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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. 04 – April 2026"** with immense pleasure our team is privileged to dedicate this issue to the book readers. Every year on 23rd April **World Book and Copyright Day** is celebrated to promote the enjoyment of books and reading. It is necessary to recognize the magical powers of books because they generate a link between the past and the future, a bridge between generations and across cultures. **World Earth Day** is celebrated to increase awareness about the importance of the planet**.**

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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BIOCHAR FOR IMPROVING SOIL FERTILITY IN VEGETABLE CROPS

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Abstract

One major challenge in vegetable cultivation is the depletion of soil fertility caused by frequent cropping and excessive use of chemical fertilisers. A promising, long-term solution is biochar, which is produced from agricultural leftovers through pyrolysis in oxygen-limited settings. It improves nutrient-holding capacity, increases water retention, and strengthens soil aggregation. By using biochar, farmers can increase the availability of essential minerals like potassium, phosphorus, and nitrogen, reduce pollution and leaching, and cultivate a healthy community of soil microbes for better nutrient dynamics and overall health. It increases crop vigour, production, yield quality, and post-harvest longevity in vegetable farming. Additionally, biochar improves resistance to abiotic stressors, including salt buildup and drought. As a result, it provides a cost-effective, environmