduct 5 Crore Soil Samples across the country during year 2023-24 to 2025- 26.so far (2026 data) 1 6,64,879 samples are collected and 6,1 0,1 77 tests are completed &SHC generated.



Nemo Drone IDID Scheme

The Government has recently approved a Central Sector Scheme forproviding drones to the Women Self Help Group (SHGs) for the period from 2024-25 to 2025-26 with an outlay of Rs. 1 261 Crores. The scheme aims to provide drones to 1 5000 selected Women Self Help Group (SHGs) for providing rental services to farmers for agriculture purpose (application of fertilizers and pesticides). Under this Scheme, Central Financial Assistance @ 80% of the cost of drone and accessories/ancillary charges upto a maximum of Rs. 8.0 Lakhs will be provided to the women SHGs for purchase of drones.

Key Features of the Scheme:

- Subsidy to Women DAY NRL-SHGs for Purchase of Drone
- 80% of Drone Cost as Subsidy upto 8 Lakhs
- Loan facility from AIF for remaining cost of Drone
- Easy Loan @ 3% interest rate
- Drone Pilot training as a part of Drone Package
- Chance to earn additional 1 lakh PA through Drone
- Renting of Drone Spray Service to Farmers through Women SHGs

Per Drop More Crop (PDMC) scheme

In order to increase water use efficiency at the farm level through Micro Irrigation technologies i.e. drip and sprinkler irrigation systems, Per Drop More Crop (PDMC) scheme was launched during 201 5-1 6. The Micro Irrigation helps in water saving as well as reduced fertilizer usage through fertigation, labour expenses, other input costs and overall income enhancement of farmers. It also supports micro level water harvesting, storage, management etc. activities as Other Interventions (OI) to supplement source creation for Micro Irrigation. OI activities allowed on need basis up to 40% of the total allocation for North East States, Himalayan States, Jammu & Kashmir, Ladakh and up to 20% for other States An area of 78 lakh hectare has been covered under Micro irrigation through the PDMC scheme from 201 5-1 6 to 2022-23.

Micro Irrigation Fund (MIF)

A Micro Irrigation Fund (MIF) of initial corpus Rs 5000 crore has been created with NABARD with major objective to facilitate the States in mobilizing the resources for expanding coverage of Micro Irrigation. Under the funding arrangement, NABARD lends to the States/UTs at 3% lower interest rate than the corresponding cost of fund mobilized by NABARD from the market. The interest subvention on the loan under MIF is borne by Centre under PDMC. Projects with loans under MIF worth Rs 471 0.96 crore have been approved so far. Loans amounting Rs.281 2.24 crore has been disbursed to States of Andhra Pradesh, Tamil Nadu, Gujarat, Punjab, Haryana and Rajasthan. The Ministry provides interest subvention on the loan availed by the States which is met from PDMC Scheme. As per the Budget 2021 -22, the corpus of the fund is to be doubled to Rs.1 0000 crores. MIF is now merged with PDMC

Paramparagat Krishi Vikas Yojana (PKVY)

Paramparagat Krishi Vikas Yojana (PKVY) aims to increase soil fertility and thereby helps in production of healthy food through organic practices without the use of agro-chemicals. The scheme is implemented in a cluster mode with unit cluster size of 20 hectares. A group shall comprise minimum 20 farmers (may be more if individual holdings are less). Farmers in a group can avail benefit of maximum of 2 ha as per provision of PKVY. 25

such clusters are converted into one large cluster of about 500 ha area to facilitate marketing of organic produce. The scheme provides for an assistance of Rs. 31 ,500 per ha to states, out of which i.e., Rs. 1 5,000 is given as incentives to a farmer directly through DBT.

Financial Assistance for Organic Farming Cluster:

- Total assistance of ₹1 4,95,030/- per cluster of 20 hectares (50 acres) for 3 years.
- Maximum assistance of ₹1 0,00,000/- per cluster for farmer members.
- Maximum assistance of ₹50,000/- per farmer per hectare, limited to 1 hectare per farmer.
- Participatory Guarantee System (PGS) Certification:
- Assistance for mobilization of farmers and formation of Local Groups.
- Support for PGS certification and quality control activities.
- Assistance for online registration, soil testing, field inspections, residue analysis, and certification processes

Conclusion

In conclusion, government schemes for farmers' welfare in India represent a comprehensive and multi-dimensional approach to agricultural development. By integrating financial support, risk management, affordable credit, technological advancement, and sustainable farming practices, these initiatives address both immediate challenges and long-term needs of the farming community. With agricultural credit flow crossing ₹25 lakh crore in recent years and increasing adoption of innovations like drones and micro-irrigation, Indian agriculture is gradually moving towards modernization and efficiency. However, the success of these schemes ultimately depends on effective implementation, awareness among farmers, and continuous policy improvements. Strengthening these aspects will not only enhance farmers' income and livelihood security but also ensure food security, rural development, and economic stability for the nation as a whole.

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The 'Namo Drone Didi' scheme will provide new opportunities and empowerment to rural women 24 MAR 2026 6:35PM by PIB Delhi https://share.google/HzrRhvNSTG9RVLQ4O

Per Drop More Crop: 1 2 DEC 2023 5:20PM by PIB Delhi; Source:PIB https://share.google/ju8jwnCLEFjinprSi

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FROM PODS TO PAGES

Article ID: AG-VO6-I07-180

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Abstract

Black gram (*Vigna mungo)* is one of the India's major pulse crop producing large amount of pod residue after harvest. These pods are burned leading to environmental pollution and wastage of valuable biomass. This article explores and innovative approach to converting black gram pods into eco-friendly paper by using cellulose rich fibres. The paper making steps are:collecting, drying, pulping, sheet formation and drying to produce biodegradable paper. This is the best way to reduce agriculture waste, conserve forest, minimize air pollution and create employment opportunities. This study investigates the valorization of blackgram pods- an abundant agricultural byproduct - as a viable cellulosic source for handmade paper production.

Introduction

India is the world's largest producer and consumer of blackgram. Black gram is cultivated nearly 4 million hectares and yielding 1.4-1.5 million tonnes of grain and 1.6- 2.2 million tonnes of empty pods and crop residue waste annually. The cellulose content of pod ranges from 25%-50% of the dry matter. The grains are consumed as food while the pods are burned, and dumped as waste.

In the view of reducing deforestation, paper can be produced from blackgram pods which was dumped as waste.



STEPS INVOLVED IN MAKING PAPER FROM BLACKGRAM PODS:

1. **Collection**

Blackgram pods are collected after harvest and clean to remove impurities and dust.

2**. Drying**

Cleaned pods are sun-dried to remove moisture content.

3**. Pulp preparation:**

The dried pods are chopped into small pieces and boiled with an eco -friendly alkaline solution to soften the fibres and separate the cellulose.

4**. Washing:**

The pulp is washed thoroughly to remove excess chemicals and impurities.

5**. Grinding:**

The softened fibres are blended with water to form a smooth paper pulp.

6. **Sheet formation:**

The pulp is spread evenly on a mesh screen allowing water to drain while the fibres interlock to form a thin sheet.

7. **Pressing and drying:**

The sheet is pressed to remove excess water and dried under sunlight or by controlled heating.

8. **Finishing:**

The dried paper is trimmed, polished and made ready for use.

Applications:

- Handmade notebooks
- Greeting cards and invitations
- Eco-friendly paper bags
- Gift wrapping paper
- Seed paper for planting
- Sustainable packaging

Conclusion

Blackgram pods should no longer be viewed as useless farm waste. The possess the potential to become eco-friendly paper that protect forests, reduces pollution and create new economic opportunities for farmers. By converting discarded pods into valuable paper products We take a meaningful step towards sustainable agriculture and environmental conservation.

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PRIMARY AGRICULTURAL CREDIT SOCIETIES (PACS): RESHAPING AGRICULTURAL CREDIT IN RURAL INDIA

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Abstract

Timely and affordable access to credit is essential for improving agricultural productivity, increasing farmers' incomes, and promoting sustainable rural development. Primary Agricultural Credit Societies (PACS) play a vital role in providing institutional credit to small and marginal farmers who often face difficulties in accessing formal banking services. Over the years, PACS have evolved from village-level credit societies into multipurpose rural service centres offering agricultural credit, digital services, agricultural inputs, and support for the implementation of various government schemes. This article highlights the evolving role of PACS in strengthening India's agricultural credit system through financial inclusion, computerisation and Multipurpose PACS. Despite significant progress, challenges related to governance, financial sustainability, political interference, and professional management remain. Strengthening these institutions is essential for achieving inclusive agricultural growth and sustainable rural transformation in India.

Keywords: Primary Agricultural Credit Societies (PACS), Agricultural Credit, Cooperative Banking, Financial Inclusion, Rural Development

Introduction

Although agriculture is the main occupation of rural India, farmers' credit access is a key factor driving the success of agriculture. For millions of small and marginal farmers, obtaining loans from formal financial institutions is often challenging because of procedural requirements,

inadequate financial awareness, and limited banking access in rural areas. In such situations, Primary Agricultural Credit Societies (PACS) have emerged as the first and most trusted source of institutional credit at the village level.

PACS form the foundation of India's cooperative credit structure, linking farmers with District Central Cooperative Banks (DCCBs), State Cooperative Banks (SCBs), and NABARD. Beyond providing short- and medium-term agricultural loans, PACS have evolved into multipurpose rural service centres that support farmers through agricultural inputs, implementation of government schemes, digital services, marketing support, and livelihood promotion. Their close connection with local communities enables them to understand farmers' needs better than most conventional banking institutions.

Recognising their growing importance, the Government of India has undertaken several initiatives to modernise and strengthen PACS. Today, more than 101,500 PACS operate across the country, accounting for nearly 41% of the rural agricultural credit network. With the ambitious target of establishing two lakh Multipurpose PACS by 2026, these institutions are expected to become comprehensive rural service centres, bringing cooperative services closer to every village.

Against this backdrop, understanding the evolving role of PACS has become increasingly important. This article explores how PACS have transformed India's agricultural credit landscape, the reforms that are shaping their future, the challenges they continue to face, and their growing contribution to financial inclusion and rural development.

Origin of PACS

PACS came into action through the Cooperative Credit Societies Act, 1904, and the first-ever cooperative credit society was established in Tirur, Tiruvallur District, Tamil Nadu, on 21st August 1904 (National Cooperative Database, 2024). Over the years, PACS have become the foundation of India’s three-tier cooperative system, which comprises District Cooperative Credit Societies (DCCBs) at the middle and the State Cooperative Banks (SCCBs) at the apex (National Federation of State Cooperative Banks Ltd., 2023). Today, PACS constitute the largest network of rural credit institutions, directly serving the farmers at the grassroots level and contributing significantly to the rural credit delivery system.

Distinct roles of PACS in the rural credit landscape

The government regards Primary Agricultural Cooperative Credit Societies as the centres through which an integrated package of services, such as credit, insurance, inputs, marketing and extension, can be delivered to farmers. This makes PACS more accessible for the farmers compared to commercial banks. Unlike commercial banks, PACS operate on a cooperative principle where farmers themselves are members and part-owners, enabling them to participate in decision-making (Shailaja & Hebbar, 2018).

The majority of farmers in India belong to the category of small and marginal farmers. They extensively rely on credit for their agricultural operations, and in terms of coverage, PACS account for a significant share of agricultural credit delivery compared with commercial banks and Regional Rural Banks (RRBs). Within the cooperative credit system, PACS play a major role in promoting financial inclusion by providing affordable credit through formal banking services. Through initiatives such as no-frills savings accounts, PACS enable economically weaker sections to participate in formal banking services without the requirement of maintaining a minimum bank balance.

PACS serve as the primary unit through which agricultural and non-agricultural borrowers can get their credit in the form of short-term and long-term loans at minimal interest. Agricultural credit includes KCC loans and loans for allied agricultural purposes such as the purchase of farm machinery, micro-irrigation, etc. Non-agricultural credits include loans for housing, personal matters and for other non-farming sectors (Ministry of Cooperation, 2024). Among the various government schemes implemented through PACS, the Kisan Credit Card (KCC)scheme plays a significant role in meeting the financial requirements of farmers at different stages of crop production (Ministry of Agriculture & Farmers Welfare, 2025). This scheme aims at providing adequate and timely credit support from the banking system under a single window with a flexible and simplified procedure for the farmers(pib.gov.in). The working of KCC is a very simplified procedure where the farmers first apply for the KCC card at a bank by giving their land and farming details, and based on this, the bank fixes a suitable credit limit, usually for a period of five years, taking into account all their professional and personal requirements. The farmer can withdraw the amount that he needs from any ATM or by using digital payment methods. This protects farmers from the financial losses incurred due to crop damage or failure.

PACS collaborates with the government to implement various development initiatives. These include Jan Aushadhi Kendras, which provide high-quality generic medicines; LPG distributorship to promote rural entrepreneurship and to improve LPG access for the rural population, PACS are being transformed into Common Service Centres and Multipurpose PACS (m-PACS), enabling them to provide services such as bill payments, consumer goods and agricultural inputs (Ministry of Cooperation, 2024; Indian Cooperative, 2024). PACS also helps in strengthening the rural community through initiatives such as the SHG-Bank Linkage programme. The main objective of this programme is to provide collateral-free, low-cost credit to rural poor for income-generating activities, fostering women's economic empowerment and reducing dependency on informal lenders (NABARD, 2023). The SHG-Bank Linkage programme has further strengthened the roles of PACS in promoting financial inclusion and women's empowerment.

Therefore, it is evident that PACS play a very constructive role in meeting the objective of a greater degree of financial inclusion in rural areas. To get the best from their land, farmers need access to affordable credit. PACS have been playing an important role in this regard.

Reforms and modernisation: shaping PACS for the future

The rural credit co-operative system is fully developed based on PACS, and with the development of society and technology, modernisation of the PACS is becoming increasingly necessary. They need modernisation to improve their efficiency, transparency, service delivery and their capacity to respond to the evolving needs of rural communities. Around 63,000 PACS were targeted to be computerised through a centrally sponsored project to ensure transparency, improve loan processing, and maintain accurate records from June 29, 2022, onwards (Ministry of Cooperation, 2024).

One of the significant reforms that have taken place in the cooperative sector is the Multi-purpose Primary Agricultural Credit Societies (m-PACS), where PACS have gone beyond the boundaries of agricultural credit. Apart from short and medium-term loan services, m-PACS provide a wide variety of services including bill payment facilities, consumer goods distribution, and sales of agricultural inputs like seeds and fertilisers. This diversification increases the sustainability of PACS in terms of both their operations and finances, while also contributing to local development through employment generation and the reinforcement of local supply chains.

As part of the Central Government initiative, 40214 PACS are now operating as Common Service Centres (CSCs) till November 21, 2024. These PACS will provide more than 300 e-services to the rural population, including banking, insurance, Aadhaar enrolment & updation, health services, legal services, etc. (Indian Cooperative, 2024). These changes are helping to make PACS into more than just a source of credit; they are becoming full-service rural centres that can assist people with livelihoods, entrepreneurship, and community development. The major schemes and policy initiatives introduced by the Government of India to strengthen the functioning of PACS are summarised in Table 1.

Table 1. Major Government Schemes and Initiatives Related to Primary Agricultural Credit Societies (PACS):

Scheme/Initiative	Description
Computerisation of PACS (2022 onwards)	To make PACS self-reliant under the Aatmanirbhar Bharat Abhiyaan, the Government approved the centrally sponsored project on 29th June 2022 for computerisation of PACS over a period of five years. Approximately 63,000 PACS were targeted to benefit under this scheme. The initiative aims to enhance the operational efficiency of PACS through seamless integration with District Central Cooperative Banks (DCCBs) and State Cooperative Banks (STCBs), while improving transparency and facilitating easier monitoring by NABARD and STCBs (Ministry of Cooperation, 2024).
Model bye-laws for making PACS multipurpose	The Model bye-laws were introduced to enhance the potential of PACS by diversifying their activities and transforming them into important economic institutions at the village level. The Ministry of Cooperation formulated these bye-laws in consultation with the State Governments/Union Territories, Central Government Ministries, NABARD, and other stakeholders. They enable PACS to undertake more than 25 business activities, including custom hiring centres, dairies, fisheries, LPG/CNG/Petrol/Diesel distributorships, fair-price shops, and common service Centres (Ministry of Cooperation, 2024).
Establishment of	Approximately 2 lakh new Multipurpose PACS (m-PACS) will be

multi-purpose PACS	established in Panchayats & villages where PACS are not currently available over the next five years (Ministry of Cooperation, 2024). These m-PACS provide services like bill payments for the farmers, sale of consumer goods, and supply of agricultural inputs. These services aim to revitalise and establish cooperatives that will create rural jobs and strengthen the supply chain.
PACS as Common Service Centres	Under the central government initiative, 40,212 PACS are functioning as Common Service Centres (CSCs) as of 21 November 2024. These CSCs are set to deliver over 300 e-services to rural citizens, which include banking, insurance, Aadhaar enrolment & updating, health services and legal services (Indian Cooperative, 2024).
Eligibility of PACS for LPG distribution	The Government of India is encouraging the involvement of PACS in LPG distributorship to promote rural entrepreneurship and improve access to LPG in rural areas. The eligibility to participate in the selection process for LPG distribution is to meet the conditions and criteria set by the GOI. (Ministry of Cooperation, 2024).
Kisan Credit Card Scheme (KCC)	The Kisan Credit Card (KCC) scheme was introduced in 1998 to provide farmers with timely access to credit. The scheme is managed by commercial banks, cooperative banks and RRBs. Though it is implemented by all these banks, PACS is the key channel for KCC insurance in rural areas. Farmers can access short-term crop loans at subsidised rates from PACS through this scheme.

Challenges and constraints

Although much modernisation has been done to PACS in the past few years, they still have a lot of problems in their institutional life that have grown over the years. The foremost challenge is their weak financial health, as many PACS continue to have a poor financial base due to substantial losses arising from the non-repayment of loans, resulting in high overdue amounts. In the long run, this weak financial position may hinder their ability to establish a stable capital base.

Another major challenge faced by PACS is the lack of professionalism among its employees. The majority of workers are elderly and have limited knowledge of technology,

limiting their ability to contribute to PACS operations. If this is the case, the institution will struggle with greater challenges over the next few years. In addition, there is a high level of political influence over the daily operations of PACS that often leads to the acceptance of unqualified loans to members that cause financial losses for the societies. The financial resources available to PACS are inadequate to meet the short- and medium-term credit needs of the rural economy. In addition, PACS also face the problem of inadequate deposits, partly due to the poverty of their members and partly because of the lack of confidence among members in these societies.

Way Forward

Going forward, there are several ways to strengthen PACS for the benefit of the rural community. The Government of India has already introduced various initiatives, including the computerisation of PACS, for which approximately ₹2,925.39 crore has been allocated (Ministry of Cooperation, 2024). Another important initiative is the establishment of new Multipurpose PACS in all Panchayats to improve access to cooperative services. A key feature of this initiative is the creation of the world's largest decentralised grain storage system in the cooperative sector, under which the Government has approved the establishment of warehouses, custom hiring centres, and other agricultural infrastructure for grain storage at the PACS level. Another initiative is the formation of Farmer Producer Organisations (FPOs) through PACS, under which an additional 1,117 FPOs are to be registered in the cooperative sector through PACS (Ministry of Cooperation, 2024).

In recent years, several amendments and improvements have helped PACS overcome many of their challenges. However, some issues still require attention. Problems such as lack of professionalism, poor leadership, and mismanagement must be addressed to improve the efficiency of PACS (Malik, 2022). To achieve this, members should be provided with appropriate management training to enable them to manage PACS more effectively. There is also a need to enhance member participation and contribution to strengthen their financial position. With these improvements, PACS can become stronger and achieve a higher level of efficiency in the future.

Conclusion

Primary Agricultural Credit Societies (PACS) have emerged as the backbone of India's cooperative credit system, playing a crucial role in improving access to affordable institutional

credit, particularly for small and marginal farmers. The main objective of this review is to highlight the evolution of PACS from ordinary rural credit institutions to multipurpose service centres that promote financial inclusion, facilitate the implementation of key government schemes such as the Kisan Credit Card (KCC) Scheme and Self-Help Groups (SHGs), and provide a wide range of agricultural and non-agricultural services. In recent years, reforms such as digitalisation, the introduction of model bye-laws, and the establishment of Multipurpose PACS and Common Service Centres (CSCs) have further strengthened their outreach and operational efficiency. Although significant progress has been made, challenges such as weak financial health, unprofessional management, and political interference continue to affect the performance of PACS. To overcome these constraints, measures such as capacity building, improved governance, and greater member participation are essential to enhance their effectiveness.

Overall, strengthening PACS is not merely an institutional requirement; it is a crucial investment for ensuring sustainable growth in rural communities, which would inevitably contribute to the overall growth of the Indian economy. A robust and well-developed PACS network can make a significant contribution to financial inclusion, agricultural development, rural employment, and the long-term economic transformation of rural India.

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EFFECT OF CONSERVATION TILLAGE ON SOIL ORGANIC MATTER AND SOIL ORGANIC CARBON – AN INSIGHT

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Introduction

Organic matter (O.M.) plays a significant role in crop production and soil health. Building and maintaining a healthy soil that has more O.M. can aid in providing a stronger foundation for higher crop yields and resiliency to environmental stresses. Higher soil O.M. levels often translate into sustainable systems that produce higher, more consistent yields and greater long-term profitability. Conservation tillage leaves an organic mulch at the soil surface, which reduces run-off, increases the surface soil organic matter (SOM) promoting greater aggregate stability which restricts soil erosion. Other beneficial aspects of conservation tillage are preservation of soil moisture and increase of soil biodiversity

Conservation tillage and its types

Conservation tillage is any form of tillage practice that minimizes soil disturbance and disruption of soil aggregates by reduced number of tillages passes and keeps the soil surface covered by a minimum of 30% with crop residues, with the aim to reduce soil erosion. Reducing the intensity of soil tillage decreases energy consumption and the emission of carbon dioxide, while increasing carbon sequestration. Reducing the intensity of tillage increases the sustainability of tillage systems by speeding up crop establishment and reducing labour demand. Organic production of field crops generally consumes up to 20% less energy than non-organic agriculture. However, environmental burdens, such as global warming potential or eutrophication, can be greater under organic farming. Thus, conservation tillage may improve the environmental and economic performance of organic farming.

Conservation or minimum tillage practices aim to reduce soil erosion, maintain soil health, and increase sustainability in agriculture. The choice of tillage equipment for conservation tillage will depend on various factors, including soil type, crop rotation, and farm management practices.

Types of conservation tillage

No-Till: This is the most extreme form of conservation tillage, in which the soil is left undisturbed, and seeds are planted directly into the soil without any prior tillage. It helps to reduce soil erosion, conserve soil moisture, and maintain soil structure.

Reduced Tillage: Reduced tillage involves minimal soil disturbance, typically only enough to create a suitable seedbed for planting. This can include practices like strip-till, which only tills narrow strips of soil where seeds will be planted, or zone-till, which creates a shallow tilled zone in the soil where seeds will be placed.

Mulch Tillage: Mulch tillage involves leaving crop residues on the soil surface to act as a natural mulch, which can help to protect against erosion, conserve moisture, and improve soil health. It can be combined with reduced tillage to create a sustainable seedbed.

Ridge Tillage: Ridge tillage involves creating ridges of soil where seeds will be planted, while leaving the furrows between the ridges untilled. This can help to improve drainage and soil aeration while still providing a suitable seedbed for planting.

Contour tillage: Contour tillage involves tilling along the contour of the land rather than up and down slopes. This can help to reduce erosion and improve soil structure on sloping land.

Soil organic matter and its significance

Soil is the biggest reservoir of organic carbon (SOC) in terrestrial ecosystems. Most agricultural soils have lost 30%-40% SOC relative to the ancestral ecosystems from which they were derived, implying that farmland soils represent a substantial potential global carbon sink. Continuous addition of plant-derived carbon (C) to soils, comprises the largest terrestrial C pool that has a decisive role in the global C cycle. SOM can be grouped into two classes: living and non-living components. The living component comprises organic materials associated with the tissues and cells of living plants, soil microorganisms and soil fauna. On the other hand, the non-living components comprise four fractions: humus, inert organic matter (IOM), dissolved organic matter (DOM) and particulate organic matter (POM).

Soil organic carbon (SOC) stands as the corner-stone of soil quality and health. Maintaining the soil health in agroecosystems necessitates a minimum of 1.5% to 2.0% soil organic carbon, crucial for sustaining proper soil structure and aggregation, efficient water retention, release, and utilization, bolstering resilience against abiotic stresses like drought and heat waves, effective nutrient retention, release, and utilization, supporting gas exchange processes vital for mitigating climate change impacts.

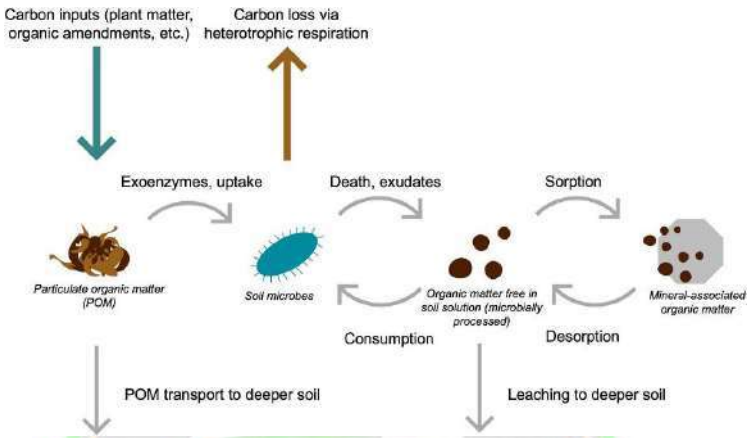


Fig. 1. Conceptual illustration of soil carbon (C) flows

Total organic matter

Soil inversion by mouldboard ploughing tends to concentrate plant residue at the bottom of the plough layer; however annual inversion results in a progressive homogenization of soil organic carbon (SOC) in the plough layer. Shallow tillage will also homogenize SOC within the depth of tillage, but may result in some stratification of SOC with depth. The degree of stratification is usually a function of intensity of disking and ploughing, with the amount of surface residue remaining after tillage acting as the most important variable.

Effects of tillage systems on soil organic matter (SOM) and organic C

Soil components	**Comparison of conservation tillage relative to conventional tillage**
Organic matter	More in the tilled layer, Similar in the untilled layer
Organic carbon	More in the tilled layer, Similar in the untilled layer, Similar throughout the topsoil
Total carbon	More in the 0-5 cm layer but similar in the 5–20 cm layer under no tillage

Tillage Influences Soil Organic Carbon at Different Soil Depths

Surface Soil (0–5 cm)

The surface layer is the most dynamic zone for carbon accumulation. Under no-tillage and conservation tillage, crop residues remain on the soil surface and gradually decompose, enriching this layer with organic carbon. The accumulation of residues also protects the soil from erosion, reduces moisture loss, and promotes microbial activity. Under conventional tillage, residues are incorporated into the soil and exposed to greater aeration. This accelerates decomposition and oxidation of organic matter, resulting in lower SOC concentrations in the surface layer over time.

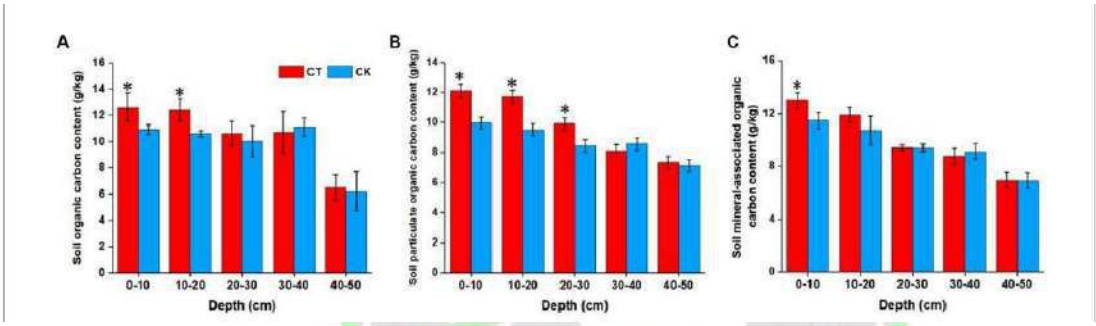


Fig. 2. Soil organic carbon (A) Particulate organic carbon (B) Mineral-associated organic carbon (C) contents at various depths under different soil tillage treatments. *CT – Conservation tillage; CK – Traditional tillage

Upper Soil Layer (5–15 cm)

This depth contains active plant roots and abundant soil microorganisms. Conservation tillage allows carbon to move slowly into this zone through root growth, earthworm activity, and natural biological processes. Soil aggregates formed in this layer help protect organic carbon from rapid decomposition. Repeated tillage disrupts soil aggregates and exposes previously protected organic matter to microbial decomposition, leading to gradual declines in SOC.

Root Zone (15–30 cm)

The influence of tillage becomes less pronounced with increasing depth. Carbon in this layer mainly originates from decomposed roots and dissolved organic compounds moving downward through the soil profile. Conventional tillage sometimes mixes surface residues into this depth, producing a temporary increase in carbon distribution. However, this mixing also increases oxygen availability, accelerating carbon loss. In no-tillage systems, SOC accumulation occurs more slowly but is generally more stable because carbon is protected within soil aggregates and root channels.

Subsoil (>30 cm)

The subsoil contains relatively lower amounts of organic carbon because fewer plant residues reach these depths. Nevertheless, carbon stored here is highly stable and may remain in the soil for decades or even centuries. Deep-rooted crops grown under conservation agriculture contribute carbon to the subsoil through root turnover and root exudates. Since tillage rarely disturbs these deeper layers, carbon stored here is less susceptible to decomposition.

Tillage affecting Soil Enzyme Activity

Conservation tillage and no-tillage disturb the soil minimally while retaining crop residues on the surface. These residues provide a continuous supply of organic matter, which serves as food for soil microorganisms.As microbial populations increase, enzyme activity also improves. Surface residues help maintain soil moisture and moderate soil temperature, creating a favourable environment for microbial growth throughout the year. Stable soil aggregates protect enzymes from degradation, allowing them to remain active for longer periods. Studies have consistently shown that soils under conservation tillage exhibit higher activities of dehydrogenase, urease, phosphatase, and β-glucosidase than conventionally tilled soils.

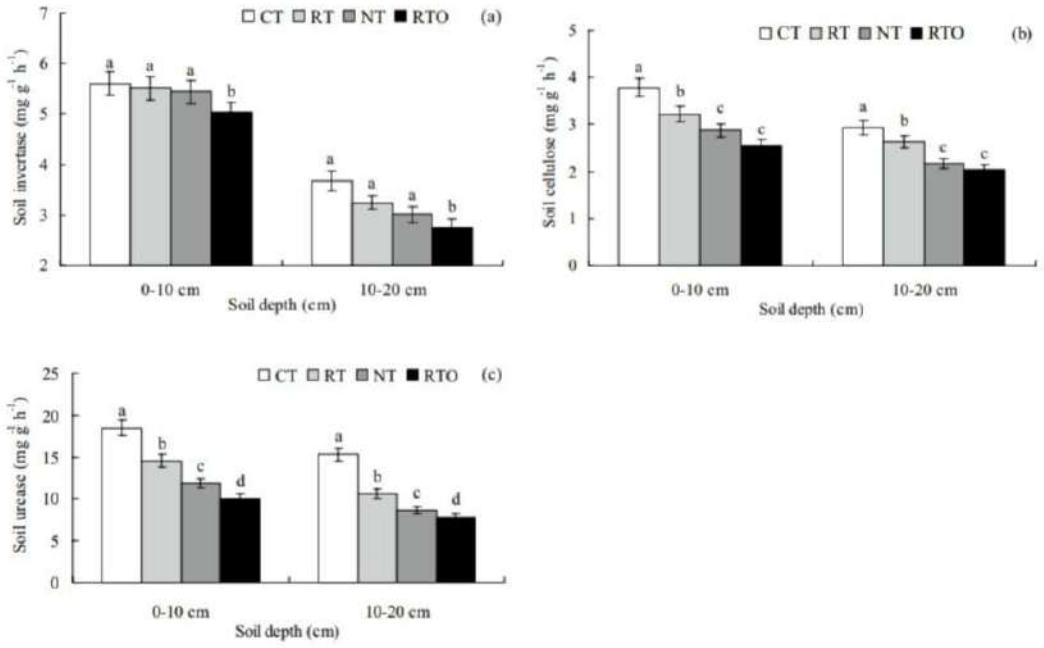


Fig. 3. Effects of different tillage treatments on soil enzyme activities in a double-cropping rice field (a) soil invertase activity (b) soil cellulase activity (c) soil urease activity

Conclusion

Healthy soils are the foundation of sustainable agriculture, and soil organic carbon is at the heart of soil health. Conservation tillage and no-tillage farming protect this valuable resource by reducing soil disturbance and preserving crop residues. These practices not only improve soil fertility, moisture retention, and crop productivity but also contribute to environmental conservation by storing carbon in the soil. As climate change and land degradation continue to challenge agriculture, increasing soil organic carbon through conservation farming offers a practical pathway towards resilient, productive, and sustainable farming systems.

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DRIP ON DEMAND: A SMART SOLUTION FOR SUSTAINABLE IRRIGATION

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Abstract

Water scarcity is one of the greatest challenges facing modern agriculture. Conventional irrigation methods often result in excessive water use, increasing production costs and reducing water-use efficiency. Drip on Demand is an automated precision irrigation system that delivers water only when required by individual plants using soil moisture sensors, Arduino-based control, and solenoid valves. The system minimizes water wastage, reduces labour and energy consumption, and improves crop productivity. Integrated with solar power, it provides an eco-friendly and sustainable irrigation solution. The project also aligns with Government of India initiatives such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) and PM-KUSUM, promoting water conservation and renewable energy in agriculture.

Keywords: Precision Irrigation, Soil Moisture Sensor, Automation, Drip Irrigation, Water Conservation, Solar Energy, Sustainable Agriculture

Introduction

Agriculture is the backbone of India's economy and consumes nearly 80% of the country's freshwater resources. However, a significant amount of irrigation water is lost through runoff, evaporation, and over-irrigation. Although conventional drip irrigation is more efficient

than flood irrigation, it supplies the same amount of water to every plant regardless of its actual requirement.

To overcome this limitation, Drip on Demand was developed as a smart irrigation system that supplies water based on real-time soil moisture conditions. By automating irrigation, the system ensures optimum water use while improving crop growth and conserving valuable water resources.

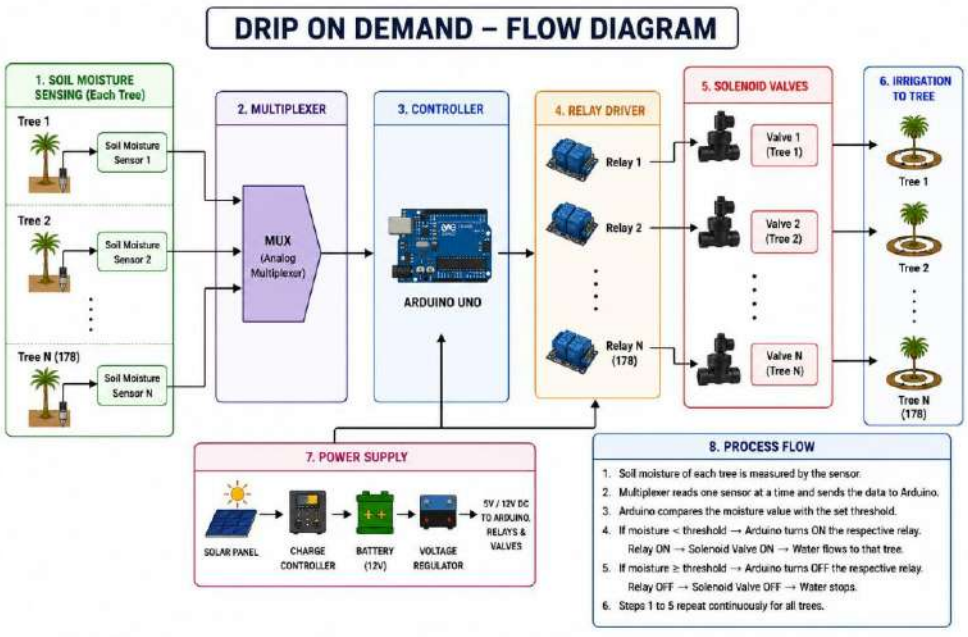
Objective

- To provide water only when required by individual plants.
- To reduce water wastage through automated irrigation.
- To minimize labour and electricity consumption.
- To improve water-use efficiency and crop productivity.
- To promote sustainable and climate-smart agriculture.

Working Principle

The system works on a feedback-based automation principle.

A capacitive soil moisture sensor continuously measures the moisture level around each plant. When the soil moisture falls below the preset threshold, the sensor sends a signal to the Arduino controller. The controller activates a relay module, which opens the solenoid valve, allowing water to flow through the drip irrigation system. Once the required soil moisture level is reached, the controller automatically closes the valve, preventing unnecessary irrigation.



Advantages

- Saves 30–60% irrigation water.
- Prevents overwatering and underwatering.
- Reduces labour requirement.
- Lowers electricity consumption.
- Improves crop growth and yield.
- Environment-friendly and sustainable.
- Suitable for orchards and perennial crops.
- Easily expandable for large farms

Government Support

PMKSY

(Pradhan Mantri Krishi Sinchayee Yojana)

The Per Drop More Crop (PDMC) component promotes micro-irrigation systems.

Subsidy:

- Small & Marginal Farmers (<2 ha): 55%
- Other Farmers (>2 ha): 45%

PM-KUSUM

(Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan) Promotes solar-powered irrigation by providing financial assistance for solar pumps, reducing dependence on conventional electricity.

Scalability

The system can be expanded from a single tree to large commercial plantations by adding more sensors, solenoid valves, and controllers. Future upgrades such as IoT, mobile applications, weather-based irrigation scheduling, and cloud monitoring can be integrated without changing the core system.

Conclusion

Drip on Demand is a smart, cost-effective, and sustainable irrigation technology that combines automation, precision agriculture, and renewable energy. By supplying water only when needed, it significantly reduces water wastage, saves labour and energy, and enhances crop productivity. With government support through **PMKSY** and **PM-KUSUM**, the system has

strong potential for large-scale adoption and can contribute to achieving sustainable water management in Indian agriculture.

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EVERY DROP COUNTS: THE FUTURE OF FARMING DEPENDS ON WATER

Article ID: AG-V06-I07-184

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Abstract

Water is the backbone of agriculture, yet it is becoming one of the most threatened natural resources due to climate change, population growth, rapid urbanization, and unsustainable water use. This article highlights the growing challenge of water scarcity and its implications for agricultural productivity, food security, and farmers' livelihoods. It explains how excessive groundwater extraction, erratic rainfall, and inefficient irrigation practices are placing immense pressure on freshwater resources. The article also discusses the wider impacts of water scarcity on soil health, ecosystems, and food availability. At the same time, it presents practical and sustainable solutions such as micro-irrigation, rainwater harvesting, soil moisture conservation, crop diversification, and climate-smart farming practices that can improve water use efficiency. It emphasizes that ensuring the future of agriculture requires the collective efforts of farmers, scientists, policymakers, and consumers. Every drop of water conserved today is an investment in resilient agriculture, environmental sustainability, and long-term food security for future generations.

Keywords: Water scarcity; sustainable agriculture; groundwater conservation; water-use efficiency; food security

Introduction

Water is the lifeline of agriculture. Every grain of rice, every fruit and every vegetable carry a hidden water footprint. For producing just one kg of rice requires about 2,500 litres of water. The virtual water required to produce one kg of yield in major food crops are given in

figure 1. These figures remind us that every meal we eat depends on a reliable supply of water. For centuries, farmers have relied on rainfall, rivers, lakes, and groundwater to produce food and sustain livelihoods. Today, however, this precious resource is becoming increasingly scarce due to climate change, population growth, rapid urbanization, and unsustainable water use. What was once considered an abundant resource is now one of the greatest challenges facing agriculture worldwide.

Agriculture is the largest user of freshwater, accounting for nearly 70% of global freshwater withdrawals, and in many developing countries this exceeds 80% **(FAO, 2021)**. At the same time, the world's population is expected to reach 9.7 billion by 2050, increasing the demand for food and placing even greater pressure on limited water resources (**United Nations, 2022a**). Climate change is making the situation worse by altering rainfall patterns, increasing temperatures, and causing more frequent droughts and floods. These extreme weather events reduce crop productivity and make farming increasingly unpredictable.

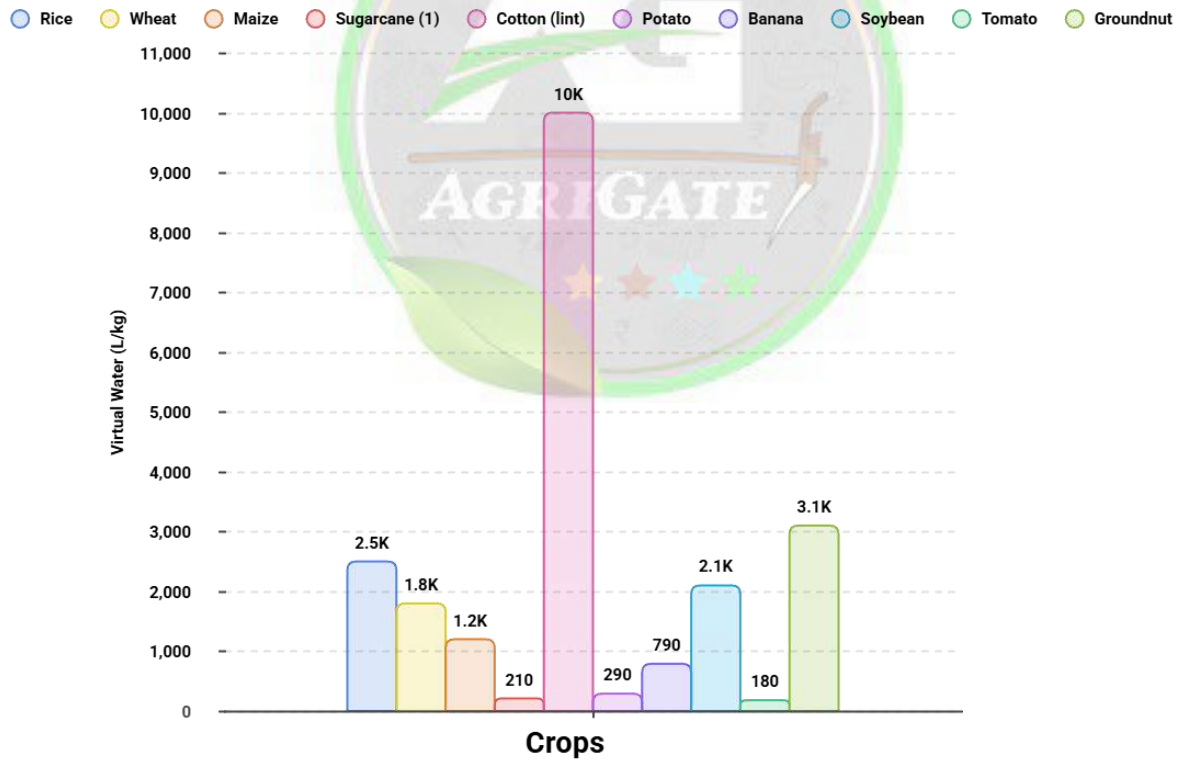


Figure 1. Approximate virtual water footprint of selected agricultural crops.

Groundwater, often called the hidden lifeline of agriculture, is also under severe stress. Across many parts of the world, aquifers are being depleted faster than they can naturally

recharge. India also facing this challenge clearly. India is the largest user of groundwater in the world, accounting for around one-quarter of global groundwater extraction (**UNESCO, 2022**). Excessive pumping, water-intensive cropping systems, and erratic monsoon rains have caused groundwater levels to decline in many agricultural regions, threatening the long-term sustainability of farming. Water scarcity is no longer a concern only for dry regions. It affects farmers everywhere by reducing crop yields, increasing production costs, and threatening food security. If current trends continue, producing enough food for a growing population will become even more difficult.

Yet, there is hope. Water-saving technologies such as drip and sprinkler irrigation, rainwater harvesting, efficient irrigation scheduling, soil moisture conservation, and climate-smart farming practices can significantly improve water use efficiency. Protecting groundwater resources and adopting sustainable water management practices are no longer optional. Every drop of water saved today is an investment in food security.

1. **Why is agriculture running out of water?**

Water scarcity is not simply the result of receiving less rainfall. It is a growing problem driven by both natural changes and human activities. Climate change has altered rainfall patterns across many regions, making rainy seasons shorter, less predictable, and more intense. Some places experience prolonged droughts, while others receive heavy rainfall within a few days, leading to floods instead of replenishing groundwater. Rising temperatures further increase evaporation from soil and water bodies, leaving less moisture available for crops (**IPCC, 2023**).

Human activities have accelerated the problem. To meet the growing demand for food, agriculture has become increasingly dependent on groundwater. Millions of borewells now supply irrigation water, often extracting groundwater much faster than nature can replenish it. In many farming regions, wells that once provided water throughout the year now run dry during critical crop growth stages. The situation becomes even more challenging when water-intensive crops such as rice and sugarcane are cultivated in regions where water resources are already limited. Urbanization and industrial development also compete with agriculture for freshwater. As cities expand, more water is diverted for domestic and industrial use, leaving less available for farming. At the same time, traditional ponds, tanks, lakes, and village water bodies that once stored rainwater has gradually disappeared or fallen into neglect. Without proper water

conservation, much of the rainfall flows away as surface runoff instead of recharging groundwater.

2. When water becomes scarce, everyone pays the price

The impact of water scarcity extends far beyond the farm. For farmers, insufficient water often means delayed sowing, poor crop growth, reduced yields, and lower incomes. Crops exposed to moisture stress during flowering or grain filling frequently produce lower yields and inferior quality, reducing market returns. Repeated crop failures also increase financial stress and discourage investment in agriculture. Water scarcity also affects soil health. Limited irrigation can reduce soil biological activity, while excessive pumping of groundwater may lead to salinity problems in some regions. Over time, declining soil quality further reduces the productivity of agricultural land, creating a cycle that becomes increasingly difficult to reverse.

Consumers are equally affected. Lower agricultural production often results in reduced market supplies, leading to higher prices for food grains, fruits, and vegetables. This places an additional burden on household budgets, particularly for low-income families. As the global population continues to grow, ensuring a stable supply of food with limited water resources will become one of the greatest challenges of this century (**United Nations, 2022b**). The effects of water scarcity also extend to the environment. Rivers, wetlands, and groundwater-dependent ecosystems suffer when excessive amounts of water are withdrawn for irrigation. Biodiversity declines, aquatic habitats shrink, and ecosystem services that support agriculture are weakened.

3. Growing more with less water: The solutions are already here

Although water scarcity is a serious issue, there are many practical solutions that can help agriculture become more resilient. The goal is not simply to find more water but to use every available drop more efficiently. One of the most effective approaches is micro-irrigation, including drip and sprinkler systems. Unlike conventional flood irrigation, these methods deliver water directly to the crop root zone, reducing evaporation and runoff while improving water use efficiency. Rainwater harvesting is another valuable strategy. Farm ponds, check dams, percolation tanks, and rooftop harvesting systems capture rainwater that would otherwise be lost as runoff. Stored water can later be used during dry periods, while part of it naturally recharges groundwater reserves.

Healthy soils also play a key role in conserving water. Increasing soil organic matter through compost, farmyard manure, crop residues, and cover crops improves the soil's ability to

absorb and retain moisture. Mulching further reduces evaporation, suppresses weeds, and helps maintain a favourable soil temperature. Crop planning is equally important. Growing crops that are better suited to local rainfall conditions, adopting drought-tolerant varieties, and diversifying cropping systems can reduce water demand without compromising farm productivity. Advances in weather forecasting, mobile advisory services, soil moisture sensors, and precision irrigation are also helping farmers make better decisions about when and how much to irrigate.

4. Lessons from countries that value every drop

Several countries have demonstrated that limited water resources do not necessarily limit agricultural productivity. By adopting innovative technologies, effective water policies, and sustainable management practices, they have successfully improved water-use efficiency while maintaining agricultural production.

Israel, despite its arid climate, has become a global leader in water-efficient agriculture through the widespread adoption of drip irrigation, precision farming, and the reuse of treated wastewater for irrigation. These practices have enabled farmers to produce high-value crops using significantly less water. Australia, one of the driest inhabited continents, has strengthened its agricultural sector through efficient irrigation systems, watershed management, and well-planned water allocation policies that encourage responsible water use. Likewise, Singapore, although not a major agricultural nation, has become a global model for integrated water management by investing in rainwater harvesting, desalination, and advanced wastewater recycling to ensure long-term water security. These examples demonstrate that water scarcity is not an insurmountable challenge but also opportunity to innovate and manage resources more efficiently. By combining modern technologies with traditional water conservation practices and encouraging community participation, India can enhance agricultural water productivity and build a more resilient farming sector. After all, the future of agriculture depends not only on the quantity of water available but also on how wisely every drop is conserved and utilized (**FAO, 2021**).

5. Every drop begins with us

Water has always been the foundation of agriculture, but today it is also one of its greatest vulnerabilities. As climate change, population growth, and increasing demand continue to place pressure on freshwater resources, the future of farming will depend on how wisely water is managed rather than how much is available. The responsibility does not lie with farmers alone.

Governments must invest in water conservation infrastructure, scientists should continue developing climate-resilient technologies, extension agencies need to promote efficient irrigation practices, and consumers can contribute by reducing food waste and valuing the resources required to produce food. Small changes made by millions of people can collectively make a significant difference.

6. Future prospects

The future of agriculture will be shaped by innovation, collaboration, and a commitment to using water more wisely. Emerging technologies such as artificial intelligence, remote sensing, drones, Internet of Things (IoT)-based sensors, and satellite-guided irrigation are making it possible to monitor soil moisture and crop water needs with greater precision. These advancements can help farmers apply water only when and where it is needed, improving productivity while reducing waste. At the same time, greater emphasis is being placed on climate-resilient farming systems, drought-tolerant crop varieties, integrated watershed management, and policies that encourage efficient water use. Strengthening community-based water management, restoring traditional water bodies, and promoting water literacy among farmers and consumers will be equally important. With the right combination of science, policy, and public participation, agriculture can become more resilient and productive, even under increasing water scarcity.

Conclusion

Water is more than just an agricultural input. It is the foundation of food security, rural livelihoods, and environmental sustainability. As freshwater resources become increasingly limited, ensuring a secure future for agriculture will depend on our ability to conserve, manage, and use water efficiently. The challenge is not simply about producing more food but about producing it with greater responsibility. The journey towards water-secure agriculture begins with informed decisions made in farms, homes, research institutions, and government offices. Every effort to harvest rainwater, improve irrigation efficiency, protect groundwater, and reduce water wastage contributes to a more sustainable food system. If we recognize the true value of water today, future generations will inherit an agriculture that is both productive and resilient. The future of farming does not depend on the abundance of water alone. It depends on our collective commitment to ensuring that every drop truly counts.

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AGENTIC AI: THE NEXT GENERATION OF SMART FARMING

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Introduction

Agriculture is experiencing a digital revolution driven by advances in Artificial Intelligence (AI), the Internet of Things (IoT), robotics, drones, and cloud computing. While conventional AI has transformed farming by predicting crop yields, identifying diseases, and optimizing irrigation schedules, the latest breakthrough is **Agentic Artificial Intelligence (Agentic AI)**. Unlike traditional AI systems that merely respond to user queries, Agentic AI can independently perceive, reason, plan, and execute tasks to achieve predefined goals with minimal human intervention.

Agentic AI represents a paradigm shift from AI as an assistant to AI as an autonomous collaborator. It integrates Large Language Models (LLMs), machine learning, computer vision, robotics, and real-time sensor networks to make intelligent decisions and coordinate multiple farming operations. This next-generation technology has the potential to improve agricultural productivity, optimize resource utilization, reduce labour dependency, and enhance climate resilience, making it a cornerstone of future smart farming.

What is Agentic AI?

Agentic AI refers to autonomous AI systems capable of independently performing complex tasks by observing the environment, analyzing data, making decisions, taking actions, and learning from outcomes. Unlike traditional AI, which typically requires continuous user input, Agentic AI can execute complete workflows without constant human supervision.

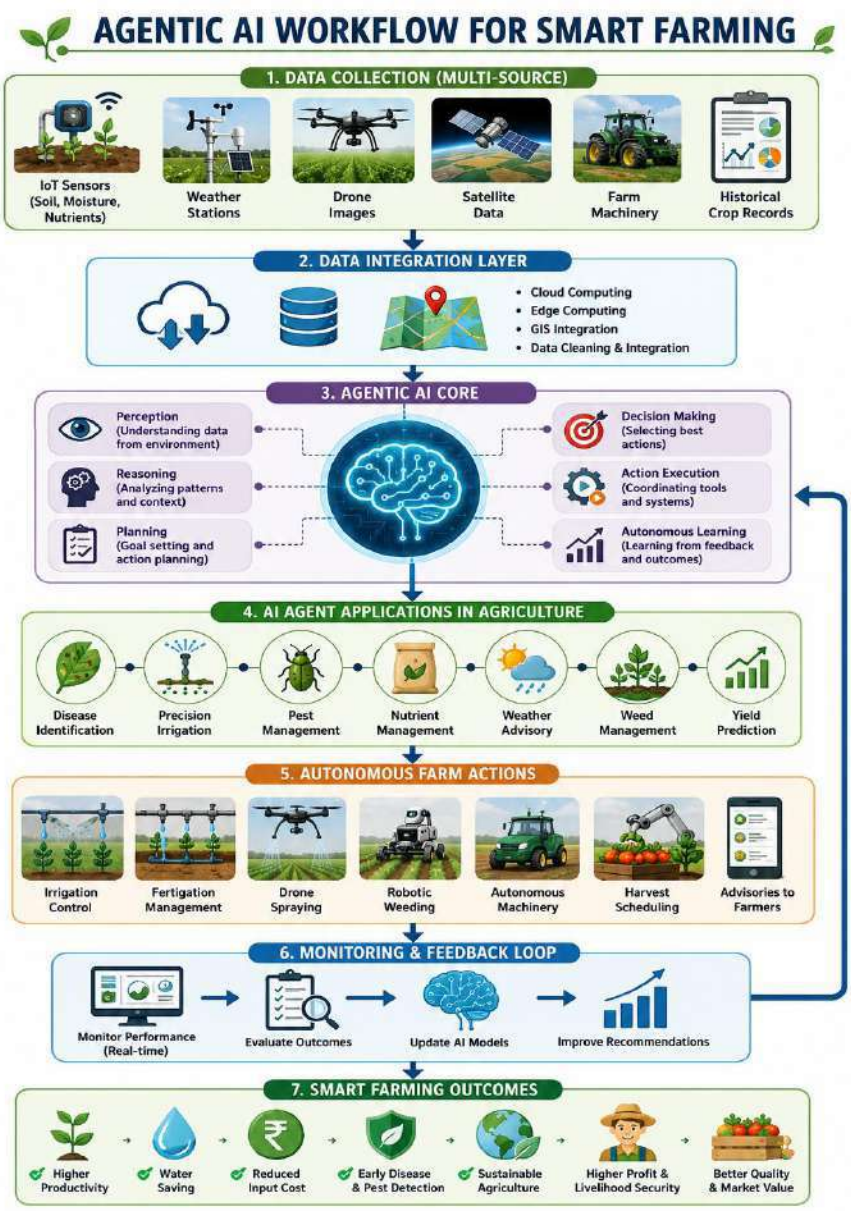
An Agentic AI system can:

- Collect information from multiple sources.

- Analyze crop and environmental conditions.
- Develop action plans.
- Execute recommended operations.
- Monitor results and continuously improve future decisions.

Agentic AI Workflow Diagram

The Agentic AI workflow illustrates how autonomous artificial intelligence transforms agricultural data into intelligent farming actions. The workflow begins with collecting real-time information from IoT sensors, drones, satellites, weather stations, and farm equipment.



This data is integrated and analyzed using advanced AI technologies, including computer vision, large language models (LLMs), and reasoning engines. Based on the analysis, Agentic AI autonomously plans and executes farming operations such as irrigation, nutrient management, pest control, and crop monitoring. The system continuously evaluates the outcomes through a feedback loop, enabling continuous learning and improving future decisions. This workflow demonstrates how Agentic AI supports precision agriculture by enhancing productivity, optimizing resource use, and promoting sustainable smart farming.

Components of Agentic AI

Agentic AI is built on multiple interconnected technologies that enable autonomous perception, reasoning, decision-making, action, and continuous learning. In agriculture, these components work together to support intelligent farm management.

The effectiveness of an Agentic AI system depends on the seamless integration of several core components. Each component plays a unique role, from collecting field data to executing farm operations and improving future performance through continuous learning. Together, these components create a comprehensive intelligent ecosystem that supports precision agriculture, climate-smart farming, and sustainable resource management.

1. Perception Layer (Data Collection)

The **Perception Layer** serves as the sensory system of Agentic AI. Just as humans rely on their senses to understand their surroundings, Agentic AI depends on this layer to collect accurate, real-time information about the agricultural environment. It continuously gathers data from multiple sources, enabling the system to monitor crop health, soil conditions, weather, and farm operations.

Modern farms generate enormous amounts of information every day. Soil moisture sensors monitor water availability, temperature and humidity sensors measure environmental conditions, while pH sensors assess soil quality. Weather stations provide localized meteorological information such as rainfall, wind speed, solar radiation, and temperature. Drones equipped with RGB, multispectral, and thermal cameras capture aerial images for crop monitoring, whereas satellite imagery offers large-scale observations of vegetation health and land-use patterns. Smart agricultural machinery supplies operational data related to planting, fertilization, spraying, and harvesting. In addition, fixed cameras and computer vision systems continuously observe crop growth and detect abnormalities.

Major Data Sources

- IoT sensors (soil moisture, temperature, humidity, pH, EC)
- Automatic weather stations
- Drones (UAVs)
- Satellite imagery
- GPS-enabled farm machinery
- Smart cameras and computer vision systems

Role: Collects accurate, continuous, and real-time agricultural data to provide situational awareness for intelligent decision-making.

2. Knowledge Base

The **Knowledge Base** functions as the "brain library" of Agentic AI. It stores agricultural knowledge, historical records, scientific information, and expert recommendations that enable the system to interpret field conditions and make informed decisions.

The knowledge base integrates crop production practices, fertilizer recommendations, irrigation schedules, pest and disease information, soil characteristics, weather history, government regulations, and previous farm records. It also incorporates agricultural research findings, extension advisories, and region-specific management practices. As new information becomes available, the knowledge base is continuously updated, ensuring that recommendations remain relevant and scientifically accurate.

Information Stored

- Crop production technologies
- Soil characteristics and fertility information
- Pest and disease databases
- Fertilizer recommendations
- Irrigation schedules
- Weather history
- Farm operation records
- Agricultural regulations and best practices

Role: Provides domain-specific knowledge that supports reasoning, planning, and recommendation generation.

3. Reasoning and Planning Engine

The **Reasoning and Planning Engine** transforms raw agricultural data into meaningful decisions. After receiving information from the perception layer and consulting the knowledge base, this component evaluates multiple alternatives and develops an optimal action plan.

For example, if soil moisture levels are low and rainfall is not expected for several days, the reasoning engine determines whether irrigation is required immediately or can be delayed. Similarly, when disease symptoms are detected, it evaluates disease severity, crop growth stage, weather conditions, and available control measures before selecting the most appropriate management strategy.

Major Functions

- Situation analysis
- Risk assessment
- Goal planning
- Task prioritization
- Decision optimization
- Resource allocation
- Strategy selection

Role: Converts agricultural information into practical management plans that maximize productivity while minimizing resource use.

4. Large Language Model (LLM)

Large Language Models (LLMs) enable Agentic AI to communicate naturally with farmers, researchers, and extension personnel. Unlike conventional computer programs, LLMs understand human language and generate meaningful responses, making AI systems more interactive and accessible.

Farmers can ask questions such as *"Why are my tomato leaves turning yellow?"* or *"What fertilizer should I apply this week?"* The LLM interprets these questions, combines them with real-time field information, and generates personalized recommendations. It can also explain complex technical concepts in simple language, prepare farm reports, summarize scientific literature, and provide multilingual advisory services.

Functions

- Understands farmer queries

- Generates personalized recommendations
- Explains AI decisions
- Produces farm reports and summaries
- Supports multilingual communication
- Assists agricultural extension

Examples: GPT, Gemini, Claude, Llama.

Role: Acts as the communication bridge between humans and autonomous AI systems.

5. Computer Vision Module

The **Computer Vision Module** enables Agentic AI to "see" and interpret agricultural images. Using deep learning models, the system analyzes photographs captured from smartphones, drones, surveillance cameras, and autonomous robots.

Computer vision is capable of identifying plant diseases, detecting insect pests, distinguishing weeds from crops, estimating plant populations, monitoring crop growth, and assessing fruit maturity. Modern models such as Vision Transformers (ViTs), YOLO, EfficientNet, and other deep learning architectures provide highly accurate visual analysis.

Applications

- Disease identification
- Pest detection
- Weed recognition
- Crop health monitoring
- Fruit maturity estimation
- Yield estimation
- Nutrient deficiency detection

Role: Converts visual information into actionable agricultural intelligence.

6. Decision-Making Engine

The **Decision-Making Engine** is the central intelligence of Agentic AI. It integrates insights generated by the perception layer, knowledge base, reasoning engine, LLM, and computer vision module to determine the most effective management strategy.

This component evaluates various alternatives by considering crop requirements, weather forecasts, economic costs, resource availability, and environmental sustainability. It

automatically selects the most suitable irrigation schedule, fertilizer dose, pest management strategy, or harvesting time.

Responsibilities

- Selects optimal management practices
- Optimizes irrigation schedules
- Recommends nutrient management
- Predicts crop outcomes
- Makes autonomous decisions
- Minimizes production risks

Role: Converts analytical insights into intelligent farm decisions.

7. Action Execution Module

After decisions are finalized, the **Action Execution Module** implements them using connected agricultural technologies. This transforms recommendations into real farm operations without requiring continuous human supervision.

The module can activate irrigation pumps, control fertigation systems, dispatch agricultural drones for pesticide spraying, guide autonomous tractors, operate robotic weeders, and schedule harvesting equipment. These automated actions improve operational efficiency while reducing labour requirements and production costs.

Technologies Used

- Automated irrigation controllers
- Smart fertigation systems
- Agricultural drones
- Robotic weeders
- Autonomous tractors
- Smart greenhouse systems

Role: Executes farming operations accurately, efficiently, and autonomously.

8. Learning and Feedback Module

One of the defining characteristics of Agentic AI is its ability to continuously improve. The **Learning and Feedback Module** evaluates the results of every action and uses this information to enhance future performance.

For example, if a particular irrigation strategy improves yield while reducing water consumption, the AI incorporates this knowledge into future recommendations. Similarly, unsuccessful decisions are analyzed to prevent repeated mistakes.

Functions

- Performance monitoring
- Outcome evaluation
- AI model updating
- Continuous learning
- Recommendation refinement
- Adaptive optimization

Role: Enables self-improvement, making the AI system more accurate and efficient over time.

9. Communication Interface

The **Communication Interface** connects farmers, extension workers, and agricultural experts with the Agentic AI system. A simple and user-friendly interface ensures that advanced AI technologies remain accessible to users with varying levels of digital literacy.

Communication may occur through mobile applications, web portals, SMS alerts, chatbots, or voice assistants. Farmers receive timely advisories, weather alerts, irrigation notifications, pest warnings, and crop management recommendations. They can also provide feedback, upload field images, and request expert assistance.

Communication Channels

- Mobile applications
- Web dashboards
- SMS alerts
- Voice assistants
- AI chatbots

Role: Facilitates seamless interaction between users and autonomous farming systems.

10. Cloud and Edge Computing

Agentic AI relies on **Cloud Computing** and **Edge Computing** to process enormous amounts of agricultural data efficiently.

Cloud computing stores large datasets, trains advanced AI models, and provides remote access to farm information. However, some agricultural decisions require immediate responses. Edge

computing addresses this need by processing data directly on local devices such as field gateways, drones, or autonomous tractors. This minimizes communication delays and allows AI systems to continue functioning even in areas with limited internet connectivity.

Cloud Computing

- Large-scale data storage
- Advanced AI model training
- Remote monitoring
- Centralized analytics
- Collaborative research

Edge Computing

- Real-time processing
- Low-latency decision making
- Offline operation
- Local AI inference
- Reduced bandwidth usage

Role: Provides the computational infrastructure necessary for intelligent, real-time farm management.

Applications of Agentic AI in Agriculture

1. Intelligent Crop Monitoring

Agentic AI continuously monitors crop growth using drone images, IoT sensors, and satellite data. It identifies crop stress before symptoms become visible and recommends timely interventions.

2. Autonomous Disease Identification

Computer vision models analyze leaf images to identify diseases such as bacterial blight, powdery mildew, rust, and leaf spot. Agentic AI not only identifies the disease but also recommends suitable fungicides, biological control options, and preventive measures.

3. Precision Irrigation

By integrating soil moisture sensors, weather forecasts, and crop water requirements, Agentic AI automatically determines when and how much irrigation is required, thereby conserving water and improving water-use efficiency.

4. Smart Nutrient Management

Agentic AI analyzes soil nutrient status and crop growth stages to recommend balanced fertilizer application. It can control fertigation systems for precise nutrient delivery while minimizing fertilizer losses.

5. Pest Surveillance

AI-powered drones and smart cameras detect insect infestations in real time. The system predicts pest outbreaks using climatic conditions and recommends Integrated Pest Management (IPM) practices.

6. Autonomous Agricultural Machinery

Agentic AI powers autonomous tractors, robotic weeders, and harvesting robots capable of performing field operations with minimal human intervention, reducing labour costs and increasing operational efficiency.

7. Weather-Based Farm Advisory

The system continuously analyzes weather forecasts to recommend suitable sowing dates, irrigation schedules, fertilizer application timing, and harvest planning while providing alerts for extreme weather events.

8. Precision Weed Management

Computer vision distinguishes weeds from crops and directs robotic weeders or targeted herbicide sprayers, reducing chemical usage and environmental impact.

9. Yield Prediction

By analyzing weather conditions, crop growth, soil health, and historical production data, Agentic AI provides accurate yield forecasts that help farmers plan storage, marketing, and logistics.

10. Farm Management Assistant

Agentic AI functions as a virtual farm manager by maintaining digital farm records, scheduling agricultural operations, tracking expenses, generating reports, and answering farmers' questions in natural language.

Benefits of Agentic AI

- Autonomous decision-making
- Improved crop productivity
- Early disease and pest detection

- Reduced labour dependency
- Efficient water and fertilizer management
- Lower production costs
- Enhanced climate resilience
- Real-time monitoring and alerts
- Data-driven farm management
- Improved profitability and sustainability

Challenges

Despite its immense potential, several challenges must be addressed:

- High initial investment.
- Dependence on reliable internet connectivity.
- Limited digital literacy among farmers.
- Data privacy and cybersecurity concerns.
- Need for high-quality agricultural datasets.
- Integration with existing farming infrastructure.
- Ethical and regulatory considerations for autonomous systems.

Future Scope

The future of Agentic AI lies in creating fully autonomous and intelligent farming ecosystems. Integration with digital twins, blockchain, 6G communication, swarm robotics, hyperspectral imaging, and climate prediction models will enable farms to monitor, analyze, and manage themselves with minimal human intervention. AI agents will collaborate across crop production, livestock management, post-harvest processing, and supply chain logistics, making agriculture more efficient, resilient, and sustainable.

Conclusion

Agentic AI marks the beginning of a new era in digital agriculture by transforming intelligent decision support into autonomous farm management. By integrating artificial intelligence with IoT, drones, robotics, and precision agriculture technologies, it empowers farmers to make timely, accurate, and sustainable decisions. Although challenges related to infrastructure, affordability, and data governance remain, continued research, policy support, and technological innovation are expected to accelerate the adoption of Agentic AI. As agriculture

evolves toward fully autonomous smart farming, Agentic AI will play a pivotal role in ensuring food security, resource conservation, and climate-resilient agricultural production.

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PERSONALIZED NUTRITION AND PRECISION LIVESTOCK HEALTH: A NEW ERA FOR SUSTAINABLE ANIMAL PRODUCTION

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Abstract

Livestock production is rapidly evolving from traditional herd-based management to individualized, data-driven animal care. Personalized nutrition and precision livestock health (PLH) represent two transformative approaches that combine advances in nutrition, genetics, sensor technology, artificial intelligence (AI), machine learning, wearable devices, Internet of Things (IoT) and big data analytics to optimize the health, productivity, welfare and sustainability of livestock. Rather than feeding or treating all animals in the same manner, these technologies recognize the unique nutritional requirements, physiological status, genetic potential, health condition and environmental exposure of individual animals. Precision feeding improves feed conversion efficiency, reduces nutrient wastage, minimizes greenhouse gas emissions and enhances profitability. Simultaneously, precision livestock health enables early disease detection, real-time monitoring and timely interventions, thereby reducing production losses and antimicrobial use. This popular article discusses the principles, technologies, applications, benefits, challenges, future prospects and practical implications of personalized nutrition and precision livestock health in dairy cattle, buffaloes, sheep, goats, pigs and poultry. The integration of nutritional genomics, microbiome research, digital agriculture and AI-driven decision support systems is expected to revolutionize animal production and support climate-smart livestock farming.

Keywords: Artificial intelligence, Biosensors, Digital livestock, Personalized animal nutrition, Precision feeding, Precision livestock farming and health,

Introduction

Livestock farming has always relied on providing adequate nutrition, proper healthcare and suitable management practices to maximize productivity. Traditionally, animals within a herd or flock are managed as a single unit, receiving the same feed formulation, vaccination schedule and healthcare interventions. However, animals differ considerably in genetics, age, physiological status, disease susceptibility, digestive efficiency, immune response and production potential. Consequently, a one-size-fits-all approach often results in inefficient nutrient utilization, increased feed costs, reduced productivity and greater environmental pollution.

The emergence of precision livestock farming (PLF) has transformed animal agriculture by utilizing digital technologies to continuously monitor animals and provide management decisions based on real-time information. Precision livestock health extends this concept by focusing specifically on disease prevention, early diagnosis, welfare monitoring and individualized healthcare. Similarly, personalized nutrition aims to supply nutrients according to the unique requirements of each animal. This concept is inspired by personalized medicine in humans and is becoming increasingly feasible through developments in sensor technologies, wearable devices, genomic analysis, metabolomics, microbiome profiling and artificial intelligence.

Today, dairy farms equipped with automated milking systems, wearable sensors, rumen boluses, smart ear tags, cameras, thermal imaging and cloud-based analytics can continuously collect thousands of data points from each animal every day. AI algorithms analyze these data to identify subtle changes in feeding behavior, rumination, activity, body temperature, milk composition and metabolic status long before clinical symptoms appear. These innovations are helping farmers transition from reactive management to predictive and preventive livestock production systems.

Why personalized nutrition is needed

Every animal possesses unique nutritional requirements depending on numerous factors:

Genetic makeup

Breed

Age

Sex

Physiological stage

Pregnancy

Lactation

Growth rate

Health status

Environmental temperature

Disease challenges

Feed digestibility

Gut microbiota composition

For example, two dairy cows producing similar quantities of milk may differ significantly in feed efficiency because of differences in rumen microbial populations and metabolic activity. Similarly, rapidly growing broiler chickens require different amino acid balances compared to slower-growing birds. Personalized nutrition seeks to match nutrient supply precisely with nutrient demand.

Components of personalized nutrition

Personalized nutrition aims to provide nutrients according to the individual animal's genetic potential, physiological status, health condition, production level, and environmental influences rather than applying a uniform feeding strategy. This precision approach improves nutrient utilization, feed efficiency, immune function, productivity and animal welfare while reducing feed wastage, metabolic disorders and environmental pollution.

1. Precision feed formulation

Precision feed formulation is the process of designing nutritionally balanced diets that meet the specific nutrient requirements of individual animals or groups with similar characteristics. Advanced feed formulation software integrates production, health, nutritional and environmental data to develop customized feeding programs that maximize productivity, improve feed conversion efficiency, reduce feed costs and support sustainable livestock production.

Modern software formulates diets based on:

Real-time production records

Real-time production records provide continuous information on milk yield, body weight, feed consumption, reproductive status, health events, and growth performance. Integrating these

data into precision feeding software allows nutritionists to make immediate dietary adjustments, ensuring that nutrient supply closely matches changing production demands and improving overall herd performance.

Milk yield

Milk yield is one of the most important parameters used in precision feed formulation. High-producing dairy animals require greater amounts of energy, protein, minerals, vitamins, and water than low-producing animals. Continuous monitoring of milk production enables precise ration adjustments that sustain peak lactation, improve milk composition, prevent metabolic disorders and enhance profitability.

Growth performance

Growth performance, measured through body weight gain, average daily gain and feed conversion ratio, provides valuable information about the nutritional adequacy of diets. Precision nutrition uses these indicators to optimize nutrient supply according to growth stage, ensuring efficient muscle development, better feed utilization, reduced production costs and improved economic returns.

Body condition score

Body condition score (BCS) is a visual assessment of an animal's body fat reserves and nutritional status. Precision feeding utilizes BCS to identify under-conditioned or over-conditioned animals and modify dietary energy and protein levels accordingly. Maintaining an optimal BCS improves reproductive efficiency, health, longevity and production performance while reducing metabolic diseases.

Feed intake

Monitoring individual feed intake is fundamental to precision nutrition because changes in consumption often indicate nutritional deficiencies, illness, stress, or environmental challenges. Automated feeding systems continuously record feed intake, enabling early detection of abnormalities and allowing nutritionists to optimize diet composition, improve feed efficiency and maintain animal health.

Environmental stress

Environmental factors such as heat, humidity, cold stress, poor ventilation, and seasonal changes significantly influence nutrient requirements and feed intake. Precision feed formulation incorporates environmental data to adjust dietary energy density, electrolyte balance, antioxidant

supplementation, and water management, thereby minimizing stress-related production losses and improving animal resilience.

'Instead of one ration for the entire herd, animals are grouped into nutritional clusters or even individually fed'

Traditional feeding systems often provide a single ration to all animals regardless of their individual needs, leading to nutrient deficiencies in some animals and nutrient excesses in others. Precision nutrition overcomes this limitation by grouping animals into nutritional clusters based on factors such as age, production level, physiological status, genetics, body condition, and health status. On technologically advanced farms, automated feeding systems can even deliver individualized diets, maximizing nutrient utilization, improving productivity, reducing feed costs, minimizing nutrient excretion and supporting environmentally sustainable livestock production.

2. Nutritional genomics

Nutritional genomics is an interdisciplinary field that investigates the interactions between nutrition and the genome to understand how nutrients influence gene function, metabolism, health and productivity. It integrates genomics, molecular biology and nutrition to develop precision feeding strategies that optimize growth, reproduction, immunity, feed efficiency and disease resistance according to an animal's genetic potential.

Nutrigenomics examines how dietary nutrients and bioactive feed components regulate gene expression by activating or suppressing specific genes involved in physiological and metabolic processes. Understanding these nutrient–gene interactions enables the formulation of personalized diets that enhance productivity, improve health, strengthen immunity and prevent nutrition-related metabolic disorders in livestock. Nutrigenomics studies how nutrients influence gene expression. Certain nutrients activate or suppress genes involved in:

Milk synthesis

Nutrients such as amino acids, energy sources, fatty acids, vitamins and trace minerals regulate genes responsible for mammary gland development and milk component synthesis. Precision nutritional interventions can enhance the expression of genes involved in lactose, protein and milk fat production, thereby improving milk yield, composition, udder health and overall dairy performance.

Muscle growth

Essential amino acids, high-quality proteins, vitamins, minerals and growth-promoting nutrients influence the expression of genes controlling muscle protein synthesis, cell proliferation and tissue development. Nutrigenomic approaches optimize muscle growth, improve carcass quality, increase lean meat production and enhance feed conversion efficiency in livestock and poultry.

Fat metabolism

Dietary energy sources, fatty acids, antioxidants, and functional nutrients regulate genes involved in lipid synthesis, fat deposition, fatty acid oxidation, and energy metabolism. Proper nutritional modulation of these genes helps control body fat accumulation, improve metabolic efficiency, reduce obesity-related disorders, and enhance the nutritional quality of meat and milk.

Immunity

Nutrients including vitamins A, D, E, C, zinc, selenium, omega-3 fatty acids and phytogenic compounds influence the expression of immune-related genes responsible for inflammatory responses, antioxidant defense and pathogen resistance. Nutrigenomic strategies strengthen innate and adaptive immunity, improving disease resistance and reducing the incidence of infectious and metabolic disorders.

Reproduction

Balanced nutrition regulates genes associated with hormone synthesis, ovarian and testicular function, embryo development, placental growth and fertility. Nutrients such as selenium, zinc, folic acid, vitamin E, omega-3 fatty acids and essential amino acids improve reproductive gene expression, leading to enhanced conception rates, reproductive efficiency and offspring viability.

Disease resistance

Nutritional genomics identifies nutrients that activate genes involved in immune surveillance, cellular repair, antioxidant defense and pathogen recognition while suppressing genes associated with excessive inflammation. Precision nutritional interventions enhance natural disease resistance, improve resilience to environmental stress, reduce dependence on antibiotics and promote healthier, more productive livestock populations. Similarly, nutrigenetics evaluates how genetic variation influences nutrient utilization. These approaches enable development of genetically optimized feeding programs.

3. Gut microbiome-based nutrition

Gut microbiome-based nutrition is an emerging approach in precision animal nutrition that utilizes the composition and function of gastrointestinal microorganisms to optimize nutrient utilization, animal health, and productivity. By understanding microbial diversity through advanced sequencing technologies, nutritionists can develop targeted dietary interventions that improve digestion, immunity, feed efficiency, metabolic health and overall livestock performance. Sequencing technologies now allow profiling of the rumen and intestinal microbiome. Customized probiotics, prebiotics, synbiotics, phytobiotics and enzymes can be selected according to microbial composition. The gastrointestinal tract contains trillions of microorganisms influencing:

Digestion

The gut microbiome plays a fundamental role in breaking down complex carbohydrates, fibers, proteins and other feed components that animals cannot digest efficiently on their own. Beneficial microorganisms produce digestive enzymes and fermentation products that enhance nutrient digestibility, improve gastrointestinal health, and increase the availability of nutrients essential for growth and production.

Energy harvest

Gut microorganisms ferment dietary fiber and other indigestible carbohydrates into volatile fatty acids (VFAs), including acetate, propionate and butyrate, which serve as major energy sources for ruminants. Efficient microbial fermentation improves energy extraction from feed, enhances feed conversion efficiency, supports metabolic functions and contributes to higher milk, meat and wool production.

Vitamin synthesis

Beneficial intestinal microorganisms synthesize several essential vitamins, particularly B-complex vitamins and vitamin K, which are required for energy metabolism, enzyme activity, blood clotting and immune function. A healthy gut microbiome reduces dependence on dietary supplementation while supporting normal physiological functions and improving the nutritional status of livestock.

Immune regulation

The gut microbiome is closely associated with the development and regulation of the immune system. Beneficial microorganisms stimulate immune cell maturation, strengthen

intestinal barrier function, inhibit pathogenic bacteria and regulate inflammatory responses. Maintaining a balanced microbial ecosystem enhances disease resistance, reduces infection risk and improves overall animal health and welfare.

Feed efficiency

A diverse and balanced gut microbial population enhances nutrient digestion, fermentation efficiency and absorption, enabling animals to obtain more nutrients and energy from the same quantity of feed. Improved microbial efficiency reduces feed costs, lowers nutrient wastage, minimizes methane emissions and increases productivity in both ruminant and monogastric livestock systems.

Sequencing technologies for profiling the rumen and intestinal microbiome

Advanced molecular techniques such as next-generation sequencing (NGS), 16S rRNA gene sequencing, metagenomics and metatranscriptomics allow detailed characterization of microbial communities in the rumen and intestine. These technologies identify beneficial and harmful microorganisms, enabling researchers to understand microbial diversity, digestive functions, disease susceptibility and nutritional responses with unprecedented accuracy.

Customized probiotics, prebiotics, synbiotics, phytobiotics and enzymes based on microbial composition

Knowledge of the gut microbial profile enables the development of personalized nutritional interventions using probiotics, prebiotics, synbiotics, phytobiotics and exogenous enzymes tailored to the animal's microbial composition. These targeted feed additives promote beneficial microorganisms, suppress pathogens, improve digestive efficiency, enhance nutrient utilization, strengthen immunity, reduce gastrointestinal disorders and support sustainable precision livestock production.

4. Metabolomics and biomarkers

Metabolomics is the comprehensive study of small molecules (metabolites) present in biological fluids and tissues that reflect an animal's metabolic and physiological status. Analysis of blood, milk, urine, saliva and fecal metabolites provides valuable insights into nutrient utilization, energy balance, immune function and health, enabling early diagnosis of metabolic disorders and precision nutritional management. Blood, milk, urine, saliva and fecal metabolites reveal the metabolic status of animals. Metabolites present in blood, milk, urine, saliva and feces serve as reliable indicators of physiological, nutritional and health status. Their analysis helps

detect energy imbalance, nutrient deficiencies, metabolic stress, inflammation, digestive disorders and disease before clinical symptoms appear, allowing timely nutritional interventions and improved livestock health management.

Blood, milk, urine, saliva and fecal metabolites reveal the metabolic status of animals. Important biomarkers include:

β-Hydroxybutyrate (BHB)

β-Hydroxybutyrate (BHB) is a ketone body produced during excessive fat mobilization, particularly in early lactation dairy animals experiencing negative energy balance (NEB). Elevated BHB concentrations indicate subclinical or clinical ketosis, reduced feed intake and impaired productivity. Regular monitoring enables timely dietary energy supplementation and prevention of metabolic disorders.

Non-esterified fatty acids (NEFA)

The NEFAs are released into the bloodstream during body fat mobilization when dietary energy intake is insufficient. High NEFA concentrations indicate negative energy balance, increased risk of ketosis, fatty liver syndrome, poor fertility and reduced milk production. Monitoring NEFA assists in optimizing transition cow nutrition and metabolic health.

Glucose

Blood glucose is a key indicator of carbohydrate metabolism and energy status. Abnormal glucose levels may reflect inadequate dietary energy, metabolic disorders, endocrine dysfunction, or physiological stress. Regular glucose monitoring supports precision feeding strategies aimed at maintaining optimal energy balance, productivity, reproductive performance and overall animal health.

Urea nitrogen

Blood or milk urea nitrogen reflects the balance between dietary protein and energy utilization. Elevated urea nitrogen levels indicate excessive protein intake, poor nitrogen utilization or inadequate energy supply, whereas low levels may suggest protein deficiency. Monitoring urea nitrogen helps optimize ration formulation, improve feed efficiency, and reduce environmental nitrogen losses.

Cortisol

Cortisol is a stress hormone released by the adrenal glands in response to physical, nutritional, environmental, or psychological stress. Elevated cortisol levels suppress immune

function, impair reproduction, reduce feed intake, and negatively affect growth and production. Measuring cortisol helps evaluate animal welfare and implement nutritional or management interventions to alleviate stress.

Haptoglobin

Haptoglobin is an acute phase protein produced by the liver during inflammation, infection, or tissue injury. Increased haptoglobin concentrations indicate early inflammatory responses before clinical signs become visible. Monitoring this biomarker facilitates prompt diagnosis, nutritional support, and therapeutic interventions, thereby improving animal health and minimizing production losses.

Acute phase proteins

Acute phase proteins, including serum amyloid A (SAA), C-reactive protein (CRP), fibrinogen, and haptoglobin, increase rapidly during infection, inflammation, trauma, or metabolic stress. Their measurement provides sensitive indicators of health status, immune activation, and disease progression, supporting early diagnosis and evidence-based nutritional and veterinary management.

These biomarkers guide nutritional adjustments before disease develops.

Biomarkers guide nutritional adjustments before disease develops

Metabolomic biomarkers provide early warning signals of metabolic imbalance, nutritional deficiencies, inflammation and physiological stress before clinical disease becomes evident. By integrating biomarker information with precision nutrition and digital health monitoring, veterinarians and nutritionists can implement targeted dietary modifications, improve metabolic efficiency, enhance immunity, prevent disease and optimize livestock productivity and welfare.

Precision livestock health

Precision livestock health is an advanced management approach that uses continuous monitoring technologies to detect health problems at an early stage, often before visible clinical symptoms appear. By integrating digital technologies, real-time data analysis, and predictive models, it supports preventive healthcare, enhances animal welfare, improves productivity, reduces treatment costs and minimizes the use of antibiotics in modern livestock production systems. Precision livestock health utilizes continuous monitoring systems to detect disease before clinical symptoms become visible. It integrates:

Sensors

Sensors are the foundation of precision livestock health, continuously measuring physiological, behavioral, and environmental parameters such as body temperature, heart rate, rumination, activity, respiration, feed intake, water consumption and environmental conditions. These real-time data enable early identification of abnormalities, facilitating prompt nutritional and veterinary interventions before diseases become clinically evident.

Artificial intelligence (AI)

AI analyzes large volumes of data generated by sensors, cameras, wearable devices and farm management systems to recognize hidden patterns and predict health risks. AI-driven algorithms identify disease outbreaks, metabolic disorders, reproductive problems and nutritional deficiencies, enabling accurate, timely and evidence-based decision-making for improved livestock health and productivity.

Cloud computing

Cloud computing provides secure storage, processing, and remote access to large amounts of livestock data collected from multiple sources. Farmers, veterinarians, and nutritionists can monitor animal health in real time through cloud-based platforms, facilitating collaborative decision-making, efficient record management, and rapid implementation of preventive healthcare strategies.

Big data

Big data refers to the enormous volume of information generated from sensors, automated feeding systems, milk analyzers, health records, environmental monitoring devices and genetic databases. Advanced analytical tools process these datasets to identify disease trends, evaluate nutritional responses, predict production performance and optimize herd management with greater accuracy and efficiency.

Automated alerts

Automated alert systems continuously compare real-time animal data with predefined health and performance thresholds. When abnormal changes such as reduced feed intake, elevated body temperature, altered rumination, or decreased activity are detected, immediate notifications are sent to farmers or veterinarians, enabling rapid intervention and minimizing disease progression and production losses.

Decision support systems

Decision support systems integrate information from sensors, artificial intelligence, health records, nutritional databases and environmental monitoring to provide scientifically based recommendations for feeding, disease prevention, reproduction and overall herd management. These systems assist farmers in making timely, accurate and economically beneficial management decisions that improve productivity and animal welfare.

The objective is prevention rather than treatment

The primary goal of precision livestock health is to shift livestock management from reactive disease treatment to proactive disease prevention. Through continuous monitoring, early diagnosis, predictive analytics, and precision nutrition, potential health problems can be identified before clinical signs appear, reducing disease incidence, veterinary expenses, antimicrobial use, and economic losses while enhancing animal welfare and sustainable livestock production.

Major technologies used

Wearable sensors

Animals wear:

Neck collars

Ear tags

Leg pedometers

Smart halters

These monitor:

Activity

Rumination

Eating behavior

Standing time

Walking

Estrus

Heat stress

Rumen boluses

Electronic rumen boluses continuously measure:

Temperature

pH

Drinking behavior

Drinking frequency

Rumen motility

Sudden changes often indicate illness.

Thermal imaging

Infrared cameras detect:

Mastitis

Foot lesions

Fever

Heat stress

Respiratory disease

Without touching the animal

Computer vision

Video cameras powered by AI evaluate:

Body condition

Lameness

Feeding behavior

Aggression

Social interactions

Mobility

Continuous monitoring improves welfare assessment.

Acoustic monitoring

Microphones recognize:

Coughing

Sneezing

Respiratory infections

Pig vocalization

Poultry distress calls

AI identifies abnormal sound patterns.

Milk sensors

Automated milking systems measure:

Milk conductivity

Fat

Protein

Lactose

Somatic cell count

Progesterone

Ketone bodies

Early detection of mastitis and ketosis becomes possible.

Artificial intelligence in precision livestock health

Artificial Intelligence (AI) has become a cornerstone of precision livestock health by transforming large volumes of real-time data into actionable management decisions. Using machine learning, deep learning and predictive analytics, AI continuously evaluates information from sensors, cameras, wearable devices, automated feeders, and environmental monitoring systems. These technologies facilitate early disease detection, optimize nutrition, improve animal welfare, enhance productivity and support evidence-based decision-making while reducing labor requirements and production costs.

Disease outbreaks

AI analyzes health records, feeding behavior, body temperature, movement patterns, and environmental conditions to identify early signs of infectious disease outbreaks before clinical symptoms become apparent. Predictive algorithms generate real-time alerts, enabling rapid isolation, treatment and biosecurity measures that reduce disease transmission, mortality, economic losses and unnecessary antimicrobial use.

Heat stress

AI continuously monitors environmental parameters such as temperature, humidity, respiration rate, body temperature, and animal activity to predict heat stress. Early warning systems recommend timely interventions, including improved ventilation, cooling systems, shade and nutritional adjustments, thereby maintaining feed intake, productivity, reproductive performance and animal welfare during hot weather.

Lameness

AI-powered computer vision, wearable sensors and gait analysis systems detect subtle changes in walking patterns, posture, standing time and weight distribution that indicate early

lameness. Prompt identification enables timely hoof care, nutritional correction and veterinary treatment, reducing pain, production losses, culling rates and improving overall animal welfare.

Reproductive disorders

AI monitors estrus behavior, body activity, rumination, hormonal changes and physiological indicators to predict reproductive disorders such as anestrus, silent heat, ovarian dysfunction and calving complications. Accurate reproductive monitoring improves breeding efficiency, conception rates, calving intervals and overall reproductive management in livestock.

Feed intake

AI continuously records feeding frequency, eating duration, feed consumption, and feed refusal through smart feeding systems and sensors. Sudden reductions in feed intake often indicate nutritional deficiencies, illness, or stress. Early detection allows farmers to adjust feeding strategies promptly, improving feed efficiency, health, and production performance.

Milk yield

AI integrates data from automated milking systems, milk composition analyzers, feed intake records and animal health parameters to predict daily milk production. It identifies factors affecting milk yield, detects production declines at an early stage and supports precision nutrition and herd management for maximizing dairy profitability.

Growth performance

AI evaluates body weight, growth rate, feed conversion efficiency, nutrient utilization, and genetic potential using continuous monitoring systems. Predictive models help optimize feeding programs, improve weight gain, reduce production variability and achieve efficient growth while minimizing feed costs and environmental impacts in livestock production systems.

Deep learning algorithms continuously improve prediction accuracy

Deep learning, an advanced branch of artificial intelligence, processes vast and complex datasets from multiple farm sources to recognize hidden patterns that traditional methods may overlook. As more data are collected over time, these algorithms continuously learn and refine their predictive accuracy, enabling increasingly reliable forecasts for animal health, nutrition, productivity, disease prevention and precision livestock management.

Applications in dairy cattle

Precision nutrition supports:

Individual concentrate feeding

Ketosis prevention

Rumen acidosis management

Transition cow nutrition

Fertility improvement

Precision health detects:

Mastitis

Milk fever

Lameness

Heat stress

Retained placenta and

Metritis, etc., Much earlier than visual observation.

Applications in beef cattle

Technology monitors:

Growth

Feed efficiency

Grazing behavior

Water intake

Body weight

Disease

Heat load

GPS collars track grazing distribution. Virtual fencing minimizes labor requirements.

Applications in sheep and goats

Sensors assist in:

Pregnancy monitoring

Lambing prediction

Grazing activity

Parasite detection

Body condition assessment

AI predicts nutritional deficiencies under extensive production systems.

Applications in pig production

Precision feeding improves:

Lysine utilization

Protein efficiency

Feed conversion ratio

Growth rate

Automated cameras detect:

Tail biting

Aggression

Respiratory disease

Reduced feed intake

Environmental sensors maintain optimal housing conditions.

Applications in poultry

Modern poultry houses utilize:

Automated weighing

Climate control

Feed intake monitoring

Water consumption monitoring

Camera surveillance

Thermal imaging

Sound analysis

AI detects:

Heat stress

Coccidiosis

Respiratory infections

Leg disorders

Mortality risks

before clinical outbreaks occur.

Precision nutrition for disease prevention

Precision nutrition is a preventive approach that provides nutrients according to the specific physiological, metabolic and health requirements of individual animals or groups. By supplying balanced diets enriched with functional nutrients and bioactive compounds, it

enhances immune competence, improves disease resistance, reduces metabolic disorders, minimizes antimicrobial dependence and supports sustainable livestock production.

Proper nutrition strengthens immunity through:

Antioxidants

Antioxidants such as vitamin E, vitamin C, selenium, polyphenols and carotenoids protect cells against oxidative stress by neutralizing harmful free radicals. Adequate antioxidant supplementation strengthens immune function, reduces inflammation, improves reproductive performance, enhances milk quality, minimizes tissue damage and increases resistance to infectious and metabolic diseases in livestock.

Vitamins

Vitamins are essential micronutrients that regulate metabolism, immunity, growth, reproduction and tissue repair. Vitamins A, D, E, C and B-complex play critical roles in maintaining epithelial integrity, enhancing immune responses, improving antioxidant defense, promoting bone development and reducing susceptibility to infectious and nutritional disorders in livestock.

Trace minerals

Trace minerals including zinc, selenium, copper, manganese, iron, chromium and iodine are indispensable for enzyme activity, immune regulation, antioxidant defense, hormone synthesis and reproductive performance. Balanced supplementation improves disease resistance, wound healing, fertility, growth and overall productivity while preventing mineral deficiency-related disorders in animals.

Omega-3 fatty acids

Omega-3 fatty acids, particularly alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), possess strong anti-inflammatory and immunomodulatory properties. They improve immune function, reproductive efficiency, cardiovascular health, and stress tolerance while enhancing the nutritional quality of milk, meat and eggs through healthier fatty acid profiles.

Amino acids

Essential amino acids such as lysine, methionine, threonine, tryptophan and arginine are vital for protein synthesis, immune cell development, enzyme production and tissue repair. Precision amino acid nutrition enhances growth performance, improves feed efficiency,

strengthens immunity, accelerates recovery from illness and reduces nitrogen excretion into the environment.

Phytogenic feed additives

Phytogenic feed additives are plant-derived bioactive compounds including herbs, spices, essential oils and plant extracts that exhibit antimicrobial, antioxidant, anti-inflammatory, and digestive-enhancing properties. They improve gut health, stimulate digestive enzyme secretion, enhance nutrient digestibility, strengthen immunity and reduce dependence on antibiotic growth promoters in livestock.

Probiotics

Probiotics are beneficial live microorganisms that maintain a healthy intestinal microbiota by suppressing pathogenic bacteria and enhancing digestive function. Their supplementation improves nutrient absorption, immune competence, gut integrity, feed efficiency and disease resistance while reducing the incidence of diarrhea, enteric infections and gastrointestinal disorders in livestock.

Yeast cultures

Yeast cultures, particularly *Saccharomyces cerevisiae*, improve rumen fermentation, stabilize ruminal pH, stimulate beneficial microbial growth and enhance fiber digestion. They increase feed intake, nutrient utilization, milk production and growth performance while reducing digestive disturbances, heat stress and metabolic disorders in both ruminants and monogastric animals.

Individual nutrient supplementation reduces disease susceptibility

Individualized nutrient supplementation tailors vitamins, minerals, amino acids, antioxidants, and functional feed additives to the specific requirements of each animal based on age, production stage, genetics, health status and environmental conditions. This precision approach optimizes immune function, prevents nutritional deficiencies, lowers disease susceptibility, improves productivity and supports sustainable livestock management.

Role of omics technologies

Omics technologies have transformed precision animal nutrition by providing a comprehensive understanding of the molecular mechanisms underlying growth, metabolism, immunity, reproduction and disease resistance. The integration of genomics, transcriptomics, proteomics, metabolomics and microbiomics enables scientists to develop personalized

nutritional strategies that optimize animal health, productivity, feed efficiency and environmental sustainability.

Genomics

Genomics is the study of an animal's complete genetic makeup (genome) and its influence on economically important traits. It identifies genes associated with feed efficiency, disease resistance, milk production, growth, fertility and adaptability, enabling the selection of genetically superior animals and the development of precision breeding and nutrition programs.

Selection of genetically superior animals

Genomic selection uses DNA markers and genomic information to identify animals with superior genetic potential for productivity, health, feed conversion efficiency, reproductive performance and resilience to environmental stress. Selecting such animals enhances breeding efficiency, accelerates genetic improvement and supports precision nutrition tailored to their specific genetic requirements.

Transcriptomics

Transcriptomics examines the complete set of RNA transcripts produced by genes under different physiological, nutritional and environmental conditions. It reveals how nutrients regulate gene activity, helping researchers understand the molecular responses to dietary interventions and identify nutritional strategies that improve immunity, metabolism, growth, and overall animal performance.

Understanding gene expression

Gene expression studies determine when and how genes are activated or suppressed in response to nutrients, stress, disease, or environmental changes. Understanding these regulatory mechanisms enables nutritionists to formulate diets that positively influence metabolic pathways, enhance immune function, improve production efficiency and reduce susceptibility to diseases.

Proteomics

Proteomics is the large-scale study of proteins, which are the functional molecules responsible for most biological processes within the body. It identifies changes in protein expression, structure, and function associated with nutrition, health and disease, providing valuable biomarkers for assessing physiological status and nutritional adequacy.

Identifying functional proteins

Functional proteins regulate growth, immunity, enzyme activity, hormone signaling, tissue repair, and nutrient metabolism. Proteomic analyses identify proteins involved in these biological processes, enabling the development of targeted nutritional interventions that improve animal health, productivity, reproductive performance and resistance to infectious and metabolic diseases.

Metabolomics

Metabolomics investigates small molecules (metabolites) produced during cellular metabolism, providing a real-time snapshot of an animal's physiological and nutritional status. It helps identify metabolic disturbances, nutrient deficiencies, energy imbalances and disease biomarkers, supporting early diagnosis and precision nutritional management for improved health and production.

Assessing metabolic pathways

Metabolic pathway analysis evaluates how nutrients are converted into energy, proteins, lipids and other essential compounds within the body. Understanding these biochemical pathways enables nutritionists to optimize dietary formulations, improve nutrient utilization, reduce metabolic disorders and enhance production efficiency under different physiological conditions.

Microbiomics

Microbiomics is the study of microbial communities inhabiting the gastrointestinal tract and their interactions with the host animal. These microorganisms play vital roles in digestion, nutrient absorption, immune regulation, vitamin synthesis and disease resistance. Manipulating gut microbiota through nutrition improves feed efficiency, health, and overall animal performance.

Optimizing gut microbial ecology

A balanced gut microbial ecosystem promotes efficient fermentation, nutrient digestion, pathogen inhibition, immune modulation, and improved intestinal integrity. Precision nutritional approaches involving probiotics, prebiotics, synbiotics, phytogenic compounds, and dietary fiber help maintain beneficial microbial populations, enhancing digestive efficiency, disease resistance, and livestock productivity.

The integration of genomics, transcriptomics, proteomics, metabolomics, and microbiomics provides a holistic understanding of the interactions between genes, proteins,

metabolites, microorganisms and nutrients. This systems biology approach enables highly individualized nutritional interventions tailored to an animal's genetic profile, physiological status, metabolic needs and gut microbiome, thereby maximizing health, feed efficiency, productivity and sustainability in modern livestock production.

Benefits of personalized nutrition

Major advantages include:

Improved feed conversion efficiency

Reduced feed cost

Higher milk production

Faster growth

Better reproductive efficiency

Improved immune competence

Lower mortality

Reduced disease incidence

Enhanced animal welfare

Better product quality

Lower environmental pollution

Reduced methane emission

Improved profitability

Benefits of precision livestock health

Precision livestock health offers:

Early disease diagnosis

Reduced veterinary expenses

Lower antimicrobial use

Better vaccination planning

Improved biosecurity

Continuous animal monitoring

Real-time decision making

Reduced labor requirements

Higher productivity

Better welfare compliance

Environmental sustainability

Precision nutrition significantly reduces nutrient losses. Better nutrient utilization leads to:

Lower nitrogen excretion

Reduced phosphorus pollution

Reduced methane production

Lower ammonia emissions

Better manure management

Consequently, livestock farming becomes more climate-friendly.

Economic advantages

Farmers benefit through:

Lower feed wastage

Reduced medicine costs

Improved production efficiency

Reduced mortality

Better reproductive performance

Higher farm income

Improved return on investment

Although the initial investment in digital technologies may be substantial, long-term economic gains often outweigh the costs.

Challenges

Several obstacles still limit widespread adoption:

High installation cost

Limited internet connectivity in rural areas

Data management complexity

Lack of skilled manpower

Integration of multiple technologies

Data privacy concerns

Sensor maintenance

Small farm affordability

Standardization issues

Farmer awareness and training

Developing countries require affordable, user-friendly precision livestock technologies tailored to local production systems.

Future prospects

The future of personalized nutrition and precision livestock health is highly promising. Emerging innovations include:

AI-driven autonomous farms
Digital twins for individual animals
Blockchain-based traceability
Nanotechnology-based nutrient delivery
Gene editing combined with precision feeding
Smart robotic feeding systems
Drone-assisted pasture monitoring
Real-time microbiome diagnostics
Precision methane mitigation strategies
Cloud-based farm management platforms
Smartphone-based livestock health applications
Integration of satellite data with grazing management

These technologies will make livestock production increasingly predictive, automated, sustainable, and resilient to climate change.

Challenges and opportunities

The convergence of personalized nutrition, AI, IoT, biosensors, robotics and omics sciences presents unprecedented opportunities for livestock producers. Governments, research institutions, universities, and the livestock industry must work together to develop affordable precision farming tools, strengthen digital infrastructure and train farmers in technology adoption. Public–private partnerships, supportive policies and investment in innovation will accelerate the transition toward climate-smart, welfare-oriented, and economically viable livestock systems.

Conclusion

Personalized nutrition and precision livestock health represent a paradigm shift from generalized herd management to individualized, evidence-based animal care. By integrating nutrition, genomics, microbiome science, artificial intelligence, wearable sensors and real-time

health monitoring, farmers can optimize feed efficiency, improve productivity, enhance animal welfare, reduce disease incidence and minimize environmental impacts. Although challenges related to cost, infrastructure and technical expertise remain, rapid technological advancements are making precision livestock farming increasingly practical and accessible. As digital agriculture continues to evolve, personalized nutrition and precision livestock health will become central pillars of sustainable, profitable and climate-resilient livestock production systems.

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DIGITAL TWIN TECHNOLOGY IN GRAIN STORAGE

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Introduction

The increasing global demand for food, coupled with significant post-harvest losses, has intensified the need for advanced grain storage technologies that ensure quality preservation, minimize economic losses, and enhance food security. Cereals such as wheat, rice, maize, barley, sorghum, and pulses are stored for extended periods to maintain year-round availability and stabilize market supply. However, improper storage conditions often result in quantitative and qualitative losses due to insect infestation, fungal growth, moisture migration, grain respiration, temperature fluctuations, rodents, and microbial contamination. According to the Food and Agriculture Organization (FAO), post-harvest losses in cereals can range from 10% to 30% in developing countries, significantly affecting food availability and farmers' income. Conventional grain storage management largely depends on periodic manual inspection and sampling, which may fail to detect localized spoilage or quality deterioration in the early stages. Consequently, there is a growing demand for intelligent storage systems capable of continuously monitoring grain conditions and providing timely interventions.

Digital Twin Technology has emerged as one of the most promising innovations for addressing these challenges. A digital twin is a dynamic virtual representation of a physical grain storage system that continuously updates itself using real-time operational data collected from sensors and monitoring devices. Unlike traditional computer models that remain static, digital twins evolve continuously by synchronizing with the physical storage environment throughout the storage period. This technology combines Artificial Intelligence (AI), the Internet of Things (IoT), cloud computing, big data analytics, simulation models, and predictive algorithms to

create a comprehensive digital replica of grain storage facilities. The digital twin continuously analyzes environmental conditions, predicts future quality changes, identifies potential risks, and supports intelligent decision-making for grain storage management.

The concept of digital twins originated in aerospace engineering but has rapidly expanded into manufacturing, healthcare, smart cities, energy systems, and precision agriculture. In grain storage, digital twins enable operators to visualize internal storage conditions that are otherwise inaccessible, such as temperature gradients within the grain bulk, moisture migration patterns, oxygen depletion, carbon dioxide accumulation, and localized insect activity. By continuously comparing simulated behavior with actual sensor measurements, digital twins provide an accurate understanding of grain quality evolution and facilitate proactive rather than reactive management.

Concept and Architecture of Digital Twin Systems

A digital twin system consists of two interconnected entities: the physical grain storage facility and its virtual counterpart. The physical system includes storage structures such as metal silos, concrete silos, warehouses, hermetic bags, or grain bins equipped with multiple sensing devices. The virtual system is a computational model that mirrors the physical system by continuously receiving and processing sensor data. The communication between these two systems is established through IoT networks, cloud platforms, and wireless communication protocols such as LoRaWAN, NB-IoT, Wi-Fi, ZigBee, Bluetooth, and 5G technologies.

The architecture of a digital twin for grain storage generally comprises five interconnected layers. The first layer consists of the physical storage infrastructure, including grain bins, aeration systems, ventilation equipment, conveyors, elevators, and environmental sensors. The second layer is the data acquisition system, where sensors continuously monitor grain temperature, moisture content, relative humidity, oxygen concentration, carbon dioxide concentration, grain level, airflow velocity, vibration, and insect activity.

The third layer is the communication network responsible for transmitting collected data to centralized cloud servers or edge computing devices. The fourth layer includes data processing and analytical modules that apply artificial intelligence, machine learning, mathematical modeling, and computational fluid dynamics (CFD) simulations to interpret sensor information. Finally, the fifth layer comprises visualization dashboards and decision support systems that

provide operators with real-time information, predictive analytics, alerts, and recommended management actions.

The continuous interaction among these layers enables the digital twin to represent the current state of the stored grain accurately while simultaneously predicting future storage conditions under various environmental scenarios. Consequently, storage managers can optimize operational decisions before quality deterioration becomes irreversible.

Working Principle of Digital Twin Technology

The operation of a digital twin begins with continuous monitoring of storage conditions using distributed IoT sensors strategically installed throughout the grain storage structure. Temperature sensors positioned at different depths within the grain bulk measure thermal variations that may indicate insect infestation or fungal growth. Moisture sensors determine localized changes in grain moisture content, while relative humidity sensors monitor ambient storage conditions. Gas sensors measure oxygen depletion and carbon dioxide accumulation resulting from grain respiration and microbial activity. Additional sensors may detect vibration, grain movement, airflow, and structural integrity of storage facilities.

The collected sensor data are transmitted to cloud-based servers where artificial intelligence algorithms preprocess, validate, and integrate information from multiple sources. Machine learning models compare real-time observations with historical storage datasets, enabling prediction of future temperature changes, moisture migration, insect population dynamics, fungal development, and grain quality deterioration. Computational fluid dynamics models simulate airflow patterns and heat transfer within the storage structure, while digital twin simulations estimate the effectiveness of aeration, ventilation, or fumigation strategies before implementation.

When the system detects abnormal storage conditions, the digital twin immediately generates warnings and recommends corrective actions. For example, localized temperature increases caused by insect respiration can be identified several days before visible spoilage occurs. Similarly, moisture migration resulting from seasonal temperature fluctuations can be predicted and corrected through optimized aeration scheduling. The digital twin continuously updates its predictions as new sensor information becomes available, thereby maintaining an accurate representation of grain quality throughout the storage period.

Role of Artificial Intelligence in Digital Twin Systems

Artificial Intelligence forms the core intelligence of digital twin technology by enabling automated learning, prediction, optimization, and decision-making. Machine learning algorithms analyze large quantities of sensor data collected over multiple storage seasons to establish relationships between environmental variables and grain quality changes. Artificial Neural Networks can accurately predict moisture migration, respiration rate, fungal growth, and insect infestation under different storage conditions. Deep learning algorithms improve the accuracy of image-based grain inspection systems capable of detecting discoloration, mold development, insect damage, and broken kernels.

Predictive analytics enables digital twins to estimate the remaining safe storage life of grain based on current storage conditions. Instead of relying solely on periodic laboratory analysis, AI continuously evaluates grain quality indicators and forecasts future deterioration. Reinforcement learning algorithms can further optimize aeration schedules by learning from previous storage cycles, minimizing energy consumption while maintaining grain quality. Explainable Artificial Intelligence (XAI) is also becoming increasingly important because it allows operators to understand why specific management recommendations are generated, thereby increasing confidence in automated decision-making systems.

Applications of Digital Twin Technology in Grain Storage

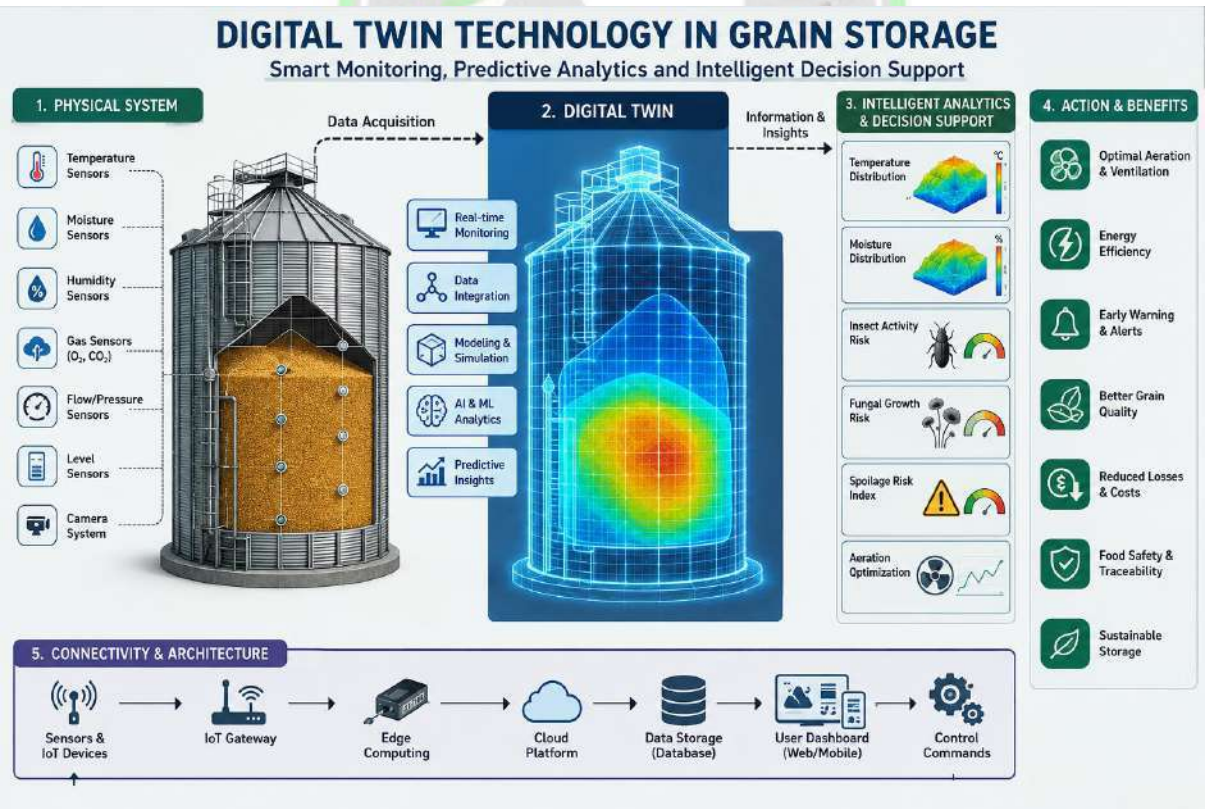
Digital twins have numerous applications throughout grain storage management. Real-time environmental monitoring ensures continuous surveillance of grain quality and storage conditions without manual intervention. Hotspot detection enables early identification of insect infestation or microbial growth before extensive spoilage occurs. Moisture migration modeling predicts condensation zones where mold development is likely, allowing preventive aeration or grain turning. Digital twins are increasingly employed for intelligent aeration management. Instead of operating aeration fans according to fixed schedules, AI algorithms analyze weather forecasts, grain temperature, moisture gradients, and airflow characteristics to determine the most energy-efficient operating conditions. This reduces electricity consumption while maintaining safe storage conditions.

Shelf-life prediction represents another important application. By integrating physicochemical data, microbial growth models, and environmental monitoring, digital twins estimate the remaining storage life of grain with greater accuracy than conventional empirical

methods. Storage managers can therefore prioritize inventory rotation, optimize marketing decisions, and reduce food losses. Digital twins also improve predictive maintenance of storage equipment. Fans, conveyors, elevators, dryers, and ventilation systems are continuously monitored for vibration, temperature, electrical current, and operational efficiency. AI algorithms identify early signs of equipment failure and schedule maintenance before breakdowns occur, thereby minimizing operational interruptions.

Integration with Smart Grain Storage Systems

Modern grain storage facilities increasingly integrate digital twins with automated aeration systems, robotic inspection devices, drones, autonomous guided vehicles (AGVs), and blockchain platforms. Drones equipped with thermal imaging cameras inspect warehouse roofs and detect heat leakage, while robotic inspection systems monitor confined storage environments without exposing personnel to hazardous conditions. Blockchain technology securely records storage history, environmental conditions, and quality data throughout the supply chain, ensuring complete traceability from farm to consumer.



The integration of digital twins with edge computing further improves system responsiveness by processing sensor data locally rather than relying entirely on cloud servers. This reduces communication delays and enables immediate corrective actions during emergency situations.

Future Research Directions

Future digital twin research will focus on integrating multi-physics simulation models capable of simultaneously predicting heat transfer, moisture migration, biological respiration, insect population dynamics, and fungal growth within stored grain. Advances in hyperspectral imaging, wireless sensor networks, quantum computing, generative AI, and digital twins driven by large language models will further improve predictive accuracy and autonomous decision-making. Researchers are also exploring self-learning digital twins that automatically adapt their predictive models according to changing climatic conditions, grain varieties, and storage infrastructure.

Another promising area involves coupling digital twins with climate-resilient storage management systems capable of predicting the influence of global warming on grain preservation. Such intelligent systems will support sustainable agriculture by minimizing post-harvest losses, improving food security, reducing greenhouse gas emissions associated with spoilage, and optimizing energy consumption.

Conclusion

Digital twin technology represents a paradigm shift in grain storage management by transforming conventional storage facilities into intelligent cyber-physical systems capable of real-time monitoring, predictive analytics, and autonomous decision-making. Through the integration of IoT sensors, artificial intelligence, cloud computing, simulation models, and advanced communication networks, digital twins provide unprecedented visibility into grain storage conditions and enable proactive interventions that preserve grain quality, reduce post-harvest losses, and improve operational efficiency. Although challenges related to implementation cost, data management, cybersecurity, and system integration remain, continuous technological advancements are expected to accelerate widespread adoption. As agriculture moves toward digital transformation and Industry 5.0, digital twin technology will become a cornerstone of sustainable, resilient, and intelligent grain storage systems.

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REGENERATIVE VEGETABLE FARMING: RESTORING SOIL HEALTH NATURALLY

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Introduction

Vegetable farming plays a vital role in ensuring food and nutritional security while providing higher income to farmers. However, intensive cultivation, excessive tillage, indiscriminate use of chemical fertilizers and pesticides, and poor soil management have gradually reduced soil fertility and productivity in many vegetable-growing regions. Declining organic matter, soil erosion, nutrient imbalance, and reduced microbial diversity have become major concerns affecting sustainable vegetable production. In this context, regenerative vegetable farming has emerged as a promising approach that restores soil health, conserves natural resources, enhances biodiversity, and improves farm resilience. Rather than simply sustaining existing production systems, regenerative agriculture focuses on rebuilding soil ecosystems to support long-term productivity and environmental sustainability.

What is Regenerative Vegetable Farming?

Regenerative vegetable farming is a holistic production system that aims to improve soil health while producing healthy and nutritious vegetables. It integrates ecological principles with scientific crop management practices to regenerate soil organic matter, increase biological activity, improve water retention, and reduce dependence on synthetic inputs. Unlike conventional farming, which often emphasizes maximum production, regenerative farming seeks to restore the natural functions of soil, making it more productive and resilient over time.

Why is Soil Health Important?

Healthy soil is the foundation of successful vegetable cultivation. It provides essential nutrients, stores water, supports beneficial microorganisms, and creates a favourable environment for root growth. Soils rich in organic matter have better structure, improved aeration, and greater nutrient-holding capacity. Healthy soils also reduce erosion, improve nutrient-use efficiency, and help crops withstand drought, heat, and other environmental stresses. Therefore, restoring soil health is essential for achieving sustainable vegetable production.

Principles of Regenerative Vegetable Farming

Regenerative farming is based on several key principles that work together to rebuild soil fertility.

1. Minimizing Soil Disturbance

Frequent and deep tillage damages soil structure, accelerates organic matter decomposition, and disrupts beneficial soil organisms. Reduced or minimum tillage helps preserve soil aggregates, enhances earthworm activity, and protects soil biodiversity.

2. Keeping the Soil Covered

Maintaining continuous soil cover through crop residues, mulch, or cover crops protects the soil from erosion, conserves moisture, suppresses weeds, and moderates soil temperature. Organic mulches such as straw, dry leaves, sugarcane trash, and compost are particularly beneficial in vegetable fields.

3. Increasing Crop Diversity

Growing different vegetable crops in rotation and incorporating legumes improves nutrient cycling, breaks pest and disease cycles, and enhances soil microbial diversity. Crop diversification also reduces production risks and improves overall farm sustainability.

4. Maintaining Living Roots

Keeping living plants in the soil for most of the year supports beneficial microorganisms by supplying root exudates that stimulate biological activity. Cover crops and green manures help maintain continuous root systems between vegetable crops.

5. Enhancing Soil Organic Matter

Regular addition of farmyard manure, compost, vermicompost, green manure, crop residues, and biochar increases soil organic carbon and improves soil fertility. Organic matter

enhances nutrient availability, water retention, and microbial activity, resulting in healthier vegetable crops.

Key Practices in Regenerative Vegetable Farming

Several practical approaches help farmers adopt regenerative farming successfully.

- Application of compost and well-decomposed farmyard manure.
- Cultivation of green manure and cover crops during fallow periods.
- Crop rotation involving legumes and diverse vegetable crops.
- Mulching to conserve moisture and reduce weed growth.
- Use of biofertilizers and microbial inoculants.
- Adoption of drip irrigation and fertigation for efficient water use.
- Recycling crop residues instead of burning them.
- Integration of livestock for efficient nutrient recycling where feasible.
- Planting flowering border plants to attract pollinators and beneficial insects.

These practices improve soil fertility while reducing production costs over time.

Role of Beneficial Soil Microorganisms

Soil contains billions of beneficial microorganisms that contribute to nutrient cycling, decomposition of organic matter, nitrogen fixation, phosphorus solubilization, and disease suppression. Biofertilizers containing species of *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate-solubilizing bacteria, and arbuscular mycorrhizal fungi enhance nutrient availability and improve plant growth. Increasing microbial diversity is one of the primary goals of regenerative farming.

Benefits of Regenerative Vegetable Farming

Regenerative vegetable farming provides multiple agronomic, environmental, and economic benefits.

- Improves soil fertility and organic carbon content.
- Enhances water infiltration and moisture-holding capacity.
- Reduces soil erosion and nutrient losses.
- Promotes beneficial microorganisms and earthworms.
- Improves nutrient-use efficiency.
- Reduces dependence on synthetic fertilizers and pesticides.
- Produces healthier and better-quality vegetables.

- Increases resilience to drought and climate variability.
- Supports biodiversity and ecosystem services.
- Improves long-term farm profitability through sustainable production.

Challenges in Adoption

Despite its advantages, adoption of regenerative farming is still limited in many vegetable-growing areas. Farmers often face challenges such as limited awareness, insufficient availability of organic inputs, initial reduction in yields during the transition period, increased labour requirements, and lack of premium markets for sustainably produced vegetables. Technical guidance, training programmes, and supportive government policies are essential to encourage wider adoption.

Future Prospects

Growing consumer demand for safe and sustainably produced food is creating new opportunities for regenerative vegetable farming. Advances in soil biology, composting technologies, precision irrigation, digital soil monitoring, and climate-smart agriculture are making regenerative practices more effective and easier to implement. Agricultural universities, research institutions, extension agencies, and farmer-producer organizations are increasingly promoting regenerative approaches to improve soil health and climate resilience. Integration of regenerative farming with protected cultivation, organic production, and precision agriculture is expected to further enhance the sustainability of vegetable production systems.

Conclusion

Regenerative vegetable farming is an effective pathway for restoring soil health while ensuring sustainable and profitable vegetable production. By improving soil organic matter, enhancing biodiversity, conserving natural resources, and reducing dependence on synthetic inputs, regenerative agriculture strengthens the resilience of farming systems against climate change and environmental degradation. Adoption of practices such as crop rotation, mulching, compost application, cover cropping, and efficient water management can significantly improve soil quality and long-term productivity. Restoring soil is not only an investment in the current crop but also a commitment to future generations, ensuring healthy soils, healthy vegetables, healthy farmers, and a healthier planet.

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ROLE OF QTL MAPPING AND MAPPING POPULATION IN CROP IMPROVEMENT

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Introduction

The continuous increase in global population, shrinking cultivable land resources and changing climatic conditions have created a tremendous challenge for agriculture to produce more food with limited resources. Improvement of crop varieties with enhanced yield potential, quality traits and resistance to biotic and abiotic stresses has therefore become a major objective of modern plant breeding. However, many economically important traits such as grain yield, drought tolerance, salinity tolerance, disease resistance, nutrient-use efficiency and quality parameters are quantitative in nature. These traits are controlled by multiple genes and are strongly influenced by environmental conditions, making their improvement through conventional breeding methods difficult and time-consuming.

The development of molecular marker technologies has revolutionized plant breeding by enabling breeders to identify genomic regions associated with quantitative traits. Such genomic regions are known as Quantitative Trait Loci (QTLs). QTL mapping is a powerful molecular genetic technique used to locate these regions within the genome and determine their contribution to phenotypic variation. The identification of QTLs allows breeders to understand

the genetic basis of complex traits and facilitates marker-assisted selection (MAS), thereby accelerating crop improvement programmes.

QTL mapping integrates phenotypic observations with molecular marker information to establish associations between genetic markers and quantitative traits. Through this approach, breeders can identify chromosome regions controlling important agricultural characteristics and utilize this information for developing superior crop varieties. Over the past few decades, QTL mapping has become an essential tool in plant genetics, genomics and breeding programmes.

DEFINITON

A QTL {Quantitative Trait Locus (Loci)} term is coined by Gelderman (1919) and is defined as "a region of the genome or locus of gene that is associated with an effect on a quantitative trait". A quantitative trait which is controlled by several genes, all the genes having small effects, additive in nature and is affected by environment. The phenotypes of quantitative trait are typically depicted by a bell curve.

- The identification of QTLs helps plant breeders develop improved crop varieties through **Marker Assisted Selection (MAS)**, genomic selection and gene pyramiding. QTL mapping has become an indispensable tool in modern crop improvement programmes.

Examples of quantitative traits include:

*Grain yield * Number of tillers

*Root length * Drought tolerance

Historical Development of QTL Mapping

The concept of quantitative inheritance was first proposed by the pioneering work of Gregor Mendel and later expanded by Ronald A. Fisher in 1918. Fisher demonstrated that continuous variation observed in quantitative traits could be explained by the combined effects of multiple Mendelian genes.

The practical identification of QTLs became possible only after the development of molecular markers in the 1980s. The introduction of Restriction Fragment Length Polymorphism (RFLP) markers enabled researchers to construct genetic linkage maps and identify chromosomal regions associated with important traits.

Subsequently, advances in DNA marker technologies such as RAPD, AFLP, SSR and SNP markers greatly enhanced the accuracy and efficiency of QTL mapping. Today, high-

throughput sequencing technologies and advanced bioinformatics tools have further improved QTL detection and analysis.

Characteristics of QTLs

The important characteristics of QTLs are:

1. QTLs govern quantitative traits.
2. They may contain one or several genes.
3. Their effects can be major or minor.
4. They interact with environmental factors.
5. Multiple QTLs may influence the same trait.
6. A single QTL may affect multiple traits (pleiotropy).
7. QTL effects may vary across environments.

Because quantitative traits are controlled by several QTLs, identification of all contributing loci is often challenging.

Criteria to select best targeted QTL

Size of effect

The distance between the marker and gene of interest should be negligible in order to avoid the linkage drags which mean selection of undesirable traits along with gene for specific trait.

Environmental interactions

Most of gene identified as quantitative trait is highly influenced by environments which are polygenic in nature shows cumulative behaviour under varying environment.

QTL epistasis

It is mainly the effect of linked marker over the gene of interest whether its shows hypostatic (being masked) or hyperstatic (shows masking) behaviour under influenced environment.

QTL mapping, principle, requirements and objectives of QTL mapping

QTL mapping is process of locating genes with effects on quantitative traits using molecular markers. A major breakthrough in the characterization of quantitative traits that created opportunities to select for QTLs was initiated by the development of DNA (or molecular) markers in the 1980s.

Principle

The basic Principle is the co- segregation of marker locus and QTL together. Cosegregation is due to linkage between marker and QTL.QTL analysis depends on linkage

disequilibrium which is the non-random association of alleles at different loci in a given population.

Requirements

The requirements of QTL mapping are mapping population, saturated linkage map, phenotypic screening and statistical package. Ideally markers should be <5 cm from a gene or QTL. Using a pair of flanking markers can greatly improve reliability but increases time and cost.

The QTL mapping strategies are choose divergent parents, Screen for marker loci polymorphism create mapping populations for generating saturated linkage map, phenotype screening and Contrast the mean of the marker attached and pair of gene of interest at every marker locus. The main objectives of this study to offer direct mean to investigate the number of genes influencing the trait. The location of the gene that affect traits of interest, to know the effect of genes on variation of the trait. Also to carry out study on linkage between genes of interest.

Type of mapping population used in QTL mapping

Non-random mating population is required for QTL mapping. It is result of mutation, natural selection, random drift etc. Size of mapping population used in QTL mapping In large sample size, QTL with small effects cannot be observed but QTL with large effects can be observed. In small sample size also, QTL with small effects cannot be observed but QTL with major effects can be observed.

Type and number of markers in linkage maps

If there is more number of markers used, amount of precision of estimation of both QTL position and effect will be more. Here, co-dominant marker shows three types of genetic difference while dominant marker shows two types of genetic difference. So, codominant marker provides more information than dominant marker regarding recombination with in marker intervals.

Phenotyping of mapping population and sample size

The target quantitative traits are measured as precisely as possible and limited amounts of missing data can be tolerated. The power to resolve the QTL location is confined first by sample size and then by genetic marker coverage of the genome. Generally, the number of individuals in a sample might appear to be large but missing data or skewed allele frequencies in

the population cause the effective sample size to diminish, thus sacrificing the statistical power. It is must to sacrifice population size in favour of data quality and this means that only major QTL (with relatively large effect) can be detected. QTL It is also preferred to measure the target trait(s) in experiments conducted in multiple (and appropriate) locations to have a better understanding of the QTL x environment interaction,

Mapping populations used in QTL mapping

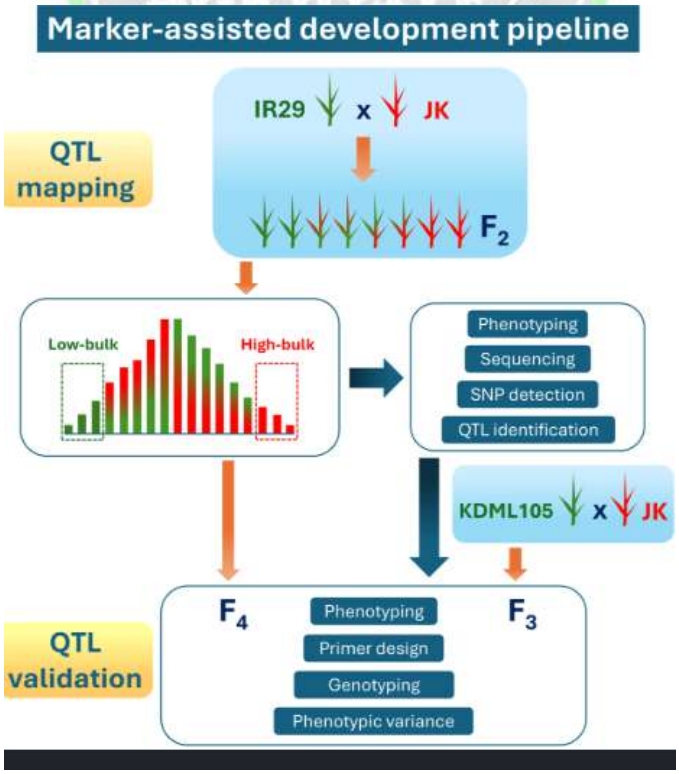
Various types of mapping population may be produced from the heterozygous **F1hybrids:** Double Haploid Lines (DHLs) Plants are regenerated from pollen (which is haploid) of the F1 plants and treated to restore diploid condition in which every locus is homozygous. Since the pollen population has been generated by meiosis, the DHLs represent a direct sample of the segregating gametes.

Backcross (BC) population: The F1 plants are backcrossed to one of the parents.

F2 population: F1 plants are selfed.

F2:3/F2:4 lines

F3/4 plants tracing back to the same F2 plant, also called F2 families parents. F2 population F1 plants are selfed. F2:3/F2:4 lines F3/4 plants tracing back to the same F2 plant, also called F2 families



MAGIC Population

MAGIC (Multiparent Advanced Generation Intercross) populations are developed from multiple parental lines. High genetic diversity, Increased recombination and Improved mapping resolution are some advantages.

Recombinant Inbred Lines (RILs)

RILs are developed by repeated selfing of F_2 individuals for several generations until near-complete homozygosity is achieved. Permanent mapping population, Suitable for multilocation testing, High mapping precision are some advantages. But Requires several generations for development.

Methods for QTL mapping (Li and Wang, 2007)

Single marker approach (SMA) It is also called as Single factor analysis of variance or single point analysis. It is widely used method for quick scanning of whole genome to determine best QTLs. It is used for each marker locus which is free from other loci. This technique is unable to determine QTL position.

Some major limitations of this approach

The method cannot determine whether the markers are associated with one or more QTLs. Chance of QTL detection decreases with distance between marker and QTL. An effect of QTL is underestimated of confounding with recombination frequencies. Its accuracy is less compare to other methods

Simple interval mapping (SIM)

SIM was first proposed by Lander and Botstein (1989) based on linkage map and also called as two marker approach. QTL is determined in interval generated between two markers at various points. It gives more accurate results compare to single marker approach but less than CIM and MIM technique. In this technique, likelihood ratio test is used to determine every QTL position in interval created by both markers. SIM is mostly preferred as it can be easily performed through statistical packages such as MAPMAKER (Lander et al., 1987) and JOIN MAP (Stam, 1993). Lander and Botstein (1989) developed formulae for significance levels appropriate for interval mapping when the genome size, number of chromosomes, number of marker intervals, and the overall false positive rate desired are given.

Composite interval mapping (CIM)

CIM techniques are developed by Zeng, 1994.It is used to minimize effects of various linked QTLs. It is based on one QTL and other markers used as covariates. This technique gives more precise results and used to exclude bias due to another QTLs (nontarget QTLs) linked to target QTL. It used to fit the parameters for a single QTL in one interval. The partial regression coefficient is used to determine genetic variance due to non-target QTLs. The merits of CIM are as follows: Mapping of multiple QTLs can be carried out by the search in one dimension. By using linked markers as covariates, the test is not affected by QTL out of region, thereby increasing the precision of QTL mapping and by eliminating as much as the genetic variance produced by other QTL, the residual variance is reduced, thereby the efficiency of determination of QTL is increased.

CIM is more efficient than SIM, but not widely used in QTL mapping as in SIM.

Multiple intervals mapping (MIM)

It is recent method of QTL Mapping techniques are developed by Jansen and Stam (1994). Multiple Interval Mapping (MIM) is the extension of interval mapping to multiple QTLs, just as multiple regression extends analysis of variance. It is used to map multiple QTLs. This method is potential tool for detection of QTL X QTL interaction. Inclusive composite interval mapping (ICIM) An approach to QTL (quantitative trait locus) mapping for populations derived from biparental crosses. QTL mapping is based on genetic linkage map and phenotypic data. To locate individual genetic factors on chromosomes and to estimate their genetic effects. ICIM has been successfully used in Wild and cultivated soybeans in mapping conserved salt tolerance QTL Rice mapping tiller angle QTL and grain length QTL Wheat mapping flour and noodle, colour components and yellow pigment content and adult-plant resistance to stripe rust QTL. ICIM extended to map Maize Nested Association Mapping design recently proposed by the Buckler laboratory at Cornell University.

Statistical method for QTL mapping T-test is used for determination of significant differences between various genotypes groups or marker classes. Linear regression Analysis is used for determination of position as well as effect at QTL Multiple regression Analysis is used for determination of additive as well as dominance effect at QTL simultaneously. Two commonly used mapping functions that convert recombination frequency into centimorgan (cM) distance are Kosambi mapping function, which assumes that recombination events influence the

occurrence of adjacent recombination events, and Haldane mapping function, which assumes no interference between crossover events. Linkage between markers is usually calculated with an odds ratio (i.e., the ratio of linkage versus no linkage). This ratio is more conveniently expressed as the logarithm of the ratio and is called a logarithm of odds (LOD) value or LOD score (Risch, 1992). LOD values of >3 are typically used to construct linkage maps. L OD values may be lowered in order to detect linkage over a greater distance. (Collard et al., 2005) Probability of the data occurring with a QTL Log of odds (LOD score) = ---------- Probability of the data occurring with no QTL Positive LOD scores favor the presence of linkage, whereas negative LOD scores indicate that linkage is less likely.

Steps Involved in QTL Mapping

QTL mapping involves a series of experimental and analytical procedures designed to identify genomic regions associated with quantitative traits. The accuracy of QTL detection depends upon careful execution of each step.

The major steps involved in QTL mapping are:

1. Selection of parents.
2. Development of mapping population.
3. Phenotypic evaluation.
4. DNA extraction and genotyping.
5. Construction of linkage map.
6. Statistical analysis.
7. Identification and characterization of QTLs.

Important QTLs Identified in Major Crops

The identification of QTLs associated with economically important traits has significantly contributed to crop improvement programmes. Several QTLs governing drought tolerance, salinity tolerance, disease resistance, yield components and quality traits have been identified in major crops.

Crop	QTL	Trait Controlled	Reference
Rice	DRO1	Deep Rooting	Uga et al., 2013
Rice	Saltol	Salinity Tolerance	Singh et al., 2018
Rice	SUB1	Submergence Tolerance	Septiningsih et al., 2015

Crop	QTL	Trait Controlled	Reference
Rice	qDTY12.1	Drought Tolerance	Bernier et al., 2007
Rice	qDTY3.1	Drought Tolerance	Venuprasad et al., 2009
Wheat	QYr	Rust Resistance	Gupta et al., 2010
Wheat	QFhb1	Fusarium Resistance	Buerstmayr et al., 2009
Maize	qHT	Plant Height	Flint-Garcia et al., 2005
Maize	qGY	Grain Yield	Xiao et al., 2017
Soybean	qSCN	Nematode Resistance	Concibido et al., 2004

Application of QTL Mapping

MAS, MABC and MARS results in indirect selection of QTLs which requires less time, labour, resource and space.

Germplasm screening of diversified materials for biotic and abiotic stresses can done in early stage like seedling stage. No need of pathogen inoculation and disease development in case of disease resistance trait. Reduction in Negative selection means linkage drag during introgression of QTL The genetic integration of agronomical, physiological and gene expression related traits (the scientific value of QTL analysis) Recently at IARI, New Delhi validation of QTLs for maize conferring downy mildew resistance (George et al.,2003;Nair et al.,2005)

Limitation of QTL Mapping

High cost

Require sophistication and technical expertise

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AI TOOLS AND TECHNIQUES IN AGRICULTURE PRACTICES

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Abstract

Nowadays AI plays major role in everyday life of human beings. It causes both positive and negative impact in our life. In agriculuture, AI can be used more efficiently to increase production and reduce the input without reducing the yield, Even sometimes it increases the yield. AI helps farmer to overcome yield loss caused by climate change, over use of fertilizers . As the human population increases day by day, it puts burden on food production. Which, In turn, grows in chemical usage. Due to lack of awareness among farmers, They use more fertilizers on field to increase their yield which causes water pollution like eutrophication, Soil degradation and emission of Greenhouse gases. By creating awareness among farmers about AI tools and techniques we can reduce environmental impacts. AI technologies like automated irrigation system, Semi-automated irrigation system and AI tools in reducing fertilizer usage can be used.

Introduction

Artificial Intelligence (AI) is transforming modern agriculture by enabling farmers to make accurate decision on farming practices. AI tools use technologies like sensors, satellite imagery, weather data, drones, and machine learning algorithms to monitor crop, climate, soil

conditions and growth stages of crop in real time. These technologies improves productivity while reducing inappropriate use of water, fertilizer, and pesticides.

AI based automated irrigation systems used to determine the right amount of water required by crop based on soil moisture level, weather forecasts and crop growth stages. Similarly, AI powered fertilizer management tools analyze and gives data on nutrient content present in the soil and nutrient requirements of soil .It also gives correct type, dose of nutrients to be applied to the soil.

AUTOMATIC IRRIGATION SYSTEM

Automatic irrigation system is the use of a device to operate irrigation structures, It uses an Arduino or microcontroller to read soil hydration levels. when soil moisture drops below a set threshold level, the microcontroller triggers a relay module to turn on a water pump, automatically watering the crops until the required moisture is restored.

Automation can be used in a number of ways:

- To start and stop irrigation through supply channel outlets
- To start and stop pumps
- To cut off the flow of water from one irrigation area – either a bay or a section of channel and direct the water to another area.

These changes occur automatically without any direct manual effort, but you may need to spend time preparing the system at the start of the irrigation and maintaining the components so it works properly.

BENEFITS OF AUTOMATIC IRRIGATION

- Reduces labour charges.
- Timely irrigation can be given when needed.
- Maintains the flow rate.
- Accurate cut-off of watering compared to manual checking.
- Reduce runoff of water.

DISADVANTAGES OF AUTOMATIC IRRIGATION SYSTEM

- Cost of purchasing, installing and maintaining the equipment.
- Reliability of irrigation system (due to human error while setting up).
- Increased maintenance of channels and equipment to ensure it is working properly.

SOME OF THE AUTOMATIC IRRIGATION SYSTEMS

- Pneumatic system.
- Portable timer system.
- Timer or Sensor hybrid.
- Supervisory control and Data Acquisition (SCADA).

ARTIFICIAL INTELLIGENCE IN SOIL ANALYSIS

It refers to the use of advanced computational methods to collect, process, and interpret soil data automatically. AI system use machine algorithms, data models and predictive analytics to analyze soil properties and provide recommendation for soil management.

These system collect soil data from various sources such as soil sensors, remote sensing, drones, satellite images, and lab tests. The AI algorithms process this data to identify patterns and relationships between soil properties and crop performances.

For example, AI can analyze soil nutrient levels, moisture content, pH, organic matter, and texture. By these data we can predict soil fertility status and suitable fertilizer applications.

TECHNOLOGIES USED IN SOIL BASED ANALYSYS

Soil sensors

These are important tools used to monitor different soil parameters directly from the field. They are placed in soil and measure factors such as soil moisture, temperature, EC, nutrient levels, pH. Continuous monitoring helps farmers make timely decisions and maintain optimal soil health.

Remote sensing

Remote sensing involves the use of satellite imagery and aerial photographs to observe soil and land conditions over large areas. These images provide information about soil moisture, vegetation health, land degradation, and nutrient status. It helps to detect problems like nutrient deficiencies, soil erosion, and moisture stress.

Drones

Dronrs, also known as unmanned aerial vehicles, are widely used in modern agriculture for detailed monitoring of field. Drones equipped with cameras and sensors capture high resolution images of fields. It helps to identify soil variability, crop stress, and areas with poor soil fertility.

Geographic information system

GIS are used to store, analyze and visualize spatial data related to soil properties .AI can combine with GIS data with predictive models to generate accurate soil fertility maps and support precision farming practices.

APPLICATIONS OF AI IN SOIL ANALYSIS

- Soil nutrient prediction.
- Soil moisture monitoring.
- Soil fertility mapping.
- Soil health assessment.
- Precision agriculture.

ADVANTAGES OF AI IN SOIL ANALYSIS

- Improved accuracy.
- Time efficiency.
- Cost reduction.
- Real-Time monitoring.
- Better decision making.
- Sustainable agriculture.
- Large scale soil monitoring.

Conclusion

Artificial intelligence have transformed modern agriculture by enabling accurate assessment of soil health and fertility. Technologies such as soil sensors, remote sensing, GIS, IoT and digital soil mapping provides reliable information for informed decision making. These tools helps farmers to apply the right amount of fertilizer and water to improve crop productivity, reduce production costs, and minimize environmental impacts.

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NATURAL FARMING: A CLIMATE-RESILIENT APPROACH FOR SUSTAINABLE AGRICULTURE IN THE ERA OF CLIMATE CHANGE

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Abstract

Climate change poses a major threat to global agricultural sustainability, impacting crop productivity, soil fertility, water availability, biodiversity and food security. Factors like rising temperatures and erratic weather patterns exacerbate the vulnerability of agricultural systems. Traditional agriculture, while boosting production during the Green Revolution, has led to environmental harm, necessitating sustainable practices. Natural farming, an agroecological system, promotes ecological processes and minimizes chemical inputs, thereby enhancing soil health, conserving biodiversity and reducing emissions. It may also improve farm profitability, yet faces challenges such as limited scientific validation, yield variability and market barriers. This review discusses natural farming's potential for climate resilience and outlines future research needs for sustainable agriculture.

Keywords: Natural farming, Climate resilience, Sustainable agriculture, Soil health, Biodiversity conservation, Carbon sequestration.

Introduction

Agriculture plays a crucial role in global food security but is increasingly threatened by climate change through rising temperatures, irregular rainfall, extreme weather events and

changing pest and disease patterns. Intensive agricultural practices based on synthetic inputs have enhanced productivity but have also contributed to soil degradation, biodiversity loss and reduced ecosystem resilience. Therefore, sustainable and climate-adaptive farming approaches are essential for future agriculture.

Natural farming offers an ecological pathway by promoting biological resource utilization, soil regeneration and harmony among soil, plants, animals, microorganisms and the environment. Practices such as Jeevamrut, Beejamrut, Ghanjeevamrut, mulching, crop residue recycling, diversified cropping and livestock integration improve soil health, nutrient cycling, water-use efficiency and biodiversity. These practices enhance the ability of farming systems to withstand climate stresses such as drought and extreme rainfall. By reducing dependence on external chemical inputs and strengthening ecosystem functions, natural farming contributes to climate-resilient and sustainable agriculture. Integration of traditional knowledge with modern scientific approaches can further support the development of productive, environmentally responsible and economically viable farming systems under changing climatic conditions.

Climate Change and Global Agriculture

Climate change is a major threat to global agriculture, affecting crop productivity through rising temperatures, changing rainfall patterns, water scarcity and increased frequency of extreme weather events. Elevated temperatures can disrupt seed germination, flowering, pollination and crop development, while irregular rainfall and drought conditions reduce soil moisture availability and crop growth. Excessive rainfall may cause soil erosion, nutrient losses and increased incidence of pests and diseases. Climate variability also alters pest and pathogen distribution, leading to greater dependence on chemical pesticides and increased production costs.

Conventional farming practices, including excessive fertilizer use, intensive tillage and crop residue burning, further contribute to greenhouse gas emissions and environmental degradation. Climate-resilient agriculture aims to maintain productivity while reducing ecological impacts through efficient resource management and sustainable practices. Natural farming supports these goals by improving soil health, enhancing biodiversity, promoting biological nutrient cycling and strengthening the resilience of agricultural ecosystems against climate stresses.

Concept and Principles of Natural Farming

Natural farming is an ecological approach to agriculture that emphasizes the use of natural processes and local biological resources while minimizing reliance on synthetic inputs like fertilizers and pesticides. It is rooted in the understanding that a thriving agricultural ecosystem is capable of maintaining soil fertility, managing pests and ensuring crop productivity through appropriate management. The practice aims to restore the interconnected relationships among soil, microorganisms, plants, animals and the environment, contrasting with conventional agriculture's focus on external inputs for yield maximization. Masanobu Fukuoka, a Japanese farmer and philosopher, popularized natural farming, advocating for minimal soil disturbance, the elimination of synthetic substances, soil cover maintenance and the application of ecological principles. His method illustrates that productivity can be achieved by promoting natural processes rather than increasing external inputs.

In India, natural farming has developed through a combination of indigenous agricultural knowledge and scientific insights into ecological systems. Key practices include *Jeevamrut, Beejamrut, Ghanjeevamrut,* mulching, crop rotation, mixed cropping, intercropping and livestock integration. These practices enhance beneficial microorganisms, improve nutrient cycling, increase soil biological activity and reduce dependency on bought agricultural inputs.

Major Principles of Natural Farming

Biological Soil Fertility Management emphasizes the significance of soil as a living ecosystem rich in microorganisms that aid nutrient transformation and promote plant growth. Natural farming enhances microbial activity using biological formulations derived from farm resources like cow dung, cow urine and plant materials, which increases microbial populations and nutrient availability.

To reduce chemical dependency, natural farming aims to minimize synthetic fertilizers and pesticides, as their excessive use can harm soil microorganisms and diminish environmental quality. The approach supports sustainable practices through biological nutrient management and ecological pest regulation. Soil cover and mulching are vital principles in natural farming, utilizing crop residues, straw and green biomass to maintain soil temperature, conserve moisture, suppress weeds and prevent erosion.

Crop diversification practices like mixed cropping, intercropping and crop rotation enhances ecosystem stability, reduces crop failure risks during climatic stress and supports

beneficial organisms by providing diverse habitats. Integrating livestock into farming systems contributes essential resources for biological inputs and nutrient recycling, creating a closed-loop system where waste is transformed into valuable agricultural resources. Ultimately, natural farming represents a transition from input-intensive practices to a knowledge-based ecological approach, merging traditional insights with modern scientific principles of soil biology and climate resilience.

Soil Health Restoration under Natural Farming

Soil health is a key foundation of sustainable agriculture and climate-resilient farming systems, supporting nutrient cycling, water regulation, carbon storage and microbial diversity. Intensive cultivation, excessive chemical fertilizer use and monocropping have resulted in soil organic matter depletion, reduced microbial activity and deterioration of soil structure. Natural farming helps restore soil quality by promoting biological processes and enhancing organic matter accumulation. Practices such as *Jeevamrut, Ghanjeevamrut*, organic residue recycling and mulching stimulate beneficial microorganisms involved in nutrient transformation, nitrogen fixation, phosphorus solubilization and decomposition. Increased soil organic carbon improves soil structure, water infiltration, moisture retention and resilience against climate stresses such as drought and irregular rainfall.

Natural farming also supports a healthy rhizosphere, where beneficial microbes improve nutrient uptake and suppress soil-borne pathogens through ecological balance. Reduced soil disturbance and continuous organic inputs contribute to long-term soil regeneration, making natural farming an effective approach for maintaining productive, resilient and sustainable agricultural ecosystems.

Carbon Sequestration and Climate Change Mitigation

Natural farming plays an important role in climate change mitigation by reducing greenhouse gas emissions and enhancing carbon sequestration in agricultural ecosystems. It improves soil organic carbon storage through practices such as biomass recycling, crop residue incorporation, mulching, diversified cropping systems and agroforestry. Increased soil organic carbon improves soil structure, microbial activity, nutrient availability and water-holding capacity, thereby enhancing ecosystem stability and crop resilience under climate stress. Reduced dependence on synthetic fertilizers minimizes nitrous oxide emissions and decreases energy consumption associated with chemical input production.

Integration of livestock, on-farm resource utilization and biological nutrient management promotes circular nutrient cycling and sustainable resource use. Natural farming also supports biodiversity conservation and ecological balance by maintaining permanent soil cover and promoting beneficial organisms. However, long-term and multi-location studies are required to quantify its carbon sequestration potential and greenhouse gas reduction capacity under different agro-climatic conditions.

Water Conservation and Drought Resilience

Water availability is a critical factor for agricultural sustainability, particularly under changing climatic conditions characterized by droughts, irregular rainfall and declining groundwater resources. Natural farming enhances water-use efficiency by improving soil structure, increasing organic matter and promoting soil organic carbon accumulation, which improves water infiltration and moisture retention. Practices such as mulching with crop residues, biomass recycling and maintaining soil cover reduce evaporation, regulate soil temperature, suppress weeds and support beneficial microbial activity.

Diversified farming approaches, including mixed cropping, intercropping and agroforestry, optimize water utilization and improve ecosystem stability compared with monocropping systems. Biological inputs such as Jeevamrut and Ghanjeevamrut enhance root development and nutrient availability, helping plants withstand moisture stress and climatic fluctuations. For small and marginal farmers, natural farming provides low-cost strategies to reduce irrigation dependency, minimize production risks and maintain stable yields. Thus, natural farming contributes significantly to the development of water-efficient, climate-resilient and sustainable agricultural systems.

Biodiversity Conservation through Natural Farming

Biodiversity is a fundamental component of sustainable agricultural ecosystems, supporting nutrient cycling, pollination, natural pest regulation and ecological stability. Intensive farming practices, including monocropping, excessive pesticide use and habitat simplification, have contributed to the decline of beneficial organisms and ecosystem functions. Natural farming promotes biodiversity conservation through diversified cropping systems, mixed cropping, intercropping, crop rotation, agroforestry and reduced chemical dependency. These practices enhance the abundance of beneficial insects, pollinators, birds and soil microorganisms, which contribute to ecological balance and improved plant health.

Diverse plant communities help regulate pests and diseases by reducing their spread and supporting natural biological control mechanisms. Natural farming also conserves indigenous crop varieties with valuable traits such as drought tolerance and pest resistance, improving climate resilience. By enhancing above- and below-ground biodiversity, natural farming strengthens ecosystem services such as soil conservation, carbon storage and nutrient cycling, transforming agricultural fields into resilient and sustainable ecosystems.

Natural Farming and Plant Health Management:

Plant health is crucial for agricultural productivity and food security, with climate change exacerbating the severity of crop pests and diseases by altering environmental conditions suitable for their development. Traditional crop protection relies heavily on chemical pesticides, which can lead to issues like pesticide resistance and environmental harm. In contrast, natural farming adopts an ecological approach, emphasizing preventive management, soil health, biodiversity and biological pest control. Healthy soils foster beneficial microorganisms that combat plant pathogens through various mechanisms. Practices such as using biological preparations like *Jeevamrut* and *Beejamrut* enhance microbial diversity and plant resilience.

Crop diversification further mitigates disease by interrupting pathogen cycles, while plant-based protection methods, including neem extracts, reduce environmental impact. Nevertheless, many traditional remedies require scientific validation to ascertain their efficacy. Combining traditional knowledge with modern plant pathology could strengthen natural farming strategies for disease management, thereby promoting a resilient agricultural ecosystem that enhances plant health through sustainable practices.

Economic Sustainability and Farmer Livelihood

Economic sustainability is a major factor influencing the adoption of agricultural systems, particularly among small and marginal farmers facing increasing costs of fertilizers, pesticides and other external inputs. Natural farming reduces input dependency by utilizing locally available resources and farm-based biological inputs such as *Jeevamrut*, *Ghanjeevamrut*, compost and crop residues, thereby lowering production costs and improving economic resilience. Recycling of agricultural waste and integration of livestock promote a circular farming system while providing additional income opportunities.

Diversified cropping systems reduce dependence on single crops and help stabilize farm income under climate and market uncertainties. Natural farming also strengthens social

sustainability by encouraging farmer knowledge sharing, community participation and collective marketing through farmer groups. However, economic benefits may vary depending on crop type, regional conditions, market access and management practices. Supportive policies, farmer training, value-chain development and long-term economic assessments are essential to enhance the adoption and profitability of natural farming systems.

Challenges and Future Research Priorities in Natural Farming

Natural farming offers ecological and economic benefits, but its large-scale adoption is hindered by several challenges. Key limitations include the lack of long-term scientific data on productivity and ecosystem services across various agro-climatic conditions, as well as potential yield fluctuations during the transition from chemical agriculture. The variability of biological inputs like Jeevamrut necessitates standardization and validation. Additionally, limited mechanization, labor demands, market linkages and insufficient technical guidance further restrict adoption. Future research should emphasize long-term trials, soil microbiome studies and efficient biological formulations. Utilizing precision agriculture and digital tools can improve natural farming systems, while socio-economic studies and policy support are essential for wider adoption and sustainability.

Conclusion

Climate change demands a transition to sustainable agriculture, focusing on resilience and ecological balance. Current agricultural practices suffer from challenges like environmental stress and biodiversity loss, making alternatives necessary. Natural farming presents a solution by enhancing ecological processes, improving soil health, conserving water, supporting biodiversity and lowering reliance on synthetic inputs. Techniques such as crop diversification and livestock integration help adapt to climate variability. However, successful implementation requires customized strategies, scientific support, farmer training and supportive policies. Natural farming not only aims for improved crop yields but also promotes a holistic ecosystem, contributing to resilient food systems and sustainable development goals.

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ENTOMOPATHOGENIC NEMATODES: AN INNOVATIVE AND ECO-FRIENDLY TECHNOLOGY FOR SUSTAINABLE INSECT PEST MANAGEMENT

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Abstract

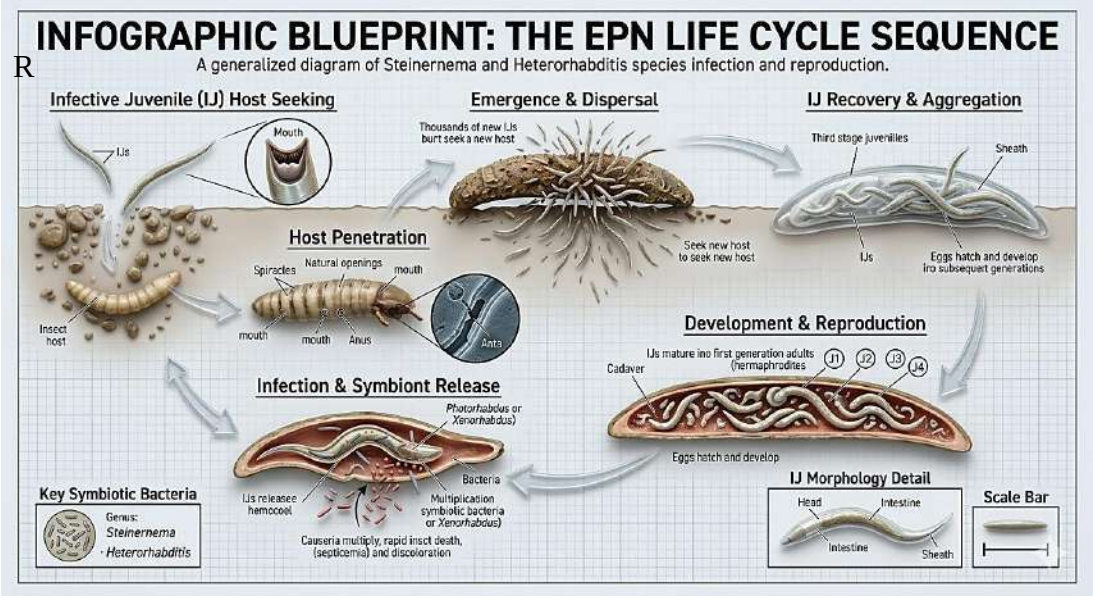
Entomopathogenic nematodes (EPNs) are beneficial microscopic roundworms that provide an eco-friendly and sustainable alternative to chemical insecticides for managing insect pests. Belonging mainly to the families *Steinernematidae* and *Heterorhabditidae*, these nematodes naturally infect and kill a wide range of economically important insect pests with the help of their symbiotic bacteria, *Xenorhabdus* and *Photorhabdus*. This article highlights the biology, life cycle, and mode of action of EPNs, along with recent advances in their mass production, formulation, and field application. Modern formulations, such as water-dispersible granules, wettable powders, and alginate capsules, have improved their shelf life and field performance. The article also discusses the role of EPNs in integrated pest management (IPM), their applications in different crops, and future opportunities for sustainable agriculture. Owing to their safety, effectiveness, and environmental compatibility, EPNs are emerging as promising biological control agents for eco-friendly insect pest management.

Keywords: Entomopathogenic nematodes, biological control, integrated pest management, sustainable agriculture, *Steinernema*, *Heterorhabditis*

Introduction

Insect pests are one of the major constraints to agricultural production, causing significant yield and economic losses every year. Farmers have traditionally relied on chemical insecticides for pest control because they provide quick and effective results. However, excessive and repeated use of these chemicals has led to several problems, including the development of insect resistance, environmental pollution, destruction of beneficial organisms, and pesticide residues in food and soil. These concerns have increased the demand for safe, eco-friendly, and sustainable pest management practices.

Biological control has emerged as an important component of Integrated Pest Management (IPM), offering environmentally safe alternatives to synthetic pesticides. Among the various biological control agents, entomopathogenic nematodes (EPNs) have gained considerable attention due to their ability to effectively control a wide range of insect pests. These microscopic, soil-inhabiting roundworms, mainly belonging to the families *Steinernematidae* and *Heterorhabditidae,* actively search for insect hosts and kill them with the help of beneficial symbiotic bacteria. EPNs are highly specific to insect pests, harmless to humans, livestock, plants, and most non-target organisms, and leave no harmful chemical residues in the environment.



Recent advances in mass production, formulation technologies, and application methods have improved the commercial use of EPNs in many cropping systems. This article discusses the biology, mode of action, production methods, recent technological innovations, practical

applications, and future prospects of entomopathogenic nematodes as an effective and sustainable biological tool for insect pest management.

Contents

Biology and Life Cycle Mechanism

Entomopathogenic nematodes (EPNs) are microscopic roundworms that naturally occur in the soil and parasitize a wide range of insect pests. Their life cycle mainly depends on the infective juvenile (IJ) stage, which is the only free-living stage capable of surviving in the soil and searching for insect hosts. The infective juveniles actively move through the soil in search of suitable insects. Once they locate a host, they enter the insect body through natural openings such as the mouth, spiracles, or anus. After entering the insect's body cavity, the nematodes release their symbiotic bacteria, which play a vital role in killing the host.

Species belonging to the family *Steinernematidae* are associated with *Xenorhabdus* bacteria, whereas *Heterorhabditidae* species carry *Photorhabdus* bacteria. These bacteria multiply rapidly inside the insect, produce toxic substances, and kill the insect within 24–48 hours. They also prevent the growth of other harmful microorganisms, allowing the nematodes to feed and reproduce inside the dead insect. The nematodes complete one or more generations within the insect cadaver. After the available food is exhausted, a new generation of infective juveniles emerges from the dead insect and disperses into the surrounding soil to search for new hosts, thereby repeating the life cycle.

Host Searching Behaviour

Different EPN species use different strategies to locate their insect hosts.

- **Ambushers**: Species such as *Steinernema carpocapsae* usually remain near the soil surface and wait for highly mobile insects. They often stand upright in a behaviour known as nictation, which helps them attach to passing insects. These nematodes are highly effective against cutworms, armyworms, webworms, and other surface-feeding caterpillars.
- **Cruisers:** Species such as *Heterorhabditis bacteriophora* actively move through the soil in search of insect hosts. They are attracted by chemical signals released from insect larvae and plant roots. These nematodes are particularly effective against white grubs, root weevils, beetle larvae, termites, and other soil-dwelling pests.

Modern Formulations of Entomopathogenic Nematodes

Successful field application of EPNs depends on maintaining their survival during storage, transportation, and application. Since infective juveniles are sensitive to heat, drying, and direct sunlight, several improved formulations have been developed to increase their shelf life and field performance.

- **Wettable Powders (WP):** In this formulation, infective juveniles are mixed with fine carrier materials such as talc or diatomaceous earth. The powder can be easily mixed with water and applied using conventional sprayers.
- **Water-Dispersible Granules (WDG):** These granules dissolve rapidly in water before application. They provide better protection to the nematodes during storage and improve their distribution in the field. Studies have shown that WDG formulations effectively suppress several insect pests under field conditions.
- **Calcium Alginate Capsules:** Infective juveniles are enclosed within calcium alginate gel capsules that help retain moisture and protect the nematodes from environmental stress. This formulation improves shelf life, handling, transportation, and field survival, making it suitable for commercial use.

Why EPNs are Effective Biological Control Agents: Entomopathogenic Nematodes (EPNs) serve as highly effective biological control agents because they rapidly kill many economically important soil and foliar insect pests within 24 to 48 hours. They represent an exceptionally eco-friendly option for modern agriculture, as they are completely safe for humans, animals, plants, and beneficial insects, while leaving absolutely no harmful pesticide residues in the environment. These unique traits make them perfectly suitable for organic and sustainable farming practices and seamlessly compatible with Integrated Pest Management (IPM) Programmes. Furthermore, EPNs offer immense practical convenience for growers since they can be easily deployed using conventional irrigation or spraying systems.

Commercially Available EPN Products

Several commercial formulations of entomopathogenic nematodes are now available worldwide for the management of economically important insect pests. These products mainly contain species such as *Steinernema carpocapsae*, *S. feltiae*, *S. glaseri*, *Heterorhabditis bacteriophora*, and *H. indica*.

Table 1. Potential Applications of Entomopathogenic Nematodes (EPNs) for Management of Major Insect Pests in India

Crop	Target Insect Pest	Scientific Name	Suitable EPN Species	Reference
Groundnut	White grub	*Holotrichia spp.*	*Heterorhabditis indica*	Kaya & Gaugler (1993); Askary & Ahmad (2015)
Cotton	Pink bollworm	*Pectinophora gossypiella*	*Steinernema carpocapsae*	Lacey (2017); Askary & Ahmad (2015)
Cotton	Tobacco caterpillar	*Spodoptera litura*	*Steinernema carpocapsae, Heterorhabditis indica*	Kaya & Gaugler (1993); Lacey (2017)
Vegetables	Tobacco caterpillar	*Spodoptera litura*	*Steinernema carpocapsae*	Lacey (2017)
Cruciferous vegetables	Diamondback moth	*Plutella xylostella*	*Steinernema carpocapsae, Heterorhabditis indica*	Askary & Ahmad (2015); Lacey (2017)
Rice	Rice yellow stem borer	*Scirpophaga incertulas*	*Heterorhabditis indica*	Kaya & Gaugler (1993); Askary & Ahmad (2015)
Maize	Fall armyworm	*Spodoptera frugiperda*	*Steinernema carpocapsae, Heterorhabditis indica*	Shapiro-Ilan et al. (2017); Lacey (2017)

Table 2. Recent Innovations in Entomopathogenic Nematode Technology

Innovation	Major Advantage
Hydrogel/polymer formulations	Longer shelf life and improved field survival
Water-dispersible granules (WDG)	Easy handling and uniform application
Calcium alginate capsules	Protection from desiccation and temperature stress

Drone-based application	Rapid coverage and reduced labour
Drip irrigation delivery	Direct application to the root zone with higher efficiency
AI-based pest forecasting	Precise timing of EPN application
Indigenous EPN strain development	Better adaptation to local environmental conditions
Automated liquid fermentation	Lower production cost and large-scale commercial production

Challenges in Commercial Adoption

Although EPNs are highly effective biological control agents, their large-scale use still faces several challenges:

- **Limited shelf life:** Infective juveniles gradually lose viability during prolonged storage.
- **Environmental sensitivity:** High temperatures, low soil moisture, and direct sunlight reduce nematode survival.
- **Production cost:** Commercial mass production and formulation require specialized facilities.
- **Storage and transportation:** Maintaining suitable temperature and moisture conditions is essential.
- **Field performance:** Success depends on proper application timing, adequate soil moisture, and compatibility with other crop protection practices.
- **Farmer awareness:** Wider adoption requires training, demonstrations, and greater availability of quality commercial formulations.

Conclusion

Entomopathogenic nematodes (EPNs) are emerging as an effective, eco-friendly, and sustainable alternative to chemical insecticides for managing economically important insect pests. Their unique association with symbiotic bacteria enables rapid control of a wide range of soil- and insect pests without leaving harmful residues in the environment. Recent advances in mass production, improved formulations, and application technologies have enhanced their commercial potential and field performance. When integrated with other biological and cultural practices under Integrated Pest Management (IPM), EPNs can reduce dependence on chemical pesticides while conserving beneficial organisms and improving environmental sustainability. Continued research on native EPN species, cost-effective production technologies, and farmer

awareness will further strengthen their role in sustainable crop protection and future climate-smart agriculture.

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FUNGAL FIXES: *TRICHODERMA*- MEDIATED BIOREMEDIATION

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Abstract

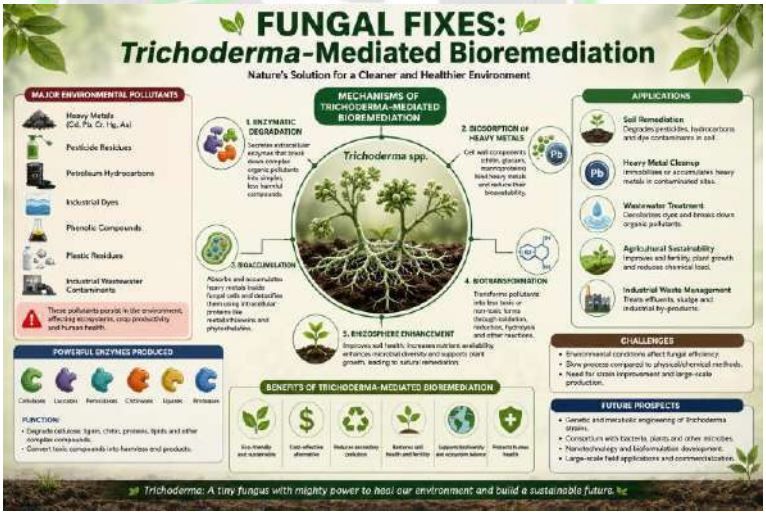
Environmental pollution caused by industrialization, intensive agriculture, mining and urbanization has become one of the greatest challenges of the 21st century. Heavy metals, pesticides, petroleum hydrocarbons and various industrial contaminants accumulate in soil and water, threatening biodiversity, crop productivity and human health. Conventional remediation technologies are often expensive, energy-intensive and may generate secondary pollution. Bioremediation, the use of living organisms to remove or detoxify pollutants, offers an eco-friendly and cost-effective alternative. Among beneficial microorganisms, ***Trichoderma***, a filamentous fungus commonly found in soil and plant rhizospheres, has gained significant attention due to its remarkable biodegradation capabilities. Besides being a well-known biological control agent against plant pathogens, *Trichoderma* can degrade toxic chemicals, immobilize heavy metals, improve soil fertility, and restore contaminated ecosystems. This article reviews the mechanisms, applications, advantages, challenges, and future prospects of *Trichoderma*-mediated bioremediation, emphasizing its role in sustainable environmental management.

Keywords: Environmental remediation, Fungal biotechnology, Soil remediation, Heavy metal biosorption, Pesticide degradation

Introduction

Rapid industrial growth and modern agricultural practices have significantly increased environmental contamination worldwide. Excessive application of synthetic pesticides, fertilizers, dyes, petroleum products, pharmaceuticals, and heavy metals has deteriorated soil and water quality. Major pollutants affecting ecosystems include:

- Heavy metals (cadmium, lead, chromium, mercury, arsenic)
- Persistent pesticides
- Petroleum hydrocarbons
- Textile dyes
- Phenolic compounds
- Plastic residues
- Industrial wastewater contaminants



Many of these pollutants persist for decades and enter the food chain, affecting both ecosystems and human health. Traditional remediation methods such as excavation, incineration, chemical oxidation, and landfill disposal are often expensive and environmentally disruptive. Consequently, researchers have increasingly focused on biological alternatives. **Bioremediation** utilizes microorganisms—including bacteria, fungi, algae, and plants—to degrade, transform, or immobilize pollutants naturally. Among fungi, ***Trichoderma* spp.** have emerged as multifunctional organisms due to their ability to:

- Colonize contaminated soils
- Produce powerful extracellular enzymes
- Enhance microbial diversity
- Promote plant growth
- Detoxify numerous environmental pollutants

***Trichoderma*:** *Trichoderma* belongs to the Kingdom Fungi and is widely distributed across agricultural soils, forests, compost, and decaying organic matter.

Common species: *T. harzianum, T. viride, T. asperellum, T. koningii, T. atroviride, T. reesei*

Trichoderma has been used as: Biological fungicide, Plant growth promoter, Compost inoculant, Bio fertilizer, Producer of industrial enzymes

Mechanisms of *Trichoderma*-Mediated Bioremediation

1. Enzymatic Degradation

Trichoderma secretes numerous extracellular enzymes capable of breaking down complex organic pollutants. Important enzymes include: Cellulases, Xylanases, Laccases, Peroxidases, Chitinases, Lipases, Proteases

These enzymes convert toxic molecules into simpler, less harmful compounds. For example:

- Phenolic compounds are oxidized.
- Petroleum hydrocarbons are metabolized.
- Organic dyes are decolorized.
- Agricultural pesticide residues are degraded.

2. Biosorption of Heavy Metals

Heavy metals cannot be biologically degraded. Instead, *Trichoderma* removes them through biosorption. Its cell wall contains: Chitin, Glucans and mannoproteins which bind to lead, Cadmium, Nickle and copper and This immobilization reduces metal bioavailability and minimizes uptake by crops.

3. Bioaccumulation

Some *Trichoderma* species actively absorb heavy metals into fungal cells. Intracellular proteins such as metallothioneins and phytochelatins help detoxify accumulated metals.

4. Biotransformation

Certain pollutants become less toxic after chemical modification by fungal metabolism. Examples include:

- Reduction of hexavalent chromium (Cr VI) to less toxic Cr III
- Transformation of pesticides into biodegradable metabolites

5. Rhizosphere Enhancement

Trichoderma colonizes plant roots efficiently.

- Root architecture
- Soil microbial diversity
- Organic matter decomposition

Healthy roots further support pollutant degradation by associated microorganisms.

Bioremediation of Heavy Metals

Trichoderma serves as a powerful agent in the bioremediation of heavy metals, which are highly persistent environmental contaminants generated by industries such as mining, electroplating, battery manufacturing, tanneries, fertilizer application, and sewage sludge disposal. The fungus actively mitigates this pollution through metal adsorption, where toxic ions bind to its cell walls, and chelation, which neutralizes metals via secreted organic molecules. Additionally, it drives the immobilization of contaminants to lock them within the soil matrix and prevent groundwater leaching, while simultaneously triggering the reduction of oxidative stress in plants to help vegetation survive toxic exposure. Research has shown that *Trichoderma*-treated plants accumulate fewer heavy metals while exhibiting improved growth under contaminated conditions.

Removal of Agricultural Pesticides

Excess pesticide use has led to contamination of agricultural ecosystems. *Trichoderma* strains play a vital role in degrading widespread pesticide groups including organophosphates, carbamates, pyrethroids, chlorinated pesticides, and herbicides. This versatile fungus effectively breaks down highly toxic and persistent chemical compounds such as chlorpyrifos, carbendazim, atrazine, glyphosate, and pendimethalin, rendering them less harmful to the ecosystem. By metabolizing these complex agricultural chemicals, the fungus prevents long-term soil contamination and helps restore heavily treated agricultural lands.

The fungus converts toxic molecules into simpler metabolites, reducing environmental persistence.

Petroleum Hydrocarbon Degradation

Oil spills contaminate soil and groundwater with hydrocarbons.

These include: Diesel, Crude oil, Engine oil, Polycyclic aromatic hydrocarbons (PAHs)

Trichoderma produces oxidative enzymes capable of breaking down these compounds.

The fungus also stimulates hydrocarbon-degrading bacteria, creating synergistic biodegradation.

Textile Dye Bioremediation

Textile industries generate colored wastewater containing synthetic dyes that resist conventional treatment.

Trichoderma enzymes such as laccases and manganese peroxidases can:

- Decolorize dyes, Reduce toxicity, Improve wastewater quality

Dyes degraded include:

- Methylene blue, Congo red, Reactive black, Crystal violet

Plastic Degradation Potential

Plastic pollution is an emerging environmental crisis.

Although *Trichoderma* cannot completely degrade conventional plastics rapidly, research indicates its enzymes may contribute to partial degradation of:

- Polyurethane, Bioplastics, Plastic additives

Future genetic improvements may enhance this capability.

Role in Soil Restoration

Contaminated soils often suffer from:

- Reduced microbial diversity
- Poor nutrient cycling
- Low organic matter
- Compacted structure

Trichoderma restores soil health by:

- Decomposing organic residues
- Increasing microbial biomass
- Improving soil aggregation
- Enhancing nutrient availability
- Promoting beneficial rhizosphere microbes

Synergy with Plants in Phytoremediation

Trichoderma enhances phytoremediation when used with plants such as:

- Sunflower, Vetiver grass, Mustard, Poplar, Willow

Benefits include:

- Increased root biomass
- Better stress tolerance
- Reduced metal toxicity
- Enhanced contaminant uptake or stabilization
- Improved plant survival

Advantages of *Trichoderma*-Based Bioremediation

Major advantages include:

- Environmentally friendly
- Cost-effective
- Self-sustaining
- Non-toxic
- Suitable for large agricultural areas
- Improves soil fertility
- Supports sustainable farming
- Compatible with organic agriculture
- Simultaneously controls plant diseases
- Promotes crop growth

Limitations

Despite its advantages, certain limitations remain.

Bioremediation efficiency depends on:

- Soil pH
- Temperature
- Moisture
- Pollutant concentration
- Native microbial populations

Some pollutants require microbial consortia rather than *Trichoderma* alone.

Heavy metals cannot be destroyed and must ultimately be stabilized or removed.

Field-scale performance may vary due to environmental conditions.

Recent Advances

Modern biotechnology is expanding *Trichoderma* applications through:

Genetic Engineering

Researchers are developing strains with:

- Enhanced enzyme production
- Improved pollutant tolerance
- Faster degradation rates

Omics Technologies

Genomics, transcriptomics, proteomics, and metabolomics help identify genes responsible for pollutant degradation.

Nanotechnology

Nanoformulations improve fungal survival, delivery, and colonization in contaminated environments.

Microbial Consortia

Combining *Trichoderma* with bacteria such as *Pseudomonas* and *Bacillus* enhances degradation efficiency through complementary metabolic pathways.

Future Perspectives

Future research should focus on:

- Large-scale field validation
- Multi-pollutant remediation systems
- Integration with precision agriculture
- Climate-resilient *Trichoderma* strains
- Bioaugmentation strategies
- Sustainable waste management
- Development of commercial bioremediation products

Combining *Trichoderma* with advanced biotechnology and environmental engineering can significantly improve ecosystem restoration worldwide.

Conclusion

Trichoderma has evolved far beyond its traditional role as a biological control fungus. Its exceptional enzymatic capabilities, adaptability, and beneficial interactions with plants make it a powerful tool for environmental cleanup. Through mechanisms such as enzymatic degradation, biosorption, bioaccumulation, and rhizosphere enhancement, *Trichoderma* effectively mitigates pollution caused by heavy metals, pesticides, hydrocarbons, dyes, and other contaminants while

simultaneously improving soil health and crop productivity. As environmental regulations become stricter and sustainable agriculture gains momentum, *Trichoderma*-mediated bioremediation is poised to become an integral component of green remediation strategies. Continued research, technological innovation, and field-scale implementation will unlock its full potential, helping restore contaminated ecosystems and supporting global efforts toward environmental sustainability.

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THE "BLUE REMEDIATION" REVOLUTION: HOW BIOCHAR AND NANOBUBBLES ARE HEALING AQUACULTURE'S TOXIC WATERS

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Abstract

Aquaculture faces increasing challenges from toxic water pollution caused by ammonia, nitrite, organic wastes and oxygen depletion, which threaten fish health, productivity and environmental sustainability. This article highlights an emerging nature-based remediation approach that combines biochar and nanobubble technology to restore water quality through pollutant adsorption, enhanced oxygen availability and stimulation of beneficial microbial activity. The article explains how agricultural residues can be converted into biochar to remove contaminants while providing habitat for microorganisms, whereas nanobubbles improve oxygen transfer and accelerate natural biodegradation processes. The combined approach offers a sustainable pathway to reduce chemical dependency, improve fish growth, enhance water quality and support environmentally responsible aquaculture. Furthermore, a future-oriented concept of integrating biochar, nanobubbles, intelligent sensors and artificial intelligence is presented as a vision for next-generation smart aquaculture. Blue Remediation has the potential to transform aquaculture into a cleaner, more resilient and sustainable food production system.

Keywords: Aquaculture, Blue Remediation, Biochar, Nanobubbles, Water Quality, Sustainable Aquaculture

Introduction

Imagine standing beside a fish pond at sunrise. The water appears calm. Fish swim quietly beneath the surface, farmers prepare feed, and everything seems perfectly healthy. Yet hidden within that seemingly peaceful water is an invisible enemy. Every uneaten feed pellet,

every fish excretion, and every decomposing organic particle releases harmful compounds such as ammonia, nitrite, hydrogen sulphide , and excessive nutrients. These pollutants silently reduce dissolved oxygen, encourage disease-causing microorganisms, trigger harmful algal blooms, and ultimately threaten fish survival. Traditional remedies—frequent water exchange, antibiotics, disinfectants, and chemicals—often provide only temporary relief while increasing costs and environmental risks. This research has led to two remarkable innovations—biochar and nanobubbles. These technologies is transforming aquaculture. Together, they have the potential to redefine how fish farmers restore polluted waters, improve productivity, and protect aquatic ecosystems. This emerging approach is now being recognized as the Blue Remediation Revolution.

Biochar: Turning Agricultural Waste into Aquatic Gold

At first glance, biochar resembles ordinary charcoal. Yet its extraordinary internal structure makes it one of the most promising environmental materials of the 21st century. Biochar is produced by heating agricultural residues—such as rice husk, coconut shell, bamboo, sugarcane bagasse, corn stalks, or other plant biomass—in a low-oxygen process called pyrolysis. Instead of burning into ash, the biomass transforms into a highly porous, carbon-rich material. A single gram of biochar contains millions of microscopic pores, creating an enormous internal surface area. These tiny pores act like natural shelters and filters within the water.



Figure 1 : The Blue Remediation Revolution

In aquaculture ponds, biochar performs several remarkable functions:

Adsorbs toxic ammonia and organic pollutants, provides habitat for beneficial nitrifying bacteria and reduces foul odours caused by hydrogen sulphide and improves microbial balance in pond ecosystems, Stabilizes water pH and enhances water clarity, stores carbon which helps to reduce greenhouse gas emissions. Here, biochar functions as a living biological sponge—absorbing pollutants while supporting beneficial microorganisms that naturally clean the water.

Nanobubbles: The Invisible Engineers of Clean Water

Now imagine bubbles so tiny that nearly 2,500 nanobubbles can fit across the width of a human hair. Unlike ordinary bubbles that quickly rise and burst, nanobubbles remain suspended in water for extended periods. Their unique physical properties make them exceptionally effective at improving water quality. Nanobubbles deliver oxygen more efficiently than conventional aerators, increasing dissolved oxygen throughout the water column. This improves fish respiration, enhances microbial degradation of organic wastes, reduces harmful anaerobic zones, and promotes a healthier pond ecosystem. Because of their minute size, nanobubbles possess a large surface area and unique interfacial properties, allowing oxygen to be transferred more efficiently into water than with traditional bubbling systems. The result is cleaner water, healthier fish, and lower energy consumption in many aquaculture systems. In essence, nanobubbles act as microscopic oxygen carriers, continuously revitalizing aquatic environments.

When Biochar Meets Nanobubbles: A Powerful Partnership

The true revolution begins when these two technologies work

Table 1 : Comparative Evaluation Of Remediation Technologies

Performance Vector	**Chemical Treatments (Copper Sulphate/Zeolite)**	**Conventional Aeration (Paddlewheels)**	**The Blue Remediation Framework (Biochar + Nanobubbles)**
Environmental Footprint	Toxic chemical residues; develops antibiotic resistance.	High carbon emission due to heavy energy demands.	Zero-waste; actively sequesters carbon via biochar.

Performance Vector	Chemical Treatments (Copper Sulphate/Zeolite)	Conventional Aeration (Paddlewheels)	The Blue Remediation Framework (Biochar + Nanobubbles)
Dissolved Oxygen (DO) Stability	No direct effect on oxygen levels.	High surface volatility; significant energy loss.	Maintains uniform, high saturation from surface to pond floor.
Ammonia Recovery	Temporary chemical masking.	Highly limited direct removal.	Permanent capture and biological conversion.
Economic Lifecycle	High recurring costs for constant chemical purchasing.	High operational electricity costs.	Low capital cost; utilizes repurposed agricultural waste.

A Vision for the Future: The Smart Blue Biochar Matrix

Imagine a future aquaculture pond equipped with floating biochar modules engineered to maximize microbial attachment. Beneath them, energy-efficient nanobubble generators continuously enrich the surrounding water with oxygen. Low-cost sensors monitor dissolved oxygen, ammonia, pH, and temperature in real time, while artificial intelligence adjusts oxygen delivery according to the pond's needs. Such a Smart Blue Biochar Matrix is a forward-looking research concept that integrates ecological engineering, nanotechnology, and digital aquaculture into a single water-remediation platform.

From Polluted Ponds to Living Ecosystems: Blue Remediation in Action

Across the world, aquaculture is evolving from a production-focused industry to an ecosystem-based enterprise. Farmers and researchers increasingly recognize that healthy water is the foundation of healthy fish. Where water quality declines, fish experience stress, immunity weakens, feed conversion efficiency falls, and disease outbreaks become more frequent. Blue Remediation addresses these challenges by restoring the pond's natural ecological balance rather than relying solely on chemical treatments.

Why This Matters to Farmers

For aquaculture producers, poor water quality translates directly into economic losses. Frequent water exchange requires large quantities of freshwater, aeration consumes electricity, and disease outbreaks increase treatment costs. By improving water quality naturally, biochar and nanobubbles can contribute to this technology which improves fish growth, survival, and feed conversion efficiency while reducing toxic ammonia, nitrite, stress, antibiotic use, and operational costs. It also enhances production stability and environmental sustainability.

Beyond Fish Farming: Protecting Rivers, Lakes, and Coastal Waters

The significance of Blue Remediation extends far beyond aquaculture ponds. When nutrient-rich wastewater is discharged untreated, it can trigger eutrophication in nearby rivers, reservoirs, estuaries, and coastal waters. Excess nutrients stimulate algal blooms that consume oxygen during decomposition, creating "dead zones" where aquatic life struggles to survive. By reducing pollutants before water leaves the farm, Blue Remediation helps protect downstream ecosystems, conserve biodiversity, and improve overall watershed health. Thus, a cleaner fish pond contributes to cleaner natural waters.

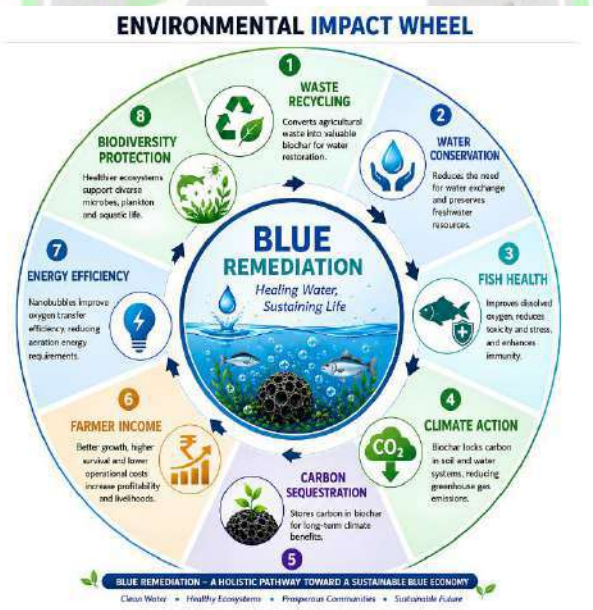


Figure 2 : Environmental Impact Wheel

Conclusion: Healing Water, Securing the Future

Water is the lifeblood of aquaculture. When water becomes polluted, every organism in the system suffers. When water is restored, productivity, biodiversity, and sustainability flourish together. The Blue Remediation Revolution demonstrates that some of the most powerful

solutions emerge from unexpected partnerships—a carbon-rich material made from agricultural waste and billions of microscopic oxygen-filled bubbles. Together, they represent more than technologies. They symbolize a shift in thinking: from pollution control to ecosystem restoration, from waste to resource, and from short-term production to long-term sustainability. As the world strives to feed a growing population while protecting fragile aquatic ecosystems, Blue Remediation offers a hopeful pathway toward cleaner waters, healthier fish, empowered farmers, and a resilient blue economy. The future of aquaculture will not be defined by how much we harvest, but by how wisely we protect the waters that sustain life.

"When we heal the water, we heal the future of food, biodiversity, and humanity itself."

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BANANA STEM FOR BETTER HEALTH

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Introduction

In the ever-evolving landscape of functional foods and sustainable health practices, underutilized plant parts are gaining renewed attention for their nutritional and therapeutic potential. One such undervalued yet abundant resource is the banana stem—a byproduct of banana cultivation often discarded post-harvest. While bananas are globally celebrated for their fruit, the pseudo stem of the plant remains largely overlooked in both scientific and commercial contexts. However, emerging research suggests that this fibrous, water-rich component holds a treasure of health-promoting compounds and industrial possibilities.

The banana plant (genus *Musa*) is widely grown in tropical and subtropical regions, generating massive quantities of biomass with each cropping cycle. Among this, the banana stem—a thick cylindrical structure formed from tightly packed leaf sheaths—has traditionally been used in indigenous medicine systems for its diuretic, anti-diabetic, and detoxifying properties. In recent years, scientific validation of these folk uses has uncovered a wealth of bioactive constituents, including dietary fiber, phenolics, antioxidants, potassium, and resistant starch, all of which contribute to its potential as a functional food ingredient.

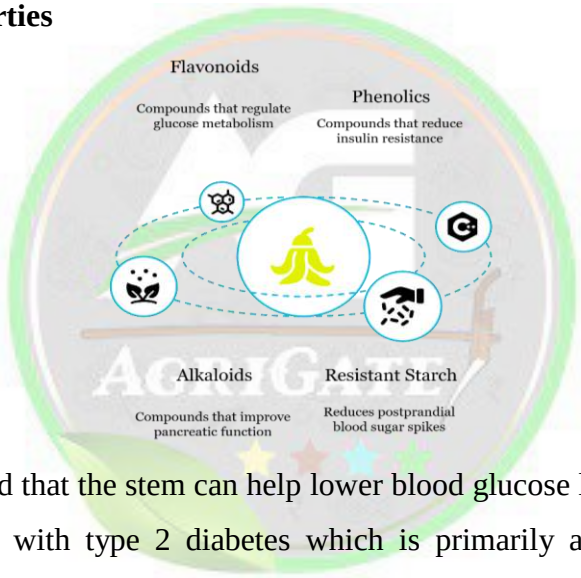
Nutritional aspect & Therapeutic potential

Rich in water (about 90%), dietary fiber, and essential vitamins, the stem serves as an effective functional food ingredient. Studies have shown that dietary fiber plays a critical role in improving bowel function, reducing constipation, and promoting a healthy gut microbiome. The fibrous nature of the stem is ideal for digestive health, as it aids in satiety and can help control

food intake, thus making it a valuable addition to weight management diets. Being rich in resistant starch, it acts as a prebiotic, stimulating the growth of beneficial gut bacteria and improving gut health. The banana stem is also an excellent source of potassium, a mineral critical for maintaining normal blood pressure and supporting cardiovascular health. Potassium-rich foods help counteract the effects of sodium in the body, contributing to better hypertension management. Additionally, it contains vitamin B6, which supports neurotransmitter synthesis, contributes to hormonal balance, and aids in maintaining mental health by regulating mood and cognitive functions.

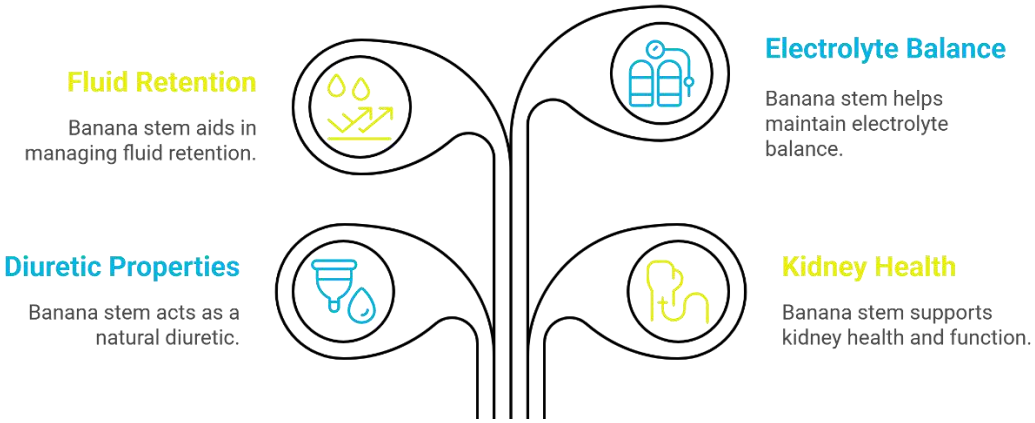
Across cultures, banana stems have been used to treat various ailments, including diabetes, kidney disorders, hypertension, and inflammatory conditions.

1. Anti-Diabetic Properties



Studies have demonstrated that the stem can help lower blood glucose levels and improve insulin sensitivity in individuals with type 2 diabetes which is primarily attributed to the bioactive compounds present in the stem.

2. Renal Protection and Diuretic Effect



Banana stem helps to flush out toxins and excess water from the body, which is crucial for individuals suffering from oedema, kidney stones, or urinary tract infections. A study showed that banana stem juice promotes renal health by preventing the formation of kidney stones, thereby improving urinary output and supporting the detoxification process. Its natural potassium content helps maintain electrolyte balance during detoxification, enhancing kidney function.

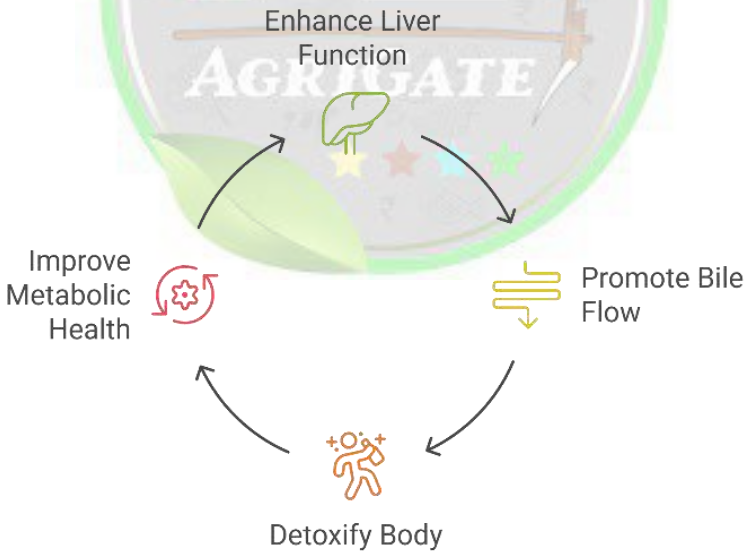
3. Anti-Hypertensive Effects

Rich in potassium, banana stem helps counteract the effects of sodium in the body, thereby supporting normal blood pressure levels. This is especially important in managing hypertension and preventing associated complications like stroke, heart disease, and kidney failure.

4. Anti-inflammatory and Antioxidant Activities

The banana stem also exhibits anti-inflammatory and antioxidant properties, making it a valuable resource for reducing the risk of chronic diseases such as cancer, arthritis, and heart disease. By mitigating inflammation, it supports joint health and offers therapeutic benefits for individuals with inflammatory conditions.

5. Liver Protection and Detoxification



Banana stems maintain liver health by enhancing the digestion, bile movement and detoxification process in the body.

Processing and Commercialization Challenges of Banana Stem

Traditional manual extraction methods, though yielding high-quality fibers, are labor-intensive and not scalable for industrial applications of banana stem. Mechanical extraction

methods, such as decortication, offer higher throughput but often result in fibers with impurities and damage due to high-speed mechanical actions. Retting processes, including water, dew, chemical, fungal, and bacterial retting, are employed to remove non-cellulosic substances. However, these methods can be time-consuming and environmentally detrimental, especially water retting, which can contaminate water resources

Chemical degumming using alkalis like sodium hydroxide and chelating agents such as EDTA has been explored to enhance fiber quality. These treatments can improve pulp yield and cellulose content but require careful control to prevent fiber degradation. Enzymatic treatments, employing enzymes like cellulase and pectinase, offer a more environmentally friendly approach. However, their effectiveness is limited, and they are often used in conjunction with other methods.

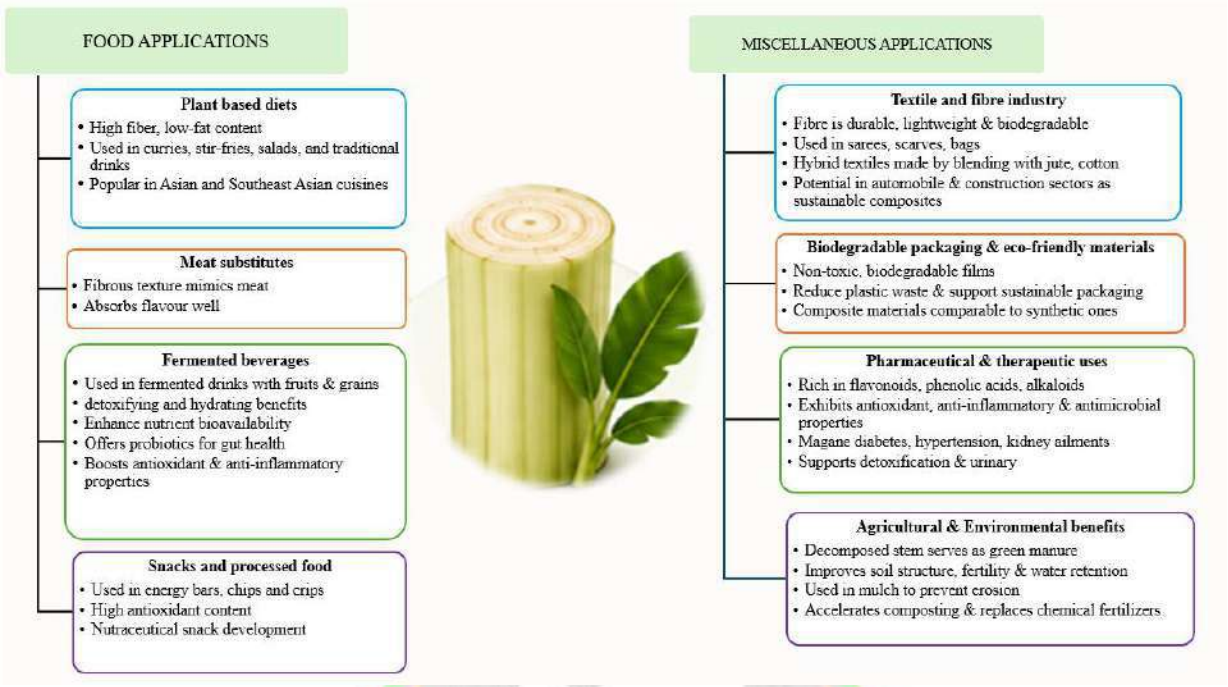
Banana stems are highly perishable, with a high moisture content that makes them susceptible to microbial spoilage. Immediate processing post-harvest is essential to prevent quality deterioration. However, in many regions, the lack of infrastructure for rapid processing and storage poses significant challenges.

Variability in banana stem properties due to differences in cultivar, soil conditions, and cultivation practices complicates standardization efforts. This variability affects the consistency of fiber quality, which is crucial for industrial applications. Establishing standardized protocols for processing and quality assessment is necessary to ensure product reliability.

Despite the potential of banana stem fibers in various industries, commercialization is hindered by economic factors. The cost of setting up processing facilities, coupled with limited market demand and awareness, affects the economic viability. Additionally, competition with established materials like jute and synthetic fibrers poses challenges in market penetration.

Applications of Banana stem

Banana stem is gaining recognition not only in food industries but also in various non-food sectors. Its diverse applications depict its potential as a sustainable resource.



Conclusion

The banana stem, once considered an agricultural waste product, has emerged as a versatile and sustainable resource with substantial nutritional, therapeutic, and environmental benefits. The application of banana stems contributes to a circular economy, ensuring that agricultural by-products are transformed into valuable, eco-friendly solutions. Its continued research and application can pave the way for more sustainable practices across industries, fostering a healthier and more eco-conscious future.

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IS SEAWATER RICE A NEW INITIATIVE AIMED AT ACHIEVING ZERO HUNGER?

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Introduction

The boundary between the land and the sea is known as coastal wetlands. It occupies a significant surface area worldwide (Hopkinson et al., 2019). The lands in these areas experience severe degradation due to saline water intrusion caused by cyclone-induced storm surges and sea-level rise. In addition, the shallow brackish groundwater table, influenced by proximity to the sea, promotes capillary rise of saline water during the dry season, further increasing soil salinity. Globally, salinity is a significant abiotic stress that affects one-quarter to one-third of the crop productivity of agricultural soils (Kamran et al., 2019). Among 230 million hectares of farmland, 20% is affected by salt, and this percentage increases every year. With the rapid growth of the global population, the demand for food is steadily increasing, making it increasingly necessary to utilize saline lands to address the impending food shortage. Scientists are attempting to increase food production by 70% in order to avoid the risk of food shortages for 9.3 billion people by 2050 (Daubenfeld et al., 2025). Rice, an important cereal crop that feeds half of the world's population, is sensitive to salinity stress (Liu et al., 2022). Improvement of salinity tolerance in rice is therefore of paramount importance for global food security. Sea-water rice capable of growing in coastal areas with yields reaching 4.6 metric tons per hectare, this crop could feed an extra 200 million people by 2030. Yuan Longping, widely known as the father of hybrid rice, pioneered this method, and by 2024, it had been adopted on over 400,000 hectares in China (Qian et al., 2021). This technology is expected to expand rapidly, emerging as a game-changer for global food security and offering significant potential to combat hunger worldwide.

What is Seawater Rice?

Seawater rice, more accurately known as salt-tolerant rice, refers to specially developed rice varieties capable of growing and producing grain in saline soils and under diluted seawater conditions. While various soil management strategies are available to alleviate salinity stress, many of these approaches are costly and often beyond the reach of resource-poor farmers. Moreover, cultivated rice (*Oryza sativa*) is not a halophyte and cannot survive in full-strength seawater. Instead, it thrives in coastal saline-alkaline soils or inland salt-affected lands where conventional rice varieties fail to survive. This innovation is particularly significant because rice is a staple food for more than half of the global population, yet it is highly sensitive to salinity, particularly during the seedling and reproductive stages. Excess sodium ions (Na^+) disrupt water uptake, nutrient balance, and reproductive development, leading to severe yield losses.

Sea Water Rice: A Salty Solution to Meet Global Hunger

As climate change intensifies and fertile land shrinks, one silent crisis is expanding across the globe, i.e., soil salinization. Rising sea levels, cyclones, poor irrigation practices, and groundwater salinity are turning millions of hectares of productive farmland into salt-affected wastelands. According to FAO estimates, more than 800 million hectares of land worldwide are affected by salinity. For countries like India, Bangladesh, Vietnam, and other coastal nations, this poses a serious threat to food security.

Along the world's vulnerable coastlines, where rising sea levels and salinity are steadily rendering fertile land unproductive, a quiet agricultural revolution is emerging in the form of seawater rice-more accurately known as salt-tolerant rice, capable of growing in saline and coastal soils where conventional varieties of cultivated rice fail. Seawater rice represents a significant innovation aimed at reclaiming saline and coastal lands for productive agriculture. These salt-tolerant varieties are capable of maintaining growth and grain yield under elevated sodium concentrations without drastic yield reduction. The concept gained global attention through the pioneering efforts of the late "Father of hybrid rice," Yuan Longping, and his research team in China. Their work led to the development of varieties such as Sea Rice 86, which can successfully grow in saline-alkaline soils unsuitable for conventional rice cultivation. This innovation is not merely about improving crop yields but about ensuring survival in changing climatic conditions, as shrinking farmland and increasing salt intrusion threaten global food security. Often described as a potential "game-changer," its ultimate success will depend on

how quickly it can be scaled to satisfy global demand. Developed using genetic traits from wild rice relatives (particularly *Oryza coarctata*), including the overexpression of genes conferring salinity and alkalinity tolerance, these varieties can maintain growth and productivity under stress conditions that would otherwise disrupt water uptake, nutrient balance, and reproductive development. Although rice cultivation has been one of the most resource-intensive farming practices, requiring suitable rainfall, fertile soil, careful water management, and significant labour, making it unsuitable for many regions; but rice can be cultivated in salt-affected soils with its challenging and long-held limitation. If seawater rice fulfils its promise, it could transform degraded coastal landscapes into productive farmland and redefine how agriculture adapts to climate change while addressing the urgent challenge of feeding a growing global population contribute toward achieving Zero Hunger. Seawater rice could become a key pillar of future climate-resilient agriculture.

Key Characteristics of Seawater Rice

- It is a specially bred salt-tolerant rice variety with C4 plant characteristics.
- It can tolerate irrigation water with salt concentrations of approximately 0.6%, significantly higher than what ordinary rice can withstand.
- It is cultivated in coastal saline-alkaline fields or inland salt-affected soils, not in open seawater.
- It helps convert unproductive saline land into arable farmland.

Seawater rice is not cultivated in the ocean; instead, it represents an innovative agricultural development aimed at combating soil salinity and increasing rice cultivation on marginal lands.

Benefits and yields

- In China, large-scale trials have achieved yields exceeding about 4-6 tonnes per hectare on salty soils, already approaching normal hybrid-rice levels (Sackey et al., 2025).

Why it matters

- It allows "wasteland" to become farmland without cutting into forests or grasslands, making more land arable while also helping to improve soil structure and fertility over time.
- For coastal countries and low-lying deltas, seawater-tolerant rice could help maintain rice production as climate-driven salinity (from sea-level rise, storm surges, and seawater

- intrusion) degrades conventional paddies.

Why Do We Need Seawater Rice?

Seawater rice is a promising innovation designed to grow in saline and saline-alkaline soils, offering hope for improving global food security. With salinity increasing due to climate change, sea-level rise, and poor irrigation practices, nearly 20% of irrigated land worldwide is now salt-affected, and since rice is highly sensitive to salt stress, it often loses over 50% of its yield under moderate salinity. Developing salt-tolerant varieties is crucial. Sea water rice is needed to address multiple emerging agricultural and food security challenges, as vast stretches of coastal and inland saline soils remain underutilized, and cultivating such varieties can bring these lands back into productive use without competing for freshwater-rich farmland. As climate change accelerates sea-level rise and increases the frequency of cyclones, saltwater intrusion is becoming more severe in vulnerable delta regions such as the Sundarbans and the Ganges-Brahmaputra delta, making salt-resilient crops essential for adaptation. For millions of smallholder farmers, salinity stress leads to repeated crop failures and unstable incomes; salt-tolerant rice can help stabilize livelihoods and improve economic security. Furthermore, with the global population projected to approach 10 billion by 2050, food demand will rise substantially, and seawater rice offers a sustainable way to boost grain production without expanding agriculture into forests or ecologically fragile areas.

How Does Sea Water Rice Survive Salt?

Seawater (salt-tolerant) rice survives saline conditions by overcoming the two major effects of salt stress: (i) osmotic stress, which restricts water uptake due to reduced soil water potential, and (ii) ionic toxicity, caused by excessive sodium accumulation that damages cells and disrupts metabolism. Salt-tolerant varieties counter these challenges through efficient Na^+ exclusion at the root level, maintenance of a favourable K^+/Na^+ balance, enhanced antioxidant defence systems to reduce oxidative damage, and stronger root architecture that improves water absorption under stress. Importantly, they exhibit improved reproductive-stage tolerance, safeguarding pollen viability and grain filling when salinity occurs during flowering. Modern breeding programs accelerate the development of such varieties by integrating traditional selection from wild rice species with marker-assisted breeding, advanced genomic approaches, and precision gene-editing tools such as CRISPR to enhance salinity tolerance without compromising yield and grain quality.

***Oryza coarctata* for developing seawater-tolerant rice**

Being a halophytic wild rice, *Oryza coarctata* is native to saline and coastal environments and is also well-known as an Asian wild rice, 'Dhani' in Bengali and "Alia" in Gujarati (Chowrasia et al. 2018). *O. coarctata* mainly grows under mud-flood in the marshy lowland areas of mangroves and is adapted to high salinity (up to an EC level of 65 dS m^{-1}) as well as submergence (12 h) (Sengupta and Majumder 2010) through several unique adaptations. Distinctive morpho-anatomical and physiological features of *Oryza coarctata* contribute to salinity tolerance. Vegetative propagation through soboles is one of the most important features of *Oryza coarctata*, while its flowers are short-lived and produce mostly sterile seeds. Its leaves are narrow, waxy, thick, and densely veined, helping it tolerate saline conditions(Shanmugham et al., 2025). Specialized salt glands called microhairs on both leaf surfaces remove excess salt from the plant. Under high salinity, these glands secrete salt crystals to maintain ion balance and protect the plant. The leaves also contain ridges and vascular bundles that quickly transport toxic salts from roots to leaves for exclusion. Additionally, the plant reduces water loss through lower transpiration and stomatal closure, contributing to its strong salt tolerance. It shows C4-like photosynthetic features, including prominent bundle sheath cells, specialized chloroplast arrangement, thickened cell walls, and densely packed leaf tissues that improve CO_2 fixation under stress (Chowrasia et al., 2021).

Genomic studies also reveal higher copies of C4-related genes, suggesting enhanced photosynthetic efficiency (Chowrasia et al. (2021); Yong et al. (2022). The plant further tolerates salinity by accumulating protective compounds such as proline, allantoin, and pinitol, along with strong antioxidant and ROS-scavenging abilities. Its dense rhizomatous roots help absorb minerals and prevent coastal soil erosion. Due to these structural, physiological, and genetic traits, *O. coarctata* is considered a valuable model halophyte and a promising resource for developing salt-tolerant rice varieties. This plant has a deep and intermingled root system, which can be used for coastal sediment trapping, the preservation of salt marshes and mangrove ecosystems and serves as a natural sequester of carbon dioxide emissions (Mishra and Farooq (2022); Banerjee et al. (2022); Chowdhury et al. (2022).

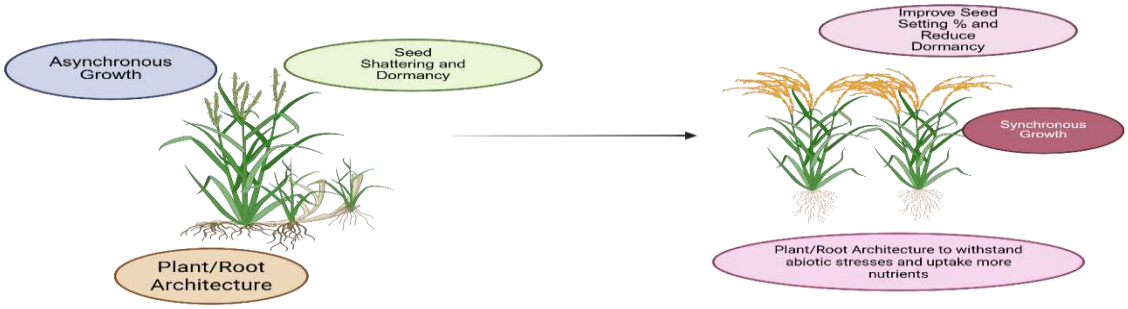


Figure 1: Potential candidate traits to be modified by genome editing for neo-domestication of *Oryza coarctata*

Socioeconomic and Environmental Implications

Seawater (salt-tolerant) rice carries significant socioeconomic and environmental implications. By enabling the cultivation of salt-affected coastal and inland soils, it facilitates the reclamation of vast marginal lands that were previously considered unproductive. This expansion of cultivable area enhances livelihood security, particularly for smallholder farmers in deltaic and coastal regions, by stabilizing farm income under saline conditions. Moreover, salt-tolerant rice contributes to climate resilience by supporting agricultural adaptation to sea-level rise, saline water intrusion, and extreme weather events. From a sustainability perspective, it helps reduce pressure on freshwater resources and fertile agricultural lands, promoting more efficient and climate-smart land use in vulnerable agro-ecosystems.

Limitations and Challenges

Despite its considerable promise, seawater (salt-tolerant) rice still faces several important challenges. Rice grown under extreme saline condition are producing lower yield than the conventionally grown area as sea water rice faces ionic toxicity.*There is limited evidence regarding whether seawater rice exhibits morphological and anatomical adaptations due to ionic toxicity, such as increased cuticle thickness and narrower xylem vessels, as mechanisms for tolerance to saline environments.* In respect to seed quality, varital improvements in taste, grain quality, and overall market acceptability are still needed. Gaps in farmer awareness, limited

access to quality seeds, and weak distribution networks further constrain widespread adoption. Additionally, inadequate infrastructure for managing saline irrigation and drainage systems poses practical difficulties in many coastal and salt-affected regions. To fully realize its potential, sustained research focusing on reproductive-stage salinity tolerance, grain quality enhancement, and climate-resilient breeding strategies is essential.

Conclusion and Perspectives

Future research on seawater rice should focus on strengthening its resilience, productivity, and adaptability under floating farm on ocean or platforms can be developed on floating ocean to withstand in tidal diturbances. Under this conditions , a key priority is the integration of reproductive-stage salinity tolerance genes, as grain filling and flowering are particularly sensitive to salt stress. It should be capable withstanding tidal disturbances, hyper-tolerant strains on **floating ocean platforms can be developed. Concept of floating farm on ocean,** seaweed-based priming solutions that trigger a plant's natural defense systems against osmotic stress. Developing multi-stress tolerant rice varieties capable of withstanding combined stresses such as salinity, submergence, and heat will be essential under climate change scenarios. The use of high-throughput phenotyping platforms can accelerate the identification of tolerant genotypes, while CRISPR-based pyramiding of multiple tolerance genes offers precise and efficient genetic improvement.

Systems biology approaches will further help unravel complex gene networks governing stress responses, enabling more targeted breeding strategies. Equally important is participatory breeding in coastal communities to ensure that developed varieties meet farmers' needs and local agro-ecological conditions. In addition, integrating precision agriculture tools and sensor-based irrigation systems can optimize water and nutrient management, thereby enhancing productivity and sustainability in saline ecosystems**.**Sea water rice represents a transformative approach to addressing salinity-induced agricultural losses and global hunger. By combining classical breeding, molecular genetics, and climate-smart agronomy, salt-tolerant rice can convert unproductive saline lands into sustainable food production systems. However, continuous research on reproductive-stage tolerance, grain quality, and integrated soil management is essential to unlock its full potential. With coordinated global efforts, seawater rice can contribute significantly to achieving Sustainable Development Goal 2 (Zero Hunger).

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THE MYSTERY OF THE MELTING SEA STARS: HOW SCIENCE UNRAVELED A MARINE HORROR STORY

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Abstract

Sea Star Wasting Disease (SSWD) triggered one of the largest marine mass mortality events ever recorded along the Pacific coast of North America, decimating populations of keystone predators such as *Pisaster ochraceus* and *Pycnopodia helianthoides*. For over a decade, the etiology of SSWD remained unresolved, with initial viral hypotheses failing to meet Koch's postulates and environmental hypotheses taking precedence. However, landmark breakthroughs between 2025 and 2026 identified the bacterial pathogen ***Vibrio pectenicida*** **strain FHCF-3** as a primary causative agent. This article reviews the historical timeline, clinical progression, ecological devastation, the shift from viral to bacterial hypotheses, thermal dynamics of the pathogen, and recent environmental DNA (eDNA) advances for species monitoring and conservation.

Key words: SSWD,Vibrio pectenicida ,Sea stars,eDNA, keystone

1. Introduction & Background

Marine disease outbreaks can fundamentally alter entire ecosystem architectures. Starting in 2013, a catastrophic marine mass mortality event known as **Sea Star Wasting Disease (SSWD)** spread rapidly from Alaska to Southern California, drastically reducing sea star populations across all monitored regions (Hewson et al., 2025).Sea stars—particularly the ochre sea star (*Pisaster ochraceus*) and the sunflower sea star (*Pycnopodia helianthoides*)—act as **keystone predators**. In rocky intertidal and subtidal habitats, they keep prey populations such as mussels (*Mytilus californianus*) and sea urchins in check. The sudden collapse of these predators led to:

- **Mussel bed expansion**, smothering intertidal biodiversity.
- **Uncontrolled sea urchin barrens**, which destroyed critical kelp forest ecosystems.

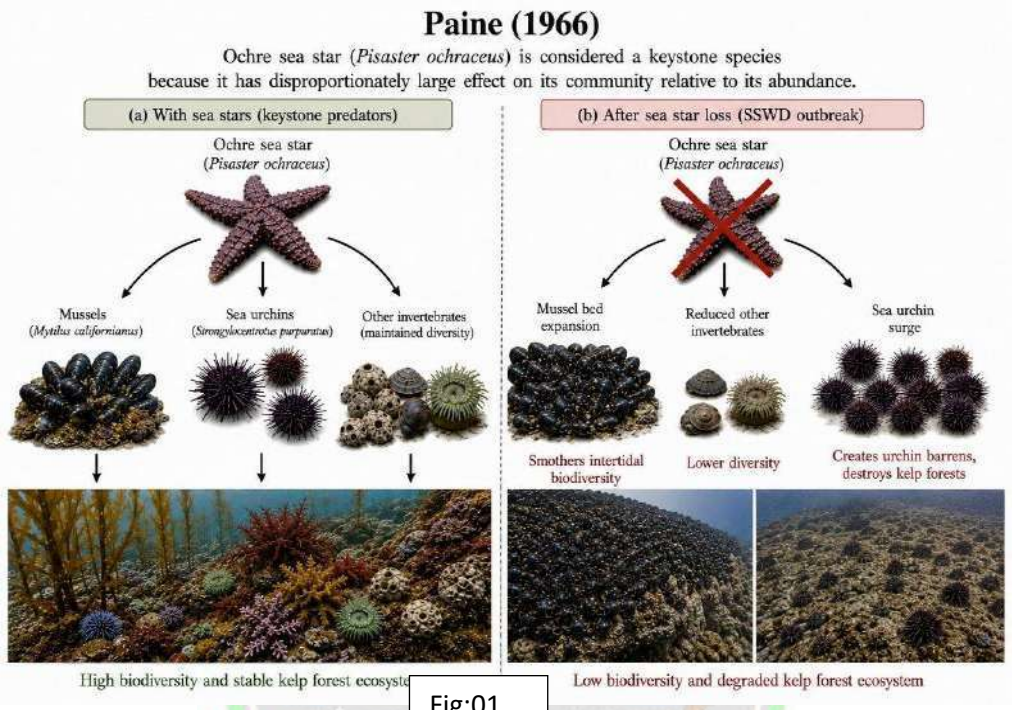


Fig:01

2.Clinical Signs and Pathology

SSWD manifests as a rapid, gruesome tissue degeneration. Affected individuals can progress from healthy adults to disintegrated mounds of organic matter within days. Clinical signs typically follow a distinct progression:

1. **Loss of Body Turgor:** The sea star loses hydrostatic pressure, appearing limp and deflated.
2. **Abnormal Posture:** Curling and twisting of arms occur.
3. **Lesions & Ulceration:** White epidermal lesions form, rapidly leading to open tissue decay.
4. **Tissue Necrosis & Autotomy:** Severe tissue breakdown leads to self-detachment of arms (autotomy).
5. **Fragmentation:** Complete body disintegration occurs, resulting in rapid death.



Fig:02 . Photos courtesy of Mandy Lindeberg, NOAA and Brenda Konar,

3.Geographic Decline and Population Impact

Monitoring across more than 90 Pacific coast sites revealed unprecedented ecological devastation (Hewson et al., 2025):

- **Adult Mortality:** Many locations lost over **75%** of adult individuals, with extreme sites experiencing **>99% decline**. Southern California registered the highest mortality rates.
- **Density Independence:** Contrary to traditional epidemiological models where higher population density drives disease transmission, researchers found **no significant relationship** between initial population density and disease severity.
- **Juvenile Recruitment Bottleneck:** While juvenile recruitment continued in northern regions, survival to adulthood was extremely poor due to an estimated **88.5% juvenile mortality rate**, severely hindering natural population recovery.

4. The Etiological Mystery: From Viruses to Environmental Stress

For over a decade, identifying the specific pathogen responsible for SSWD proved elusive.

4.1 The Densovirus False Alarm

In 2014, Sea Star–Associated Densovirus (SSaDV) was proposed as the primary cause. However, subsequent studies failed to satisfy **Koch's Postulates** (Hewson et al., 2025):

- SSaDV was frequently detected in healthy sea stars.

- Diseased animals often lacked detectable SSaDV.
- Challenge experiments using filtered tissue homogenates could not be consistently replicated.
- Histopathology failed to reveal consistent viral lesions.

4.2 The BLODL Hypothesis

As viral hypotheses lost support, environmental and multifactorial models emerged. The **Boundary Layer Oxygen Diffusion Limitation (BLODL)** hypothesis became the leading explanation:

1. Increased organic matter enrichment in seawater stimulates bacterial proliferation on the skin surface.
2. High microbial respiration consumes localized oxygen, creating a hypoxic boundary layer.
3. Surface tissues experience oxygen deprivation, causing tissue breakdown and permitting opportunistic secondary microbial invasion (e.g., *Tenacibaculum*, *Clostridia*, and ciliates like *Philaster apodigitiformis*).

5. The Breakthrough: Vibrio pectenicida strain FHCF-3

The long-standing mystery experienced a major shift following recent discoveries. *Vibrio pectenicida*, a Gram-negative marine bacterium originally described by Lambert et al. (1998) as a larval pathogen of scallops (*Pecten maximus*), was identified as a primary pathogen associated with SSWD (Blackwood et al., 2026).

Key Findings:

1. **Fulfillment of Koch's Postulates:** Landmark research demonstrated that *Vibrio pectenicida* strain FHCF-3 acts as a causative bacterial agent of SSWD in *P. helianthoides* and other sea star species (Prentice et al., 2025).
2. **Virulence Mechanisms:** Pathogenic strains of *V. pectenicida* produce destructive extracellular products, including cytoplasmic hemocyte-killer toxins capable of damaging host immune cells (Lambert, Nicolas and Bultel, 2001).
3. **Thermal Dynamics:** Blackwood et al. (2026) demonstrated that *V. pectenicida* grows optimally between **6°C and 25°C**, but growth rapidly declines at **27–30°C**. This thermal window explains why elevated seawater temperatures during 2014–2015 acted as

a disease amplifier by accelerating bacterial metabolic activity and host physiological stress without destroying the pathogen itself.

6. Conservation and eDNA Advances

To support the recovery of critically endangered species like the sunflower sea star (*Pycnopodia helianthoides*), researchers developed high-sensitivity, species-specific **environmental DNA (eDNA)** assays using qPCR and droplet digital PCR (ddPCR) targeting the mitochondrial *nad5* gene (NOAA/Hakai Institute, 2026).

This non-invasive tool allows scientists to:

- Detect rare, low-density surviving populations in remote coastal habitats.
- Monitor population recovery without disturbing fragile benthic ecosystems.
- Measure biomass correlations (R^2 \approx 0.67) to assist captive breeding and reintroduction programs.

7. Lessons Learned and Future Directions

The investigation into Sea Star Wasting Disease highlights several key takeaways for wildlife pathology:

- **Histopathology is Paramount:** Molecular sequencing must be paired with tissue histology to confirm primary tissue invasion versus opportunistic colonization.
- **Rigorous Controls:** Challenge experiments require purified isolates to avoid experimental artifacts driven by dissolved organic matter or handling stress.
- **Standardized Monitoring:** Universal disease scoring systems and proper sample preservation (e.g., liquid nitrogen or RNAlater) are critical for international outbreak responses.

Conclusion

Over a decade after Sea Star Wasting Disease (SSWD) devastated Pacific marine ecosystems, the search for its cause has reached a major turning point. The shift from the rejected densovirus theory to environmental models—and ultimately to the identification of ***Vibrio pectenicida*** **strain FHCF-3** as a primary bacterial pathogen—highlights the complex nature of marine disease outbreaks. Ultimately, resolving the SSWD mystery demonstrates the power of combining microbiology, genomics, and field ecology to understand and protect ocean life in a changing climate.

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BIOSPECKLE LASER TECHNIQUE FOR FOOD QUALITY AND SAFETY ASSESSMENT

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Abstract

The assessment of food quality and safety is a critical component of the global food supply chain, necessitating the development of non-invasive, rapid and objective monitoring technologies. Biospeckle Laser (BSL), also known as Dynamic Laser Speckle (DLS), has emerged as a powerful optical tool for evaluating biological activity in various food matrices. This technique relies on the interference of coherent light scattered from living tissues, where microscopic movements such as cytoplasmic streaming, organelle motion and microbial growth induce temporal variations in the resulting speckle pattern. This review provides a comprehensive analysis of the BSL technique, detailing its physical mechanisms and its diverse applications in food science. In the realm of quality assessment, BSL has proven effective in monitoring fruit ripening (e.g., tomatoes and apples), evaluating seed vigor and germination potential across numerous species (e.g., wheat, beans, and sunflowers) and detecting physical damages such as bruising. Regarding food safety, the technique offers sensitive detection of microbial radial growth and pest infestations, such as those caused by *Drosophila suzukii* in berries. Recent advancements in portable hardware and spectral analysis are paving the way for on-site applications. Despite challenges in signal specificity, BSL represents a transformative approach for real-time, non-destructive food analysis.

1. Introduction

Ensuring the quality and safety of agricultural products is paramount for consumer health and economic stability. Traditional methods for assessing food properties often involve

destructive sampling, chemical analysis, or subjective visual inspections, which are time-consuming and labour-intensive. Consequently, there is a growing demand for non-destructive technologies that can provide real-time information on the physiological state of food items.

Biospeckle Laser (BSL) technology has gained significant attention as a non-invasive optical method capable of probing the internal dynamics of biological samples. By utilizing the properties of laser light interference, BSL captures the "biological signature" of a sample, reflecting its metabolic activity and structural integrity (Braga et al., 2024). Unlike static imaging, BSL analyzes the temporal fluctuations of speckle patterns, which are directly influenced by microscopic movements within the tissue (Kato, 2022). This review explores the fundamental principles of BSL and its specialized applications in assessing food quality and safety, highlighting its potential as a diagnostic tool in modern agriculture and food processing.

2. Mechanism

The biospeckle phenomenon occurs when a coherent laser beam illuminates a biological sample. The light is scattered by the sample's internal structures and surfaces, and the scattered waves interfere to form a granular pattern of light and dark spots known as a speckle pattern is shown in the following Figure 1. In non-living materials, this pattern remains stationary; however, in biological tissues, the movement of scatterers such as organelles, cells, flowing fluids, and microbial colonies causes the speckle pattern to fluctuate over time (Aizu et al., 1991; Kato, 2022).

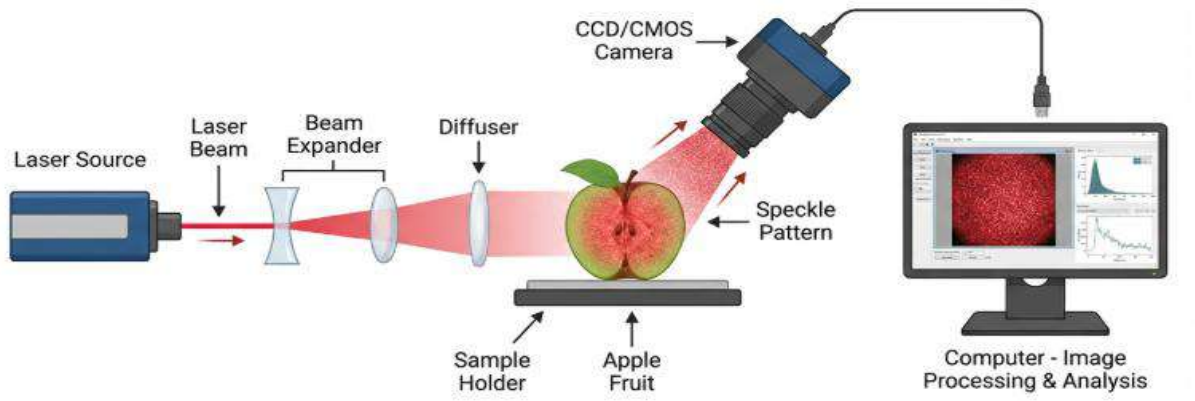


Fig. 1. Schematic representation of Biospeckle Laser Technique

The quantification of these fluctuations is the core of BSL analysis. Several mathematical metrics are employed to interpret the biological activity:

- **Inertia Moment (IM):** Measures the spread of the temporal co-occurrence matrix, providing a direct index of biological activity.
- **Speckle Contrast:** Relates the standard deviation of intensity to the mean intensity, often used to map flow or activity regions.
- **Correlation Coefficients:** Evaluate the rate of decorrelation in the speckle pattern over time, indicating the speed of internal changes.
- **Generalized Difference (GD):** A method used to highlight regions of high activity by calculating differences between successive frames (Janaszek-Mańkowska et al., 2022).

Recent advancements have introduced spectral decomposition and multiple-exposure strategies. Spectral approaches allow researchers to separate signals originating from different physiological processes, such as water motion and respiration (Alves, 2013). The typical experimental setup involves a low-power coherent laser (e.g., He-Ne or diode laser), imaging optics, and a high-speed camera or photodetector to capture the dynamic patterns (Vicentini et al., 2024).

3. Quality Assessment

The application of BSL in food quality assessment spans from pre-harvest monitoring to post-harvest storage and processing.

3.1 Fruit Ripening and Maturity Monitoring

Monitoring the ripening process is essential for determining the optimal harvest time and managing the supply chain. BSL activity has been shown to correlate strongly with climacteric ripening stages. For instance, in tomatoes (cultivars Admiro and Starbuck), BSL activity at 640 nm and 830 nm wavelengths effectively predicted firmness, chlorophyll and carotenoid content, with higher activity observed as the fruit matured (Pieczywek et al., 2018). Similarly, the technique has been applied to apples and *Acrocomia aculeata* fruits to relate biospeckle activity to firmness and other quality attributes (Igarashi et al., 2025).

3.2 Seed Vigor and Physiological Quality

Seed quality is a primary determinant of crop yield. BSL provides a rapid, objective alternative to traditional germination tests. It has been successfully used to distinguish between high-vigor and aged seeds in species like beans (*Phaseolus vulgaris L.*), wheat and sunflowers (Nascimento et al., 2007; Vicentini et al., 2024; Bouzaouia et al., 2024). The technique can track

the progress of germination by monitoring increasing speckle activity in the embryo region (Blotta et al., 2009). Furthermore, BSL is an efficient tool for evaluating the effectiveness of seed priming treatments such as hydropriming and chemical priming with sodium chloride or urea by quantifying the resulting physiological activity (Singh et al., 2018; Singh et al., 2020).

3.3 Detection of Physical Damage and Shelf-life

Physical injuries, such as bruising, often remain invisible to the naked eye in the early stages but significantly reduce shelf-life and quality. BSL can detect bruised regions in apples and potatoes by identifying areas with distinct activity levels compared to healthy tissue (Blotta et al., 2009; Janaszek-Mankowska et al., 2022). In minimally processed foods, such as fresh-cut carrots, BSL has been used to monitor respiration rates and water activity, providing a spectral signature that correlates with mass loss and physiological changes during storage (Alves, 2013).

4. Safety Assessment

Food safety applications of BSL focus on detecting contaminants and biological hazards that may compromise consumer health.

4.1 Microbial Growth and Contamination

The detection of microbial contamination is a critical safety requirement. BSL is highly sensitive to the radial growth of microbial colonies. By mapping regions of high speckle activity on culture media or food surfaces, researchers can identify microbial presence and growth kinetics non-destructively (Al-Ogaidi et al., 2024; Balmages et al., 2025). The frequency response of biospeckle images has specifically been utilized to detect fungal contamination in bean seeds (Janaszek-Mankowska et al., 2022).

4.2 Detection of Pest Infestation

Early detection of internal pest infestations can prevent large-scale crop losses. A notable application of BSL is the detection of *Drosophila suzukii* (spotted wing drosophila) in highbush blueberries. The technique identifies infested fruits by detecting increased biospeckle activity caused by the presence of eggs, larvae and associated pathogens. The Biospeckle Activity Index (BAI) has been identified as a reliable discriminant for separating healthy fruits from those infested by the pest (Janaszek-Mankowska et al., 2022).

4.3 Chemical and Nanoparticle Impact

Safety assessment also extends to the impact of chemical treatments and emerging contaminants. Biospeckle Optical Coherence Tomography (bOCT) has been employed to

monitor the rapid impact of Copper (Cu) and Copper Oxide (CuO) nanoparticles on lentil seeds and leaves. The technique revealed size-dependent physiological changes in plant tissues following exposure, highlighting its utility in assessing the environmental and toxicological risks of nanomaterials in the food chain (Tyagi et al., 2025).

5. Future Trends

The future of BSL in the food industry lies in miniaturization and enhanced signal processing. The development of portable BSL systems using digital cameras and mini-microscopes represents a significant step toward field-based quality control (Vicentini et al., 2024). Furthermore, the integration of BSL with other imaging modalities, such as Optical Coherence Tomography (OCT), provides deeper structural and functional insights (Tyagi et al., 2025).

Research is also focusing on improving signal specificity through advanced mathematical models and machine learning. Distinguishing between various biological processes (e.g., respiration vs. water movement) remains a challenge that requires sophisticated spectral isolation techniques (Alves, 2013). As standardized protocols and automated analysis tools are developed, BSL is expected to become a staple in high-throughput screening for both agriculture and food processing industries.

Conclusion

The Biospeckle Laser technique offers a versatile and powerful platform for the non-destructive assessment of food quality and safety. By capturing the dynamic fluctuations of laser interference patterns, BSL provides a window into the microscopic physiological processes of living tissues. Its applications ranging from monitoring fruit maturity and seed vigor to detecting microbial growth and pest infestations demonstrate its broad utility. While challenges in signal interpretation persist, the trend toward portable, automated, and spectrally refined systems positions BSL as a critical technology for ensuring the integrity and safety of the global food supply.

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HIDDEN PLASTIC IN OUR FOOD: ABSORPTION OF MICROPLASTIC BY PLANTS

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Abstract

Microplastics are the tiny fragments which reach the agricultural soils and absorbed by the plants which causes effect in plants as well as human health and affects the crop productivity causes contamination in agriculture. Reduction of microplastic pollution is done by reduction in use of plastic, use of organic manure, biochar and compost etc.,

Keywords: Microplastics, ultraviolet, plastic pollution, root absorption, plant uptake, food safety, environmental condition, crop productivity.

Introduction

Microplastics become widespread contaminants in the environment. They enter the agricultural soils and plants absorbed buy the roots then transported it the stem, leaves, fruits and vegetables. Management strategies are essential for promoting a sustainable agriculture.

What are microplastics?

Microplastics are tiny fragments generated from breakdown of plastic litter in the environment. The size of the fragments 5mm or 1/16 of an inch which are synthetic made of polymer. Microplastics degrade by geochemical process, ultraviolet radiation, mechanical collision, aging and degradation.

Source of microplastic

There are two sources of plastics, primary source and secondary source. Primary source plastics are plastic pellets, paints, wastewater washing, sewage sludge and vehicle tire wear,

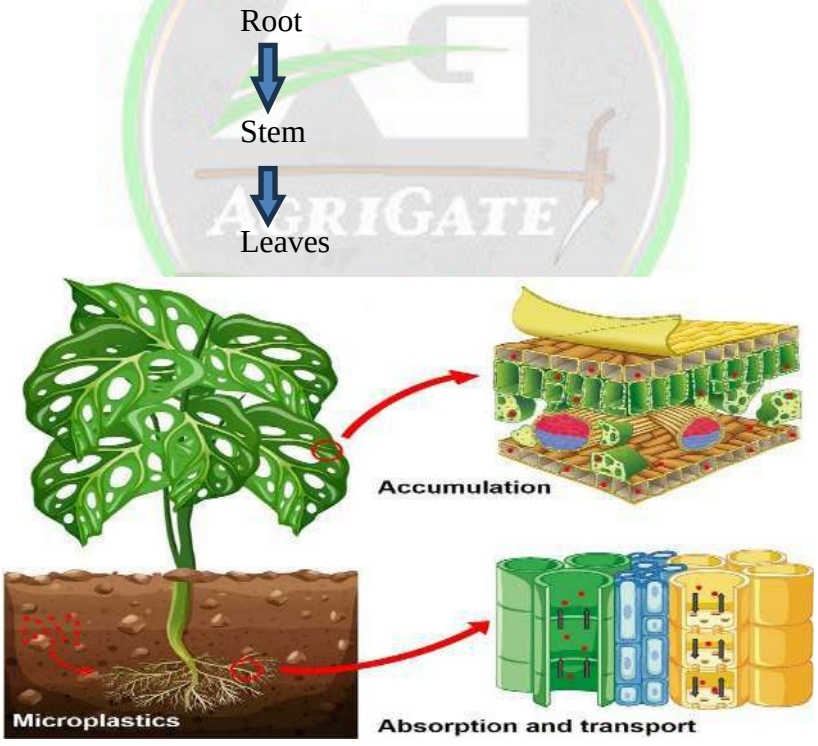
plastic mulch film, greenhouse covers, irrigation tubing. Secondary source plastics are municipal debris, plastic bags, bottle, fishing wastes, farming film. Vehicle tire waste is most important due to rapid increase in number of vehicles.

How microplastics reach agriculture soil?

Microplastics reach agriculture soil through mulch films (LDPE-Low density polythene) which undergoes disintegration(fragmentation), degradation(mineralization) and the fragments mixed in the soil by tillage. Soil organisms like earthworm, mites, collembolans move microplastics from topsoil to deep. Microplastics also reach by sewage sludge, irrigation from contaminated water and airborne deposition.

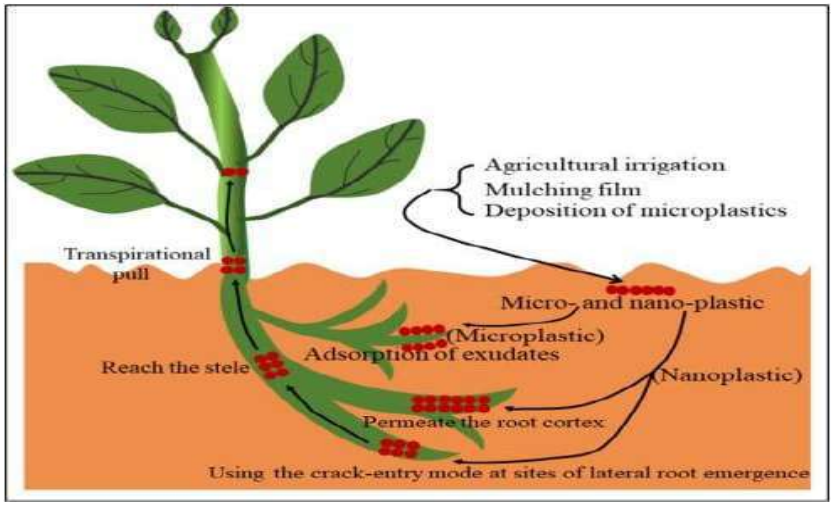
Mechanism of microplastic absorption by plants

Microplastics are enter plants by different ways crack entry (natural gap), apoplastic transport (cell wall), symplastic transport (cell membrane), stomata and waxy cuticle. Transportation takes place by transpiration pull (upward movement).



Effects on plant growth and crop productivity

Absorption of microplastics reduces the seed germination, alter root and shoot growth and effect on nutrient uptake, induce toxic oxidative stress, stunt growth, lower crop yields and decrease chlorophyll content. Accumulation of plastic in tissues induce risk to food chain.



Crops reported to be higher levels of microplastics

Root crops appear to accumulate higher level of microplastics than shallow rooted crops Chinese cabbage-19.84µg g^{-1}. In turkey tomato 3.63±1.39 particles g^{-1} and carrot, radishes, rice also accumulation of microplastic seen.

Levels of microplastic

- In root highest amount of microplastic is accumulated due to direct contact with soil.
- In leaves and stems contain translocated microplastics
- In fruits and grains lowest levels nano plastics have been detected.

The number of plastics in plants usually expressed as,

- µg\g (micrograms per gram)
- ng\g (nanograms per gram)

Contamination in Agriculture

In south India's agricultural microplastic pollution through plastic culture degradation and cities like Chennai, Bengaluru, Hyderabad use municipal wastewater for peri urban farming. Coastal farmlands in Kerala and Tamil Nadu may absorb ocean sourced MPs through tidal floods, sea water intrusion, atmospheric deposition. Industrial/urban emissions also a reason for microplastic contamination. In Northern India, extensive irrigation networks sourcing water from the Ganga, Yamuna, and Sutlej rivers it is significant risks of microplastic infiltration into the farmland. Western India experience high contamination due to urban plastic waste, industrial effluents, and irrigation practices.

Potential risks to human health and the food chain through contamination in agriculture

Microplastic contamination in agriculture is growing threat to ecosystem health, human wellbeing and food safety. Long term exposure linked to metabolic disorders, endocrine disruption and immunological abnormalities. Consuming microplastic and nano plastic agricultural products leads to accumulation in human organs, blood and tissues.

Strategies to reduce microplastic pollution in agriculture

Bio-degradable mulch films can be used which composed of PLA, PHA, PBAT and starch mixture. Organic amendments such as biochar, compost, green manure, farmyard manure decrease the microplastic levels which enhance the microbial population that breakdown polymers. Biochar's effectiveness in reducing microplastic pollution due to high porous structure.

Conclusion

Microplastic contamination becomes a challenge in modern agriculture, affecting the soil health, crop productivity, food safety and plant growth. Microplastic enter human through the food chain. Accumulation poses the potential risk to ecosystem and human health. Reducing plastic use and adopting the biodegradable alternatives, promoting sustainable farming practices are essential to reduce the risk. Awareness is essential to protect the agricultural ecosystem.

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POST-HARVEST TECHNOLOGIES FOR EXTENDING SHELF-LIFE AND MAINTAINING QUALITY OF BANANA (MUSA SPP.)

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Abstract

Banana (*Musa* spp.), a major tropical fruit crop, plays a critical role in global food security, nutrition, and economies, particularly in India, the world's leading producer. Njali poovan (a local cultivar) is valued for its unique flavor and market potential but suffers from high post-harvest losses due to its climacteric nature, rapid ripening, physiological weight loss (PLW), and susceptibility to spoilage. This study, drawing from experimental data on Njali poovan bananas, evaluates the efficacy of various post-harvest treatments—hot water treatment, tap water precooling, cold water precooling, ice flake precooling, edible wax coating (e.g., Waxol 2%), vacuum infiltration with 1% $CaCl_2$, $CaCl_2$ dipping, and control—in minimizing losses and extending shelf-life under ambient conditions. Hands from matured bunches were subjected to treatments and stored at ambient conditions. Key metrics included PLW (%), days to 50% and 100% yellowing, shelf-life (days), and chemical parameters (TSS, acidity, total/reducing/non-reducing sugars). Results showed significant variations. Treatments involving $CaCl_2$ (vacuum infiltration and dipping) and precooling notably reduced PLW compared to control, attributed to retarded respiration/transpiration and strengthened cell walls via calcium pectate formation. Shelf-life was extended most effectively by certain precooling and coating treatments (up to ~17

days in superior treatments vs. ~11-12 days in control), with delayed yellowing (e.g., 5.5–9 days to 50% yellowing). Chemical composition showed limited treatment effects on TSS and sugars (non-significant in many cases), but acidity varied, with control often higher. Hot water and wax treatments helped control microbial decay. Mechanisms include reduced ethylene action, moisture barrier formation, and enzymatic inhibition. These low-cost, accessible treatments offer practical solutions for smallholders, reducing 20-30% typical post-harvest losses in India and supporting export potential. The findings underscore the value of integrated post-harvest technologies. Future research should explore combinations with modified atmosphere packaging (MAP) or 1-MCP for synergistic effects. This work contributes to sustainable banana value chains, minimizing waste while preserving nutritional quality.

1. Introduction

Banana (*Musa spp.*) is one of the most widely cultivated tropical fruits and serves as an important source of carbohydrates, vitamins, minerals, and dietary fibre. India contributes significantly to global banana production. Despite high productivity, considerable losses occur after harvest because banana is a climacteric fruit with a high respiration rate and ethylene production.



Post-harvest deterioration begins immediately after harvest due to:

- High respiration rate
- Excessive transpiration
- Rapid ripening
- Mechanical damage

- Microbial infection

These factors reduce both market value and consumer acceptance. Therefore, adopting suitable post-harvest treatments is essential for maintaining fruit quality and extending storage life.

2. Objectives

The study was conducted to evaluate different post-harvest treatments for:

- Reducing physiological loss in weight (PLW)
- Delaying ripening
- Extending shelf-life
- Maintaining chemical quality
- Improving marketability

3. Materials and Methods

Mature Njalipoovan banana hands were harvested and subjected to eight post-harvest treatments.

Treatment	Description
T_1	Hot water treatment at 45 ± 5°C for 2 minutes
T_2	Tap water dip for 10 minutes
T_3	Pre-cooling with cold water (10°C) for 15 minutes
T_4	Pre-cooling with ice flakes for 10 minutes
T_5	Wax coating (Waxol 2%)
T_6	Vacuum infiltration with 1% Calcium Chloride for 3 minutes
T_7	Dipping in 1% Calcium Chloride for 3 minutes
T_8	Untreated Control

Observations included:

- Physiological loss in weight
- Days to 50% yellowing
- Days to 100% yellowing
- Shelf-life
- Total soluble solids (TSS)
- Acidity
- Total sugars

- Reducing sugars
- Non-reducing sugars

4. Results and Discussion

4.1 Physiological Loss in Weight (PLW)

Physiological loss in weight increased continuously during storage because of moisture loss through transpiration and respiration.

Among all treatments:

- **Vacuum infiltration with 1% Calcium Chloride (T_6)** recorded the **lowest weight loss**.
- The untreated control showed the highest loss.

Reason

Calcium strengthens the cell wall by forming calcium pectate, which:

- reduces respiration,
- decreases transpiration,
- slows water loss,
- maintains firmness.

4.2 Delay in Ripening

Ripening was assessed by observing yellow colour development.

Days to 50% Yellowing

Treatment	Days
Control	5.5 days
Hot water	6.0 days
Tap water	8.5 days
Cold water	9.0 days
Ice pre-cooling	7.0 days
Wax coating	6.5 days
Vacuum infiltration + $CaCl_2$	**9.0 days**
$CaCl_2$ dip	7.0 days

Vacuum infiltration and cold-water pre-cooling delayed yellowing the most.

Days to 100% Yellowing

Maximum delay occurred in

- Vacuum infiltration with $CaCl_2$
- Cold-water pre-cooling

The untreated fruits ripened much earlier.

4.3 Shelf-Life

Shelf-life varied considerably among treatments.

Treatment	Shelf-life
Control	11.0 days
Hot water	12.5 days
Tap water	**17.0 days**
Cold water	16.0 days
Ice flakes	12.0 days
Wax coating	12.5 days
Vacuum infiltration + $CaCl_2$	**17.5 days**
$CaCl_2$ dip	15.5 days

Best Treatment

Vacuum infiltration with **1% Calcium Chloride** produced the **longest shelf-life (17.5 days)**.

4.4 Chemical Quality

Total Soluble Solids (TSS)

TSS ranged approximately from **27.5–30.5°Brix**.

The treatments did not produce statistically significant differences.

Acidity

Acidity showed slight variation.

- Highest acidity: Control
- Lowest acidity: Cold-water pre-cooling

Lower acidity indicates better ripening and eating quality.

Sugars

Total sugars and reducing sugars increased during ripening.

No significant differences were observed among treatments, indicating that post-harvest treatments mainly delayed ripening rather than altering fruit composition.

5. Mechanism of Important Post-Harvest Treatments

A. Calcium Chloride Treatment

Calcium:

- strengthens cell walls,
- delays softening,
- reduces respiration,
- lowers transpiration,
- decreases physiological weight loss,
- delays senescence.

Result:

✔ Longer shelf-life

✔ Better firmness

✔ Improved storage quality

B. Vacuum Infiltration

Vacuum pressure removes air from fruit tissues.

When pressure is released:

- Calcium solution penetrates deeply into tissues.
- Uniform calcium distribution occurs.
- Ripening slows significantly.

Advantages:

- Better calcium absorption
- Longer storage
- Reduced spoilage

C. Pre-Cooling

Immediately after harvest, field heat is removed.

Benefits:

- lowers respiration,
- reduces ethylene production,

- slows ripening,
- maintains freshness.

D. Wax Coating

Wax forms a thin protective film over the fruit surface.

Functions:

- reduces moisture loss,
- lowers respiration,
- improves appearance,
- delays shrivelling.

E. Hot Water Treatment

Hot water destroys surface pathogens and reduces microbial infection.

It also minimizes post-harvest diseases without affecting fruit quality.

6. Importance of Post-Harvest Technology

Post-harvest technologies help to:

- Reduce quantitative and qualitative losses
- Increase shelf-life
- Maintain nutritional quality
- Improve transportability
- Reduce wastage
- Increase farmers' income
- Enhance export potential
- Ensure year-round fruit availability

Effect of post-harvest treatments on PLW during ripening in Njalipoovan banana under ambient conditions

Treatment	3 DAS (%)	6 DAS (%)	9 DAS (%)	12 DAS (%)	15 DAS (%)	18 DAS (%)
T_1	15.600	22.750	29.500	34.600	ND	ND
T_2	10.1	15.9	19.7	22.4	26.	ND

Treatment	3 DAS (%)	6 DAS (%)	9 DAS (%)	12 DAS (%)	15 DAS (%)	18 DAS (%)
	00	50	50	00	00	
T_3	10.450	16.600	19.350	23.200	25.05	ND
T_4	12.050	18.600	20.350	31.500	ND	ND
T_5	12.150	16.250	19.100	22.550	ND	ND
T_6	3.100	4.600	7.100	9.350	15.85	23.15
T_7	12.000	21.150	23.550	27.900	30.20	ND
T_8	15.450	28.600	33.900	42.900	ND	ND
CD (0.05)	**3.234**	**3.191**	**NS**	**NS**	**NA**	**NA**

Effect of post-harvest treatments on chemical composition of ripe fruits of Njalipoovan banana

Treatment	TSS (°Brix)	Acidity (%)	Total Sugars (%)	Reducing Sugars (%)	Non-reducing Sugars (%)
T_1	27.500	0.545	19.880	18.550	1.330
T_2	27.500	0.590	19.600	18.060	1.540
T_3	27.500	0.390	20.930	19.410	1.520
T_4	30.500	0.420	22.450	19.925	2.525

Treatment	TSS (°Brix)	Acidity (%)	Total Sugars (%)	Reducing Sugars (%)	Non-reducing Sugars (%)
T_5	30.000	0.530	21.990	19.235	2.755
T_6	29.000	0.600	21.000	19.140	1.860
T_7	28.500	0.570	22.150	20.725	1.425
T_8	30.500	0.640	23.800	22.845	0.955
CD (0.05)	**NS**	**0.41***	**NS**	**NS**	**1.21***

Note: * = Significant at 5% level; NS = Non-significant.

Effect of post-harvest treatments on days to 50% and 100% yellowing and shelf-life in Njalipoovan banana

Treatment	50% Yellowing	100% Yellowing	Shelf-life
T_1	6.0	8.0	12.5
T_2	8.5	10.5	17.0
T_3	9.0	10.5	16.0
T_4	7.0	7.0	12.0
T_5	6.5	8.5	12.5
T_6	9.0	11.0	17.5
T_7	7.0	9.5	15.5
T_8	5.5	8.5	11.0

Conclusion

The study clearly demonstrates that post-harvest treatments significantly improve the storage performance of Njalipoovan banana. Among all treatments, **vacuum infiltration with 1% Calcium Chloride** was the most effective, resulting in the **lowest physiological loss in weight**, **delayed ripening**, and the **longest shelf-life (17.5 days)**. **Cold-water pre-cooling** also

effectively delayed ripening, while **tap-water pre-cooling** extended shelf-life to 17 days. Although these treatments had little effect on chemical constituents such as TSS and sugars, they successfully maintained fruit quality by slowing physiological processes. Therefore, integrating calcium chloride treatment with proper pre-cooling techniques offers an efficient and economical post-harvest management strategy for bananas, reducing losses and improving market value.

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WEATHER AND CLIMATE CHANGE ON AGRICULTURE

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Abstract

Climate change can affect agriculture through their direct and indirect effects on the crops, soils, livestock and pests. Increase in atmospheric carbon dioxide has a fertilization effect on crops with C3 photosynthetic pathway and thus promotes their growth and productivity. Increase in temperature can reduce crop duration, increase crop respiration rates, alter photosynthesis process, affect the survival and distributions of pest population. Indian agriculture is highly prone to the risks due to climate change; especially to drought, because 2/3rd of the agricultural land in India is rainfed and even the irrigated system is dependent on monsoon rain. Flood is also a major problem in many parts of the country, especially in eastern part, where frequent flood events take place. In addition, frost in north-west, heat waves in central and northern parts and cyclone in eastern coast also cause.

Introduction

Agriculture continues to be the primary source of livelihood for a large section of India's population, with over half of the country's people depending on it for their income and survival. However, the increasing occurrence of extreme weather events such as heatwaves, unpredictable

rainfall patterns, extended droughts, and floods has made farming more challenging and uncertain.

These climate-related changes impact not only farmers but also the broader food system, affecting food availability, prices, and nutritional security. The consequences are not experienced equally across all communities. Small and marginal farmers, who own less than 2 hectares of land, especially women farmers and those in rain-dependent areas, face the greatest difficulties due to limited access to technology, financial support, and adaptation resources. At the same time, soil degradation and the overuse of natural resources pose serious risks to sustainable agriculture, long-term food security, and environmental balance.



CLIMATE CHANGES AFFECT THE CROP PRODUCTIVITY

Climate change affects every stage of agricultural production. Rising temperatures, irregular monsoon patterns, prolonged dry periods, and unseasonal rainfall reduce crop productivity by causing heat stress, disrupting flowering and pollination, and damaging crops during the grain-filling and maturity stages.

Major food crops such as wheat, rice, and maize are particularly vulnerable. Studies project that an increase of 2.5–4.9°C in temperature across India could reduce wheat yields by 41–52% and rice yields by 32–40%.

The impact is further intensified by soil degradation and water scarcity. Continuous monocropping and excessive use of chemical fertilizers have reduced soil fertility by depleting essential nutrients and organic matter. Elevated atmospheric carbon dioxide levels have also

been associated with lower concentrations of protein, iron, and zinc in staple crops such as rice, wheat, and maize. Climate-sensitive horticultural crops, particularly tomatoes, are also highly affected. Their perishable nature, combined with unpredictable weather conditions and fluctuating market prices, often results in significant economic losses for farmers.

CLIMATE CHANGE EFFECT ON SMALL SCALE FARMERS

Small landhold farmers, who make up over 85% of India's farming population, are among the most vulnerable to climate change. Most depend on rainfed agriculture, have limited access to irrigation, credit, crop insurance, and reliable markets, making it difficult to cope with climate-related risks. Frequent droughts and unpredictable weather often lead to crop failures, debt, and reduced income.

In hilly and remote regions, small and marginal farmers face additional challenges such as poor irrigation facilities, limited land, and high costs of adopting climate-resilient crops. Similarly, the adoption of practices like organic farming remains difficult due to financial and resource constraints. Climate change is also increasing migration from agriculture. In coastal regions, rising soil salinity and loss of cultivable land have forced many farmers to leave farming and seek alternative livelihoods, increasing their economic vulnerability.

CLIMATE CHANGE IMPACT ON INDIAN AGRICULTURE (2026):

Climate change is no longer a future concern but a growing challenge for Indian agriculture. Rising temperatures, erratic monsoons, droughts, floods, and groundwater depletion are reducing crop productivity and threatening food security, farmers' livelihoods, and the nation's economy. A 51-year study across 563 Indian districts found that a 1°C increase in temperature can reduce crop yields by about 8%. According to the World Bank, climate change could lower India's agricultural output by 16% and reduce GDP by 2.8% annually by 2030 if effective adaptation measures are not implemented.

Recent surveys conducted and reports from Semi Arid Tropics (SAT) regions indicated that dry root rot (Rhizoctonia bataticola) in chickpea and charcoal rot (Macrophomina phaseolina) in sorghum had increased many folds in last 2-3 years due to rise in temperature and prolonged moisture stress (Sharma and Pande, 2013). Similarly high intermittent rains resulted in outbreak of phytophthora blight in pigeonpea (Phythophthora drechslerif. sp.cajani) in SAT regions in the last 5 years (Pande and Sharma 2009; Pande et al., 2011). I

The major impacts include declining yields of rice, wheat, maize, and pulses, increased water scarcity, changing rainfall patterns, and higher production risks. To address these challenges, India is promoting climate-resilient agriculture through improved irrigation, climate-smart farming practices, crop insurance, resilient crop varieties, and government adaptation programmes. Climate change also creates new opportunities in climate-smart agriculture, sustainable farming, agricultural research, and environmental policy, making it an important area for future careers.

APPROACHES TO BUILD CLIMATE-RESILIENT AGRICULTURE

Several strategies are being adopted to improve climate resilience in agriculture based on local conditions. Cimate-smart agriculture: Practices such as zero tillage help conserve soil moisture, reduce labour and water use, and improve farm profitability. Crop diversification and millet cultivation: Promoting climate-resilient crops like millets enhances food security, nutrition, and water-use efficiency, especially in rainfed areas. Organic and regenerative agriculture: Methods such as crop rotation, agroforestry, and natural composting improve soil health, reduce dependence on chemical inputs, and enhance long-term sustainability. Gradual adoption is more effective than sudden transition.

Community-based adaptation: Self-help groups and local community organizations support farmers by promoting sustainable farming practices, crop diversification, and better access to government schemes. These approaches strengthen agricultural resilience while supporting sustainable livelihoods, food security, and environmental conservation under changing climatic conditions.

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ECONOMIC ANALYSIS OF MARKETING CHALLENGES AND INSTITUTIONAL UNDERUTILIZATION AMONG MAIZE FARMERS IN TAMIL NADU: A REVIEW

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Abstract

Maize (*Zea mays*) has emerged as a pivotal commercial crop in Tamil Nadu, driven by the expanding poultry and starch industries. However, the economic viability of maize cultivation is increasingly threatened by systemic marketing inefficiencies. This paper reviews the economic landscape of maize marketing in Tamil Nadu, focusing on price volatility, the role of intermediaries, and the persistent underutilization of formal marketing institutions such as Regulated Markets (RMs), warehouses, and Farmer Producer Organizations (FPOs). Through a synthesis of existing literature, this review identifies structural, financial, and behavioral barriers that hinder farmers from accessing institutional support, ultimately recommending a strategic shift toward integrated value-chain development.

1. Introduction

In Tamil Nadu, maize is primarily cultivated in districts such as Perambalur, Ariyalur, Dindigul, and Salem. Over the last two decades, it has transitioned from a subsistence crop to an industrial raw material. Despite high production volumes, the "marketing problem"—defined by price instability and asymmetrical information—continues to erode farmer profit margins. While the government of Tamil Nadu has established a robust network of Regulated Markets and warehouse facilities under the Tamil Nadu State Agricultural Marketing Board (TNSAMB),

empirical evidence suggests a profound gap between institutional capacity and farmer participation.

2. Economic Dynamics of Maize Marketing in Tamil Nadu

2.1 Price Stagnation and Cost of Cultivation

The economic analysis of maize farming reveals that farmers are often "price takers." According to data from the Tamil Nadu Agricultural University (TNAU), the cost of cultivation has escalated due to rising input costs (seeds, labor, and irrigation). However, the farm-gate price remains largely dictated by private traders who capitalize on the immediate post-harvest liquidity needs of the farmers.

2.2 The Role of Intermediaries

A significant portion of maize in Tamil Nadu is sold through a multi-layered chain of village traders, commission agents, and wholesalers. Studies indicate that the producer's share in the consumer's rupee in Tamil Nadu often fluctuates between 55% and 65%, significantly lower than what could be achieved through direct institutional marketing. The intermediation cost is high not only due to profit margins but also due to implicit costs like informal credit arrangements.

3. Reasons for Underutilization of Marketing Institutions

The disconnect between Tamil Nadu's maize farmers and formal marketing infrastructure is rooted in a complex interplay of socioeconomic factors.

3.1 Financial Dependency and "Debt-Traps"

The primary reason for bypassing Regulated Markets is the "interlocking of markets." Most small and marginal farmers rely on private traders for informal credit (production loans). These traders act as both creditors and buyers. When harvest arrives, the farmer is contractually or socially obligated to sell the produce to the lender at a price below the prevailing market rate, effectively precluding the use of RMs or warehouse receipt systems (WRS).

3.2 Transaction Costs and Logistical Hurdles

While RMs are designed to provide fair trade, they impose "hidden" transaction costs on farmers:

- **Transportation:** Smallholders often lack the infrastructure to transport bulk produce to designated RMs, which may be located far from the farm gate.

- **Time Delays:** The administrative processes at RMs (weighing, grading, and payment delays) discourage farmers who require immediate cash for the next cropping season.
- **Preference for Farm-Gate Sales:** Private traders offer doorstep collection services, which, while offering a lower price, eliminate the transport and handling costs incurred by the farmer.

3.3 Awareness and Information Asymmetry

Despite the digitization initiatives by the TNSAMB (such as the *e-NAM* integration), many farmers in remote districts remain unaware of the Minimum Support Price (MSP) operations or the process of availing pledge loans against the Warehouse Receipt System.

3.4 Inadequacy of Cooperative Infrastructure

While Primary Agricultural Cooperative Credit Societies (PACCS) are prevalent in Tamil Nadu, their involvement in maize marketing remains limited. Most cooperatives focus on paddy and sugarcane. Maize farmers perceive cooperatives as credit providers rather than marketing platforms, leading to a institutional vacuum regarding maize procurement.

4. Institutional Review: Regulated Markets and Warehouses

The Tamil Nadu Regulated Market system was established to prevent trade malpractice. However, the system is currently facing a transformation crisis:

1. **Infrastructure Gaps:** Many warehouses lack modern cleaning, grading, and moisture-testing equipment, which are essential for maize (which is highly susceptible to aflatoxin contamination).
2. **Market Intelligence:** There is a lack of localized, real-time dissemination of market price fluctuations. Farmers often sell in a panic during peak arrival seasons (February-March), causing a supply glut and plummeting prices.

5. Economic Policy Implications

To improve the economic welfare of maize farmers in Tamil Nadu, the following interventions are critical:

- **Integrated Aggregation:** Strengthening Farmer Producer Companies (FPCs) is essential. FPCs can act as the bridge between small farmers and RMs, aggregating produce to achieve economies of scale and bargaining power.
- **Warehousing Reform:** Expanding the Negotiable Warehouse Receipt (NWR) system is vital. By providing low-interest credit against stored maize, the government can enable

farmers to hold their produce and sell during the off-season, when prices typically appreciate.

- **Digital Extension Services:** Leveraging mobile-based advisory services to provide real-time price data can reduce dependence on traders for market information.

Conclusion

The marketing of maize in Tamil Nadu is currently trapped in a cycle of traditional, trader-centric practices that limit the value realization of the farmer. While the institutional infrastructure (RMs, warehouses) exists, its utility is negated by the immediate financial pressures on farmers and the lack of efficient logistics. A transition toward institutional marketing requires not just physical infrastructure, but a policy focus on breaking the "credit-marketing" link and supporting collective action through FPOs. Future research should focus on the impact of digital platforms on price discovery in these specific Tamil Nadu districts to assess if the "digital divide" is further complicating marketing outcomes.

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THE INVISIBLE HAND THAT FEEDS AND FLEECES: IS THE AGRICULTURAL MIDDLEMAN A SAVIOUR OR A THREAT?

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Introduction

Imagine a farmer in the rain-soaked fields of Punjab, India, or the sunbaked farmlands of rural Kenya, rising before dawn and working until dusk to harvest a bounty of tomatoes. He toils for months battling pests, weather and mounting debt only to watch the fruits of his labour sold for a fraction of what the consumer pays at the city market. Who pockets the difference? More often than not, it is the middleman. The agricultural middleman variously known as a broker, commission agent, trader, aggregator, or mandi trader is perhaps one of the most controversial figures in the global food economy. For centuries, these intermediaries have occupied the critical space between the producer and the consumer, wielding enormous power over prices, market access and food security. In some narratives, they are the unsung heroes who oil the wheels of commerce; in others, they are parasitic exploiters who rob farmers of their hard-earned livelihoods.

The debate has never been more urgent. With over 570 million farms worldwide, most of them stallholders a global food system that wastes nearly one-third of all food produced (FAO, 2023), the role of the intermediary is under the microscope. Agricultural reforms, digital revolutions and a post-pandemic world have shaken old certainties. This article dives deep into

the world of the agricultural middleman examining who they are, what value they add, what damage they cause and whether they are evolving, declining, or simply reinventing themselves.

WHO IS THE MIDDLEMAN?

Understanding the Intermediary Ecosystem

The term 'middleman' is deceptively simple. In reality, the agricultural intermediary universe is a complex, layered ecosystem. At one level, there are village-level traders who buy crops directly from farmers at the farm gate. Above them are wholesale merchants who aggregate produce and sell to urban markets. Commission agents operate in regulated wholesale markets mandis in India, souks in North Africa, trading posts in sub-Saharan Africa charging a fee for facilitating transactions. Exporters, food processors, logistics firms and even retailers can all be considered intermediaries in the broader sense.

According to the World Bank (2022), agricultural value chains in low and middle-income countries involve an average of four to six intermediary layers between the farm and the consumer. Each layer adds a margin. In India alone, research by the National Council of Applied Economic Research (NCAER, 2021) found that farmers receive as little as 20 to 35 percent of the final retail price of vegetables with the remainder captured by intermediaries, transport operators and retailers.

Yet to condemn the middleman purely on the basis of margin is to oversimplify a story with many chapters. The agricultural supply chain is not merely a transaction; it is a web of trust, credit, risk-sharing, storage and knowledge. And in many parts of the world, the middleman is the only person willing or able to provide all of these services at once.

THE CASE FOR THE MIDDLEMAN

Why Intermediaries Still Matter

1. Bridging the Infrastructure Gap

In countries where roads crumble, cold chains are absent and market information is scarce, middlemen are not a luxury they are a necessity. A smallholder farmer in Ethiopia or Odisha, India, often lacks the transport to move produce to markets 50 or 100 kilometers away. The local trader who arrives at the farm gate with a truck is providing a service that no government agency or technology platform can yet fully replicate in remote regions.

Research published in the Journal of Development Economics (Fincham's & Hill, 2008) showed that in Uganda, traders who purchased coffee directly from smallholders provided critical market

access and price information that farmers could not otherwise obtain. The middleman, in this context, was an information equalizer connecting isolated producers to global price signals.

2. Informal Credit and Risk Absorption

Perhaps the least-acknowledged role of the middleman is that of informal banker. In economies where, formal credit is inaccessible to small farmers, the local trader often extends seasonal loans for seeds, fertilizers farm inputs to be repaid at harvest time. This system, known as interlinking of credit and product markets, may carry high implicit interest rates, but it fills a void that banks and microfinance institutions have largely failed to fill.

A study by the International Food Policy Research Institute (IFPRI, 2020) found that over 60 percent of smallholder farmers in South Asia relied on trader-credit for at least part of their agricultural inputs. Eliminating the middleman without providing an alternative credit mechanism, the study warned, would leave millions of farmers without the capital to plant the next season's crop.

3. Aggregation, Storage and Quality Management

No urban retailer, food processor, or exporter wants to deal with ten thousand individual farmers. The middleman performs the critical function of aggregation assembling small lots from numerous producers into commercially viable quantities. Alongside this, many intermediaries provide storage, grading and quality sorting services, reducing post-harvest losses and ensuring that produce meets market standards.

The FAO estimates that post-harvest losses in fruits and vegetables in developing countries can reach 30–40 percent (FAO, 2023). Where cold storage and proper warehousing exist often provided by larger aggregators and traders these losses drop significantly. The middleman, in this sense, is an efficiency gain for the system, even if the benefits are not always equitably distributed.

THE CASE AGAINST MIDDLEMAN

Exploitation, Cartels and Broken Promises

1. Price Manipulation and Monopsonistic Power

The darker side of the middleman story is well-documented. In many agricultural markets particularly in South Asia and Sub-Saharan Africa a handful of large trader’s exercise monopsonistic power: the buyer's equivalent of a monopoly. With few alternative buyers available, farmers have no choice but to sell at whatever price the trader dictates. In Indian

mandis (regulated wholesale markets), commission agents often collude to fix prices, effectively extracting rents from both farmers and buyers.

The Shanta Kumar Committee Report (Government of India, 2015) found that only 6 percent of Indian farmers sell their produce at the minimum support price (MSP), while the vast majority are forced to sell below the guaranteed price due to middlemen's dominance. In some vegetable markets, trader margins ranged from 100 to 400 percent of the farm gate price a stunning indictment of market failure.

2. Debt Traps and Bonded Relationships

The informal credit extended by middlemen, while necessary, often becomes a trap. Farmers who borrow from a trader at the beginning of the season find themselves contractually or socially obligated to sell exclusively to that trader at harvest time, regardless of prevailing prices. This system of tied sales creates dependency, erodes farmer autonomy and perpetuates poverty cycles across generations.

A 2021 study by Oxfam International documented that in cotton-growing regions of Telangana, India, farmers who were indebted to local traders received, on average, 18 percent less for their produce than debt-free farmers selling in open markets. The debt relationship, rather than facilitating commerce, was actively suppressing farmer incomes.

3. Opacity, Misinformation and Market Exclusion

Knowledge is power in commodity markets and middlemen have historically hoarded it. By controlling market price information, they create information asymmetry knowing exactly what the buyer will pay while the farmer has no idea. This allows traders to buy cheap and sell high, with farmers never able to negotiate from an informed position.

The rise of mobile phones and internet connectivity has begun to challenge this dynamic. Platforms like Reuters Market Light, Agri Market (India)and M-Farm (Kenya) now provide real-time price information directly to farmers. A landmark study by Jensen (2007) on the adoption of mobile phones by fishermen in Kerala found that market price information eliminated fish waste by nearly 5 percent and increased fisher profits by 8 percent suggesting that information alone could dramatically reshape the power balance.

DIGITAL DISRUPTION

Is Technology Killing the Middleman?

The 21st century has brought a wave of techno-optimism to agriculture. Digital platforms,

blockchain, e-NAM (Electronic National Agriculture Market), direct-to-consumer models and farmer producer organisations (FPOs) have all been hailed as tools that can eliminate or bypass the traditional middleman.

India's e-NAM platform, launched in 2016, aimed to create a unified national agricultural market, allowing farmers to sell produce online to buyers across the country. By 2023, the platform had onboarded over 1,000 mandis and 1.8 crore farmers (Ministry of Agriculture, 2023). Pilot studies showed that e-NAM increased price realisation for certain commodities by 15–20 percent in connected markets. However, digital literacy gaps, logistics challenges and resistance from entrenched trader lobbies have slowed its broader impact.

Blockchain technology offers a more radical reimagining of agricultural supply chains. By creating transparent, tamper-proof records of every transaction from farm to fork, blockchain could render price manipulation technologically impossible. Pilot projects by Walmart and IBM Food Trust demonstrated that the time needed to trace the origin of food could be reduced from 7 days to just 2.2 seconds (IBM, 2022) a transformation with profound implications for food safety and farmer empowerment. Yet the narrative of the tech-enabled death of the middleman is premature. Research by Reardon et al. (2021) cautions that digital platforms often end up creating new types of intermediaries platform companies, aggregators and logistics firms rather than eliminating intermediation altogether. The middleman, it seems, simply changes his clothes.

POLICY PERSCPECTIVES

Reforming the Agricultural Marketing Chain

Governments across the world have repeatedly attempted to reform agricultural marketing systems, with varying success. India's three controversial farm laws of 2020 which sought to allow farmers to sell outside regulated mandi systems were repealed in 2021 following massive farmer protests. The episode revealed the profound complexity of the middleman problem: reforms designed to weaken exploitative intermediaries were resisted by farmers themselves, partly because dismantling the mandi system risked removing price floors, credit networks and logistical infrastructure that farmers depended upon.

The lesson is that the middleman cannot simply be 'cut out' without providing viable alternatives. Successful reform models share certain characteristics. Farmer Producer Organisations (FPOs) and cooperatives such as the Amul dairy cooperative in India have shown that when farmers collectively aggregate, market and process their own produce, they capture far

greater value. In India, Amul transformed the dairy sector, ensuring that farmers receive over 75 percent of the consumer price of milk compared to just 25–30 percent for vegetable growers still dependent on traditional middlemen (NDDB, 2022).

Contract farming, when well-regulated, offers another pathway. By directly linking farmers to processors and retailers under binding price and quality agreements, contract farming reduces dependence on spot-market middlemen. However, as experience in Punjab (India) and Kenya's horticulture sector shows, contract terms are often loaded in favour of the corporate buyer creating a new form of dependency that critics call 'vertical integration without equity.

GLOBAL COMPARISION

The Middleman Through a Global Lens

The middleman dilemma is not unique to South Asia. Across Sub-Saharan Africa, small-scale traders known as 'jua kali' in Kenya or 'bayam-sellam' in Cameroon are the backbone of food distribution systems that feed hundreds of millions. In Latin America, the domination of large agri-food corporations over value chains has effectively converted traditional middlemen into corporate logistics employees, stripping them of independence while marginalizing smallholder farmers.

The experience of the European Union offers a cautionary tale from the consumer end. As supermarket chains consolidated power in the 1990s and 2000s, they squeezed out traditional wholesalers and local traders. Today, five supermarket chains in the UK control over 65 percent of food retail (Competition and Markets Authority, 2023) and UK farmers report that they are price-takers, not price-setters, despite the absence of traditional middlemen. This points to a crucial insight: the problem is not the middleman, but the concentration of bargaining power. Whether that power resides in a local trader, a national wholesaler, or a global supermarket chain, the effect on farmers can be similarly exploitative.

Conclusion

Saviour and Threat: The Middleman's Paradox

The agricultural middleman is neither purely a villain nor an unqualified hero. He is a paradox simultaneously the solution to and the symptom of a broken food system. In an ideal world, with perfect infrastructure, universal credit access, seamless market information and efficient logistics, the middleman would be redundant. But in the imperfect, resource-constrained, climate-uncertain world in which billions of farmers actually live and work, the

middleman continues to perform functions that no alternative actor has yet fully replicated. The path forward is not elimination but transformation. Farmers must be empowered through better market information, collective action via FPOs and cooperatives, access to formal credit and digital marketing platforms. Regulations must curb cartelization, ensure price transparency and enforce fair trade practices. And governments must invest urgently and at scale in rural roads, cold chains, warehousing and logistics infrastructure that reduces farmers' dependency on any single intermediary.

At the same time, it is important to recognize that in many regions, the local middleman is not an outsider exploiting the farmer but a community member embedded in social and economic relationships built over decades. Reforms that ignore this social fabric risk unintended consequences, as India's farm law protests demonstrated with visceral clarity.

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CAN WEATHER PREDICT WHEN MUSTARD GETS SICK? THE SCIENCE OF CROP DISEASE FORECASTING IN RAPESEED–MUSTARD

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Abstract

Imagine planting a crop in October, tending it through the cold winter months and then watching it wither in February not from drought, not from frost but from a disease that arrived unseen, spread silently and by the time you noticed the dark spots on the leaves had already stolen a third of your harvest. For millions of mustard farmers across the Indo-Gangetic plains of India, this is not imagination. It is a routine risk, recurring season after season with bewildering variability.

Introduction

Rapeseed and mustard together occupy the third position among the world's edible oilseeds, behind only soybean and oil palm in cultivated area and gross oil production (Food and Agriculture Organization, 2024). *Brassica juncea* (L.) Czern. Indian mustard contributes close to a third of India's domestic vegetable-oil production. Yet average farm yields remain stubbornly between 1.2 and 1.4 tonnes per hectare, far below the 2.5 to 3.0 tonnes achievable in well-managed demonstration plots. Among the many reasons for this gap, recurrent disease is one of the most consequential. Disease forecasting is the deliberate attempt to anticipate the onset and intensification of an epidemic before injury becomes measurable. When it works, it replaces the blunt instrument of a calendar-based preventive spray programme with a sharper, threshold-driven intervention: spray when conditions demand it, hold off when they do not. That single discipline waiting for the forecast before reaching for the fungicide -can save money? reduce chemical residues in food and soil and protect beneficial insects from unnecessary exposure.

"A workable forecast converts the prophylactic calendar spray into a threshold-triggered intervention and that single shift can save both money and the environment"
— Madden, Hughes & van den Bosch (2007)

Table 1: Comparative yield losses from principal mustard diseases

Disease	Min. loss %	Typical loss %	Max. loss %	Risk rating	Main season
Alternaria blight	10	35	57	Very High	Jan–Feb
White rust	10	30	60	Very High	Dec–Feb
Sclerotinia stem rot	15	40	80	Extreme	Feb (flowering)
Downy mildew	5	15	30	Moderate	Nov–Jan
Powdery mildew	3	10	18	Low–Moderate	Feb–Mar

The idea of accumulating daily "severity values" integer scores reflecting the day's weather favourability for infection was borrowed from potato farming. BLITECAST, developed in the 1970s for forecasting potato late blight was one of the first computerised disease warning tools anywhere in the world (Krause, Massie & Hyre, 1975). Indian plant pathologists adapted its framework for mustard in the 1990s, eventually creating software platforms such as *Brassicogen* and *PAB-BJEST* that generated probabilistic early warnings for Alternaria blight and white rust from weather inputs.

Table 2: The Alternaria brassicae infection window — risk by temperature and leaf wetness

Leaf wetness (h)	10 °C	15 °C	20 °C	25 °C	30 °C
4 h	None	Low	Low	Low	None
8 h	Low	Moderate	**HIGH**	**HIGH**	Low
16 h	Low	**HIGH**	**HIGH**	**HIGH**	Low
24 h	Moderate	**HIGH**	**HIGH**	Moderate	Low

The four-step logic of a modern mustard disease forecast as follows. **First**, sensors at weather stations or increasingly, low-cost IoT devices inside individual fields measure temperature, humidity, rainfall and leaf wetness on an hourly basis. **Second**, these measurements are compared against known infection thresholds for each pathogen. **Third**, daily severity values are summed over a rolling window of seven to fourteen days. **Fourth**, when the cumulative score crosses the defined threshold, the system issues an advisory: spray now.

Table 3: Evolution of mustard disease forecasting approaches, 1970s to the present

Era	Dominant approach	Representative achievements	Key strength	Key limitation
1970s–1980s	Field surveys; controlled-environment infection experiments	Kolte (1985) monograph; Humpherson-Jones & Hocart (1983) infection thresholds	Established the biological foundation for all later models	Retrospective only: described past epidemics, predicted nothing
1990s–early 2000s	Multiple regression; BLITECAST-adapted severity-value accumulators	First prospective forecasts; India weather–disease correlations established	Gave farmers a 7-day predictive horizon for the first time	Models trained in one location degraded sharply when tested elsewhere
Mid 2000s–2010s	Decision-support software (Brassicogen, PAB-BJEST); GIS risk mapping	Spatial risk maps for north-Indian mustard belt; integrated advisories	Bridged research and extension; improved spatial coverage	Sparse ground-truth data limited accuracy of interpolated risk maps

2010–2020	Remote sensing; multispectral and hyperspectral imaging; UAV surveys	Sub-metre disease detection; pre-symptomatic Sclerotinia thermal signals	Sub-field spatial resolution; early warning before visual symptoms appears	Detecting existing disease is not the same as forecasting future spread
2015–present	Machine learning: CNN, LSTM, random forest, XGBoost; IoT sensors; edge AI	CNN leaf-image diagnosis >90 % accuracy; LSTM severity forecasts 7–14 d ahead; real-time smartphone advisories	Higher accuracy; learnable features; field-scale personalisation possible	Dataset bias; model opacity; limited independent validation across regions

Principal phases of mustard disease forecasting research from the 1970s to the present, with representative achievements and key limitations of each era. CNN = convolutional neural network; GIS = geographic information system; LSTM = long short-term memory network; IoT = Internet of Things; UAV = unmanned aerial vehicle.

The most recent phase has been shaped by the twin arrivals of artificial intelligence and agricultural IoT. Convolutional neural networks trained on thousands of photographs of diseased mustard leaves can now identify Alternaria blight, white rust and downy mildew with reported accuracies above 90 % (Saharan, Verma, Meena & Kumar, 2014).

The pattern that emerges is consistent: models perform well in the location and time period where they were developed and less well when taken elsewhere. A regression model that explains 82 % of the variance in Alternaria severity in Rajasthan may explain only 45 % in West Bengal. A CNN trained on a mix of laboratory and field photographs may achieve 94 % accuracy on its test set and 70 % in an actual field deployment. This cross-site portability problem is not unique to mustard; it affects plant disease forecasting globally but it has been insufficiently acknowledged in the Indian literature.

Three additional limitations, **First**, almost every operational threshold currently in use was calibrated on weather data from 1985 to 2015. Climate change has since altered minimum winter temperatures, dew duration and the timing of cold-humid windows in the *rabi* season. A threshold that reliably predicted an Alternaria epidemic in 1998 may now trigger too late or too early for conditions in 2025. **Second**, forecasting models overwhelmingly treat the host crop as a constant, when in reality different mustard cultivars differ substantially in resistance to *Alternaria*. **Third**, most published models have never been tested in an actual decision-support context. Accuracy on a historical dataset is not the same as utility in a farmer's hand.

"*The next decade will not want for technical tools. What it needs most is the discipline to deploy those tools in ways that protect mustard yields, livelihoods, and the environment*"

Conclusion

Fifty years of work have carried mustard disease forecasting from qualitative weather rules of thumb to multi-station regression, to GIS-integrated decision support and finally to UAV-borne phenotyping and deep-learning sequence models. The intellectual journey reflects both the maturing of plant disease epidemiology and the diffusion of computational tools through agricultural research. What remains unresolved is not a lack of technical sophistication. It is the gap between the research paper and the farmer's decision. A model that achieves 92 % accuracy on a historical test dataset is an academic contribution. A model whose advisory reaches eight million farming families in time to prevent a damaging spray cycle or to trigger a justified one is something more: it is food security in practice. Closing that gap through open data, interpretable AI, climate-resilient recalibration and the deliberate embedding of forecasts within national plant-protection extension systems is the defining challenge of the coming decade.

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ROLE OF THE ALEURONE LAYER IN SEED GERMINATION: THE HIDDEN ENGINE OF CEREAL SEED GROWTH

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Abstract

A crucial phase of the plant life cycle is seed germination, when reserves are released to promote the growth of early seedlings. The aleurone layer, a metabolically active structure that reacts to gibberellic acid (GA_3) generated by the embryo, is crucial to cereal crops. Hydrolytic enzymes, such as α-amylases, proteases, lipases, and cell wall-degrading enzymes, are produced and secreted in response to this hormonal signal. These enzymes transform stored starch, proteins, and lipids into the basic nutrients needed for embryonic growth.By preserving seed dormancy, the antagonistic activity of abscisic acid (ABA) controls this process. Beyond its function in germination, the aleurone layer's abundance of proteins, dietary fibre, vitamins, minerals, and bioactive substances greatly enhances seed vigour, crop establishment, malting quality, and human nutrition. Molecular biology continues to show promise for enhancing seed performance and producing cereals that are climate resilient.

Keywords: Aleurone layer; Seed germination; cereals; Gibberellic acid (GA_3); α-Amylase; Nutrient mobilisation

Introduction

The earliest and most important phase of a plant's life cycle is seed germination. Under favorable environmental circumstances, it is the process by which a dormant seed begins metabolic activity and grows into a seedling. A specialized tissue known as the aleurone layer is essential for starting and maintaining germination in cereal crops like rice, wheat, maize, barley, oats, and sorghum. The aleurone layer is a very active physiological and biochemical center that controls the mobilization of stored food stores for the growing embryo, despite being just one to

three cells thick (Bewley et al., 2013).

The outermost living layer of the endosperm is called the aleurone layer, and it is located right below the seed coat (pericarp and testa). Aleurone cells survive even in ripe dry seeds, in contrast to the starchy endosperm, whose cells die at maturity and mainly store starch. Proteins, lipids, minerals, vitamins, and specialized storage organelles called aleurone grains which include storage proteins and phytin, a significant phosphorus reserve—are abundant in these cells. Because of its special makeup, the aleurone layer can act as a metabolic control center and a reservoir for nutrients during germination (Taiz et al., 2018).

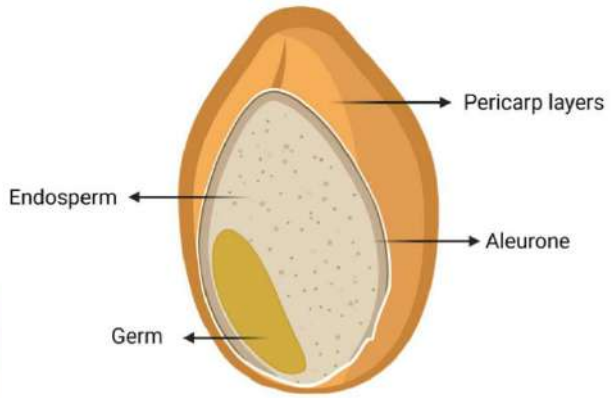


Figure 1. Structure of a Cereal Grain Showing the Aleurone Layer

From Dormancy to Growth

Imbibition, or the dry seed's quick absorption of water, is the first step in seed germination. Hydration induces the production of the plant hormone gibberellic acid (GA_3) in the embryo, enhances respiration, and reactivates cellular metabolism. After diffusing from the embryo to the aleurone layer, the hormone attaches to certain receptors and triggers a series of gene expression events that lead to the manufacturing of enzymes (Yamaguchi, 2008).

One of the most well-understood instances of plant hormone regulation is this hormonal signaling. While abscisic acid (ABA) acts antagonistically by inhibiting enzyme production and preserving seed dormancy, gibberellins induce the transcription of genes encoding hydrolytic enzymes. Accordingly, whether a seed germinates or stays dormant depends on the ratio of GA to ABA (Nonogaki et al., 2010).

Hydrolytic Enzyme Production

The production of hydrolytic enzymes and their secretion into the starchy endosperm is

the main job of the aleurone layer. These enzymes break down complicated food sources into simpler molecules that the developing embryo can consume.

α-Amylase

The most significant enzyme produced during the germination of grain seeds is α-amylase. It breaks down the endosperm's stored starch into maltose, glucose, and dextrins, which supply the energy needed for respiration and seedling development. Gibberellic acid almost completely controls the production of α-amylase(Fincher, 1989).

Proteases

Storage proteins are broken down into amino acids by proteases. The embryo receives these amino acids and uses them to create structural proteins, enzymes, nucleic acids, and other cellular components necessary for quick cell division and tissue development (Bewley et al., 2013).

Lipases

Lipases hydrolyse stored lipids into fatty acids and glycerol. Through β-oxidation and the glyoxylate cycle, these products are converted into carbohydrates that supply additional energy during germination, particularly in cereal species with appreciable lipid reserves (Taiz et al., 2018).

Enzymes that Break Down Cell Walls

Additionally, the aleurone layer secretes cellulases, xylanases, β-glucanases, and other enzymes that break down polysaccharides. These enzymes help radicles develop by softening the endosperm's cell walls, which facilitates the efficient movement of nutrients toward the embryo (Fincher, 1989).

A Unit for Biological Food Processing

One way to think of the aleurone layer is as a highly effective biological food processing plant. It transforms complicated macromolecules into easily transported glucose, amino acids, and fatty acids just when the embryo needs them, rather than passively storing nutrients for later use. This regulated mobilisation guarantees effective use of stored reserves without needless energy loss. Because it synchronises hormonal signals with nutrient mobilisation, scientists frequently refer to the aleurone layer as the "biochemical engine" or "command centre" of cereal seed germination (Bewley et al., 2013).

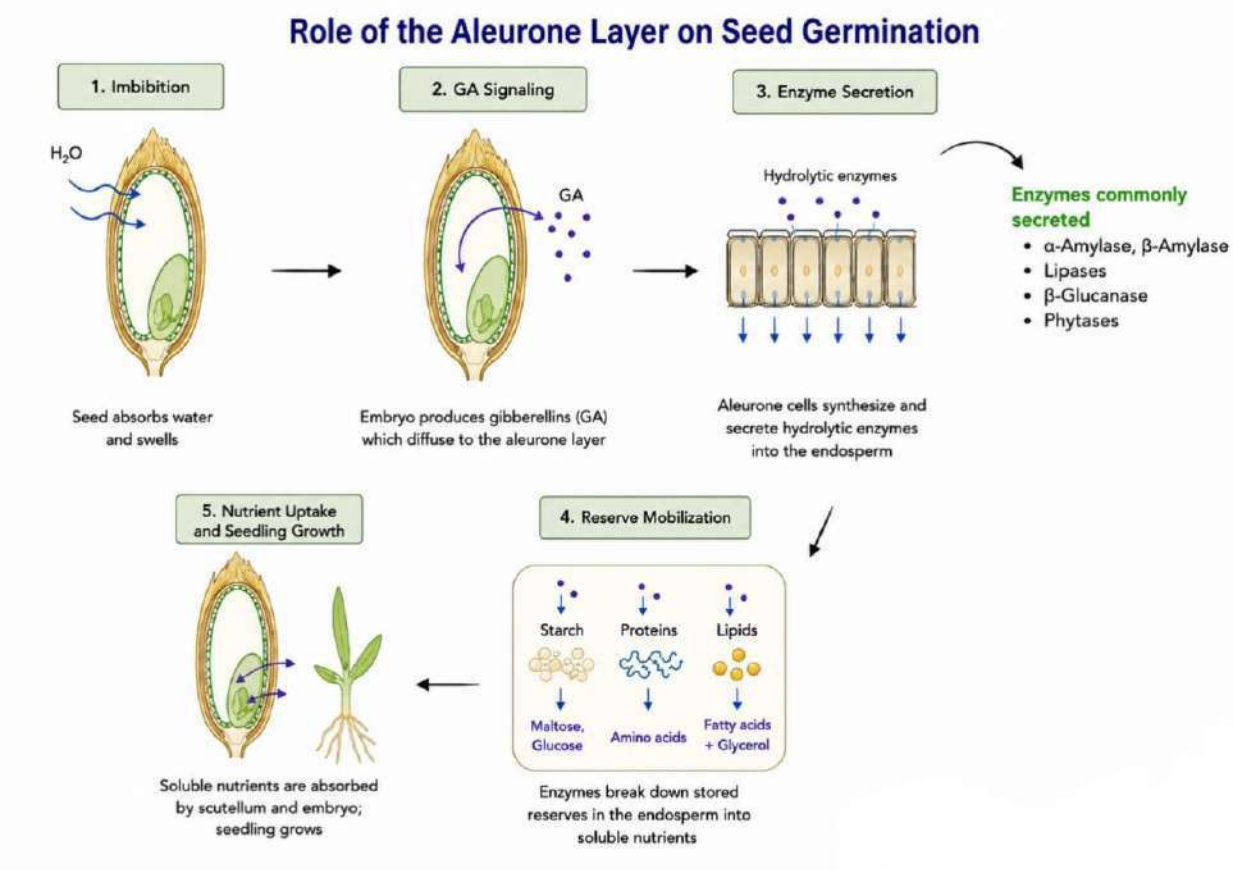


Figure 2: Aleurone layer and its role on seed germination

Importance in Seed Technology

Efficient functioning of the aleurone layer directly influences seed vigour and field establishment. Rapid enzyme synthesis promotes:

- Early germination.
- Uniform seedling emergence.
- Improved seedling vigour.
- Better crop establishment.
- Enhanced tolerance to environmental stresses during early growth.

By initiating metabolic processes related to the aleurone layer prior to sowing, seed priming strategies frequently enhance germination performance, leading to faster enzyme production and better field performance (Paparella et al., 2015).

Relevance to the Brewing and Malting Sector

In barley malting, the aleurone layer is extremely important economically. Aleurone cells produce a lot of α-amylase, β-amylase, proteases, and β-glucanases during regulated

germination. These enzymes transform starch into the fermentable sugars needed to make beer and other goods made from malt. As a result, barley cultivars chosen for malting have great germination capacity and superior aleurone enzyme activity (Briggs, 1998).

Significance in Nutrition

In addition to being crucial for seed germination, the aleurone layer plays a major role in human nutrition. Proteins, dietary fibre, vitamin E, B-complex vitamins, minerals (iron, zinc, magnesium, and phosphorus), antioxidants, phenolic compounds, and bioactive phytochemicals are all abundant in it. A large portion of the aleurone layer is removed along with the bran during grain milling, which lowers the nutritious value of refined flour. In addition to offering several health advantages, such as better digestive health and a lower risk of chronic illnesses, eating whole grains protects the aleurone layer (Fenech et al., 2012).

Recent Research Perspectives

The aleurone layer controls several genes related to enzyme secretion, stress tolerance, food transport, and programmed cell death, according to developments in molecular biology. In order to boost seed vigour, improve germination under abiotic stress, and increase nutrient availability in cereal crops, researchers are looking for ways to alter these pathways through breeding and biotechnology. Sustainable food production and climate-resilient agriculture are anticipated to greatly benefit from such advances (Sreenivasulu & Wobus, 2013).

Conclusion

The aleurone layer represents one of the most remarkable examples of functional specialization in plant seeds. It is only a thin layer of living cells, it controls the biochemical processes that turn a dormant seed into a vigorously growing seedling. It is the metabolic engine of cereal seed germination because it senses hormonal signals from the embryo, synthesises hydrolytic enzymes, mobilises stored nutrients, and supports early seedling development. In addition to its biological role, it has significant significance in agriculture, seed technology, food processing, and human nutrition.

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CAN WE GROW CROPS BEYOND EARTH?: THE FUTURE OF SPACE AGRICULTURE

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Abstract

Space agriculture is the practice of growing crops beyond earth to facilitate easy availability of food for the astronauts rather than getting it from earth This article provides for the technologies available for growing crops in space, the challenges faced by the scientists to grow crops as well as the solution for the challenges faced by them**.**

Introduction

Space agriculture refers to growing of crops in space that may be within the ISS or in the moon, mars that is beyond earth. Many people think the plants cannot be grown in the space. But in real, it is approved that the plants can be grown in the space. As we all know that plants can be grown in earth. Do we think how astronauts in space getting food? The answer might also know to some people that they consume food by small capsules as spirulina. It is used as life supporting system in space. By growing crops in space, astronauts can be able to get oxygen, to reduce carbon dioxide in space and to easily get food with high protein and vitamins without getting it from the earth.

NEED OF SPACE FARMING:

Sometimes the astronauts may plan for the long duration space missions. During the

time, they cannot depend only the food taken from earth, in that case space farming will be helpful.

During the research done in moon and mars by the scientists for assessing the chances to get permanent habitat, they must spend more months or years to complete the research, At the time space farming will be helpful. To make a permanent habitat in moon or mars, there must be a cultivation practice there. Because we won't be completely relying on the food supply from the earth every time. Space farming will be more helpful in those times.

HISTORY OF GROWING CROPS IN SPACE:

The Soviet Union conducted an experiment that showed that seed can be able to germinate in microgravity too in the Salyut space station in the year 1970s to 1980s.They experimented in the plants like Arabidopsis and onions. In 1980s to 1990s, Svet greenhouse was installed on Mir space station. In that greenhouse, they grew the crops like wheat, lettuce and peas. Wheat seeds completed its full life cycle from seed to seed.it tells us that plants can be able to reproduce in space. From 2002 onwards, Russia developed the Ladda greenhouse for the ISS, where peas, wheat, barley and leafy vegetables were grown. They also investigated about the long-term plant growth and seed production for future missions.

In 2014, NASSA introduced the veggie plant growth system on the ISS where the plants like Chinese cabbage, zinnia flowers, red Romania lettuce were grown. In 2015, astronauts ate space grown lettuce after confirming it was safe to consume.

HOW CROPS ARE GROWN IN SPACE:

HYDROPONICS:

It is the growing of the crops in water with added nutrients but without using soil.it is simply soilless media. It is one of the most promising methods for producing fresh food during long duration space mission



Hydroponics in space

AEROPONICS:



It is the method of growing crops in in the air and providing nutrients through the mist where the roots are hanging in the air through which plants get its enough nutrients.

ARTIFICIAL LIGHTING:

In space, there is a high amount of radiation than the earth, so it will damage the plant cells. By using led light that provide the wavelength required for the photosynthesis. we can be able to grow crops without plant damage.



VEGGIE SYSTEM OF CROP PRODUCTION:

It is a vegetable production system developed by NASA to grow crops on ISS. It is a chamber where the crops are grown in a soilless media where the crops are grown in pillow-like substance which contains nutrient media and the required water is injected into the pillows. And it also uses the LED light for photosynthesis. Some of the crops grown in veggie are lettuce, radish, chilli peppers, spirulina, etc.

CHALLENGES OF GROWING CROPS IN SPACE:

Growing crops in space have many difficulties such as there is high radiation in space than earth, microgravity (root can't be able to grow downwards making it to absorb nutrients is

very challenging) in space, there is no chance for natural pollination in plants like bees, etc.so manmade pollination is the only method to pollinate the plants. And one more challenge is there is a limited resource like electricity, water, and nutrients in space, so it should be used efficiently to grow crops.

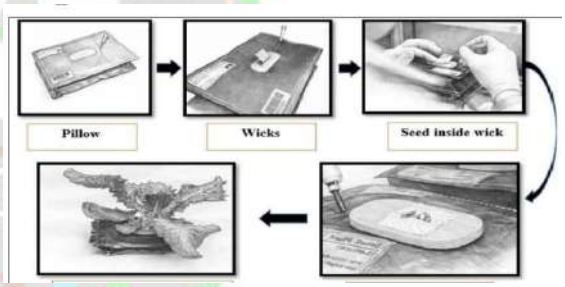
BENEFITS OF GROWING CROPS IN SPACE:

Space agriculture provides the astronauts fresh and nutritious food, it provides oxygen through photosynthesis, removes carbon dioxide, recycles water and organic wastes, reduce the dependency of earth for food, improves the mental health of astronauts by gardening activities.

FUTURE TECHNOLOGIES:

In space high radiation, drought and low gravity are some of the problems in space agriculture, scientist may develop the crops that tolerate these challenges. By using robotics, robots can plant and harvest with minimal effect. If we have a habitat in moon and mars in future green house is built to grow crops using local materials.





Conclusion

By using the space agriculture, it provides food, oxygen and psychological benefits to the astronauts without dependent on earth. Although, there are many technical challenges, scientist done many successful experiments ISS (International Space Station) that shows growing crops beyond the earth is possible. Continued research will help in making the future settlements on Moon and Mars while also providing innovative farming solutions on earth.

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APPLICATIONS OF HAPLOID AND DOUBLE HAPLOID TECHNOLOGIES IN CROP IMPROVEMENT

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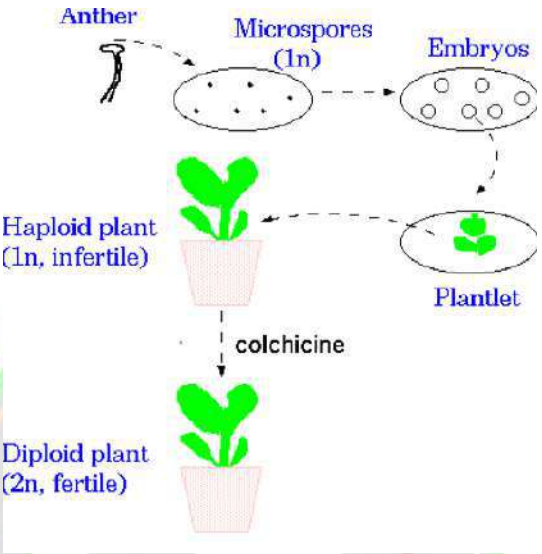
Introduction

The term haploid refers to those plants which have gametophytic number of chromosome as compared to the sporophytes from which they have been developed. Spontaneously in natures they are produced through the process of apomixes and parthenogenesis (i.e. from an unfertilied egg). Looking at the wide and unevitable application of diploids in crop development and improvement many new artificial strategies to develop haploids such as through distant hybridization, chemical treatment, x-ray irradiation, hormone treatment and temperature shock methods have been developed. Broadly they can be divided into two groups:

Monohaploids or Monoploids: As the name suggest they contains only one basic set of chromosome. They are derived from diploid species e.g. rice, maize etc. Polyhaploids: Although they contains the gametophytic set of chromosome, but the basic set of chromosome is more than one e.g. wheat haploids contains 3X basic set of chromosome. Haploid production through anther culture, microspore culture or pollen culture i.e. which uses male gamete is called as *androgenesis* while those which uses female gametes e.g. ovule is called as *gynogenesis*. The basic principle is to stop the development of immature gametic cell into a gamete and force it to develop into a haploid plant.

Haploid production in barley was practiced by wide hybridization; cultivated barley was crossed with wild relative *Hordeum bulbosum*. Chromosomes from *Hordeum bulbosum* were

selectively eliminated during early seed development stage. This is also known as bulbosum technique (Kasha *et al.,* 1974). Percentage of haploid seeds was very low as compare to hybrids when tobacco (*Nicotiana tabacum*) was crossed with *Nicotiana africana*. It is an alternative method for haploid production other than anther culture in tobacco.



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A doubled haploid is produced through chromosome doubling of haploids. Doubled haploid is implicated for plant breeding programme. Pollen, egg cell, anther cell and cells from gametophyte are used for haploid production. The haploids plants are shorter in size and infertile in nature, male and sterile in nature because they are unable to produce pollen or egg due to absence of their homologous pair during meiotic division. For the survival of these haploid the chromosome number must be doubled.

The haploids produced from diploid plants known as monoploid and the haploids derived from tetraploids or hexaploids known as polyhaploids. The dihaploids produced from tetraploid crops help in incorporating genome of wild relatives in breeding programme. Six to seven

breeding cycle is required to produce homozygous line (though they are not fully homozygous, nearer to complete homozygous) but the doubled haploids are the product of one generation of breeding cycle with surely full homozygosity.

When a plant breeder crosses two elite fruit varieties, the resulting offspring are a genetic patchwork, heterozygous, unpredictable, and far from the uniform lines needed for commercial cultivation. To develop a pure-breeding variety, breeders traditionally rely on generations of selfing, a process that can span 7–9 years. For fruit crops with inherent biological hurdles, long juvenile phases, large plant size, cross-incompatibility, and high heterozygosity, this timeline is even more daunting. Here comes the role of haploid and doubled haploid (DH) technology.

A haploid plant contains only one set of chromosomes (n), while a doubled haploid is produced by artificially doubling those chromosomes to restore the diploid (2n) state, but with complete homozygosity. In a single generation, DH plants achieve what conventional breeding requires a decade to accomplish. Since the first reported haploid in fruit crops was induced in kiwifruit using gamma-irradiated pollen in 1971, the field has grown considerably, yielding DH reference genomes for banana, pear, apple, peach, and orange.

Applications of haploid and double haploid in plant breeding

Mapping quantitative trait loci

QTL (Quantitative trait locus) is the locus having many genes, each having additive effect on the traits. But the phenotype is highly influenced by the environment. So it is very difficult to correlate the actual effect of the genes in the phenotype. So many replication trials were practiced in different environment to know the accurate effect of the genes which is a time consuming and laborious job. In these cases DH is the solution to get homozygous for each allele in the QTL. Haploid and doubled haploid populations are used finding markers linked to traits and QTLs through MAS (marker assisted selection) (Forster and Thomas, 2003) and having a reasonable effect on Australian Barley Mapping Project.

Backcross breeding

Doubled haploids produced through gametic embryogenesis need only one breeding cycle in case of heterozygous, cross pollinated and self-incompatible parents. Pure line production is quite easy in self-pollinated crop than cross pollinated one. But 6-7 generation selfing is required for both the cases; after that also we didn‟t get pure line at every loci. Now a day haploid and doubled haploid are the best existing way to get rid of this hectic selfing cycle in

case of perennial crops. In perennial fruits crop it is a good way to produce homozygous line. In case of quantitative trait evolution, application of doubled haploid is highly significant. In nine crop species 130 QTL were mapped through DH. In case of annuals more than 280 new varieties was developed through different methods of doubled haploids (http://www.scri.sari.ac.uk/assoc/COST851/, Forster and Thomas 2005).

Production of homozygous lines

Homozygous plants can be obtained in a single generation by diploidization of the haploid. This kind of production of stable, homozygous dihaploids (DH) in a single generation equivalent considerably shortens the breeding cycle. Generally, colchicineis recommended to diploidize the pollen plants.

Induction of mutations

Detection and isolation of recessive mutants in the haploid state and rapid induction of the mutated gene in a homozygous diploid state is a special merit of haploidy in higher plants. Application of mutagenic treatment at the microspore stage, which is a single celled structure, has the added advantage of obtaining solid mutants.

Genetic manipulation

Haploids are utilized in detecting linkages associated with quantitative inherited characters and could be used in calculating recombination values between linked genes.

How are Haploids Produced in Fruit Crops?

Several approaches have been developed to induce haploids in fruit species, each with its own strengths and limitations:

Methods	**Fruit Crops Applied**
Anther/microspore culture	Citrus, apple, pear, peach, banana
Irradiated pollen parthenogenesis	Kiwifruit, mandarin, walnut, loquat, pear
Intraspecific hybridization	Citrus (diploid × tetraploid)
CENH3-mediated genome elimination	Banana (research stage)
Spontaneous / twin seedling	Blueberry, almond, date palm, citrus

Challenges: What Still Stands in the Way?

Despite clear advantages, several hurdles limit the routine application of DH technology in fruit crops:

1. Low induction frequencies, particularly in polyploid species like banana and kiwifruit.
2. Albinism in regenerated plantlets, caused by plastid abnormalities, is common in cereals and increasingly noted in woody plants.
3. Genotype-specificity: protocols optimised for one cultivar often fail in another, demanding laborious re-optimisation.
4. Long juvenile periods in fruit trees delay the evaluation of DH lines under orchard conditions.
5. Aneuploidy (abnormal chromosome number) can occur in up to 15% of androgenesis-derived plants, complicating downstream use.
6. Chemical chromosome doubling agents like colchicine are toxic and require careful dose optimisation.

The Road Ahead: Emerging Technologies

The next frontier in haploid technology lies at the intersection of molecular biology and precision breeding. CENH3-mediated genome elimination, pioneered in Arabidopsis and now being explored in banana, offers the prospect of haploid induction without in vitro culture by modifying the centromere-specific histone protein. Minichromosome technology, using engineered B chromosomes as 'super vectors' for multi-gene transfer, could create 'super haploid inducers' that autonomously trigger genome elimination without toxic chemicals. B chromosomes, which naturally occur in citrus, banana, and pomegranate, are attractive platforms for this approach.

CRISPR-based editing of haploid lines is also gaining traction. Because DH plants are fully homozygous, edited traits are immediately fixed without the need for additional backcrossing, dramatically compressing the timeline from gene editing to cultivar release. Combining these technologies with advances in high-throughput genomic selection and digital phenotyping promises to fundamentally reshape how fruit varieties are developed in the coming decades.

Conclusion

Haploid and double haploid production is an alternative methodology to overcome the limitation of the breeding. But standardizing the tissue culture protocol protocol for this is an uphill task for the plant researchers which need to be taken care of. As most of the fruit crop releases phenolics during culture affecting their growth and even sometimes the culture died also. So, for future developing standard protocol remains a challenge. Haploid and doubled-

haploid technologies represent among the most transformative tools available to the modern fruit-crop breeder. By compressing decades of conventional breeding into a single generation, DH lines unlock genetic potential that would otherwise remain inaccessible. From sequencing the apple genome to dissecting apple fruit quality traits, the impact of this technology is already tangible. As molecular tools mature and protocols become more robust, haploidisation in fruit crops is set to move from a specialised research technique to a mainstream breeding strategy, delivering better varieties, faster, for growers and consumers alike.

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KUDAVALAI RICE – A TRADITIONAL TREASURE OF TAMIL NADU: A STUDY ON TRADITIONAL RICE CULTIVATION

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Introduction

Vedaranyam, a historic coastal town in the Nagapattinam, district of Tamil Nadu, is a land where nature, tradition, and agriculture blend seamlessly. Known for **its salt pans, rich wet lands, and fertile deltaic soils**, Vedaranyam has been a cradle of traditional farming practices. The region lies close to the Bay of Bengal and is influenced by seasonal monsoon rains, coastal winds, and saline tolerant ecosystems, all of which shape its unique agricultural identity. For centuries, the farmers of Vedaranyam have conserved indigenous paddy varieties that are naturally suited to its environment. Among these heritage grains, **KUDAVALAI RICE holds a special place.** The clayey and saline mixed soils, combined with traditional water management systems, provide ideal conditions for cultivating this resilient rice variety.

Kudavalai has been grown not merely as a crop, but as a part of the cultural and food heritage of the region. Vedaranyam's farming communities follow age-old practices rooted in sustainability, biodiversity, and respect for nature. The continued cultivation of traditional rice varieties like Kudavalai reflects the regions deep agricultural wisdom and its role in preserving Tamil Nadu is native seed wealth. Thus, Vedaranyam stands not only as a geographical location, but as a living landscape that nurtures heritage crops and traditional food systems for future generations. kudavalai rice is a traditional rice variety native to Tamil Nadu, India. It has been cultivated for generations, especially in **the cauvery delta and coastal region.** This variety is valued for its unique medicinal value, good taste and trational farming practices.



ORIGIN OF THE NAME:

The name "KUDAVALAI" comes from the Tamil words

- **KUDAM** – POT
- **VALAI** – CURVE

The paddy panicles bend and curve downwards like a pot when mature, giving this rice variety its distinctive name.

TYPES

- **Paalkudavalai**
- **Panakudavalai**
- **Vellaikudavalai**
- **Sivapukudavalai**
- **Panakaattukudavalai**

The different types of kudavalai rice are identified based on the different husk color.

Crop Duration

- Kudavalai rice is a **medium to long** duration traditional paddy variety that in mainly cultivated during the **Samba**, **Late samba**, **Thaladi** seasons. The total crop duration ranges from about **135** – **150 days** from sowing to harvest.
- After nursery raising , the seedling are usually transplanted into the main field **within 20 days** , and the requires a steady supply of water during its vegetative and flowering phases, Because of its longer growth period, kudavalai rice develops strong plants and well filled grains , making it well suited for traditional , low inputs farming systems and regions with reliable water availability .

Grain and Plant Characteristics

1. The grains are **medium to bold** in size with slightly curved, bowl like shape. Which is the reason for the name.

2. The husk colour generally ranges from **light brown to reddish tones,** indicating the presence of a rice bran layer when unpolished.
3. Unlike modern refined rice varieties, kudavalai retains its natural fiber and nutrients, giving it **mild earthy aroma** and a wholesome taste that reflects traditional food habits.
4. The kudavalai paddy plant grow **tall** and **strong,** with a well-developed root system that helps it withstand local climatic variations. It produces **more tillers** and some varieties produces **awn.**
5. It matures over a duration of about 135 – 150 days , making it suitable for traditional cropping seasons.
6. The **Sturdy stem** structures reduces **lodging** and allows the plant to thrive even under less intensive management. This rice variety is well adapted to indigenous farming conditions and performs reliably without heavy dependence on chemical inputs.
7. Overall, the grain and plant characteristics of kudavalai rice highlight its suitability for sustainable agriculture and traditional food systems, making it a valuable heritage crop of Tamil Nadu.
8. Unlike polished white rice, Kudavalai retains

- **Natural fiber**
- **Bran layer**
- **Earthy taste**

Cultivation Practice

Kudavalai traditional rice is mainly cultivated using age old farming practices that are closely connected with nature. This variety is **well suited for organic inputs** and low input agricultural systems, where chemical fertilizers and pesticides are rarely used. Farmers traditionally rely on **farmyard manure**, **green manure** and **natural soil amendments** to nourish the crop. Kudavalai rice adapts well to clayey and loamy soils and can also grow in slightly saline lands, making it ideal for coastal and delta regions of Tamil Nadu.

The crop requires **moderate rainfall** and is commonly grown under **rain-fed** or flood-irrigated conditions. Kudavalai paddy shows **good tolerance** to **local climate stress**, **pests**, and **diseases** when cultivated following traditional methods. Seeds are usually selected and preserved from the previous harvest, ensuring seed purity and continuity across generations. The strong root system and tall plant structure support steady growth even with minimal external inputs.

These cultivation practices not only reduce the cost of farming but also help maintain soil fertility and ecological balance. Overall, Kudavalai rice cultivation reflects the wisdom of traditional farmers, promoting sustainable agriculture and long- term food security.



Kudavalai Rice Plant

Land Preparation

- Summer ploughing is necessary and proper leveling is done.
- Organic manure or farmyard manure is applied to enrich the soil.
- Water is retained to keep soil moist and fertile.

Nursery Preparation

- Seeds are selected from healthy crops. Nursery bed is prepared separately.
- Seeds are sown directly in the nursery bed.
- For 1 acre of nursery 10 kg seeds are required.
- Transplanting is done within 20 days to the main field.

Water Management

- Controlled irrigation is followed, excess water is avoided.
- Field is drained at required stages.
- Sources of irrigation is mainly RAINWATER in the cultivated region .

In operation of Azolla increases the earthworm which enriches the soil is very useful in kudavalai rice cultivation.

Weed management, pest and diseases management are required whenever it is needed because kudavalai rice is pest and diseases resistance.

Harvest

- Crop matures in 110 – 135 days.
- Harvesting is done through both manually and machine.
- The yield for 1 acre – 25 bags (60 kg /bags)

Nutritional and Medicinal Benefits

- Kudavalai traditional rice is valued not only for its taste but also for its rich nutritional and medicinal qualities. When consumed in its unpolished or semi – polished form, its rice retains essential nutrients such as **dietary fiber** , **complex carbohydrates**, **iron** , and other **natural minerals** .
- The presence of the bran layer makes kudavalai rice more nourishing than refined white rice and supports overall body health. Its slow releasing carbohydrates provide sustained energy, making it an ideal staple food for people involved in physical labour.
- From a health perspective ,
- Kudavalai rice is known to support **good digestion** and **improve gut health** due to its high fibre content. Traditional food practices suggest that regular consumption helps **regulate blood sugar levels**, making it suitable for people people managing diabetes when eaten in moderation.
- Village elders have long belived that kudavalai rice strengthens the body, keeps the digestive system cool, and reduces stomach related discomfort. The natural antioxidants present in this rice also help improve immunity and general wellbeing.
- Overall, kudavalai traditional rice stands as a wholesome food that combines nutrition, medicinal value, and the wisdom of ancestral diets.

Conclusion

Kudavalai rice cultivation is a sustainable, economical, and traditional method that promotes eco – friendly farming. It plays an important role in protecting soil health, saving water and ensuring food security for future generations.

"Ancient grains, modern strength – that's the power of Kudavalai "

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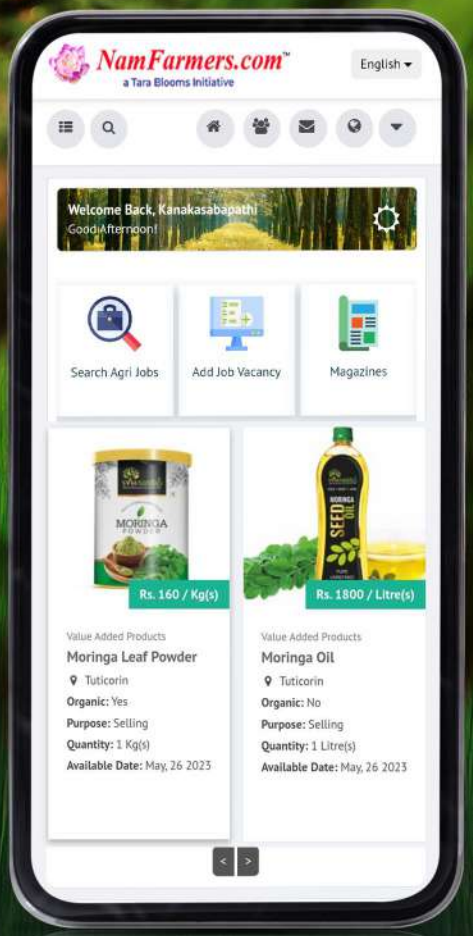
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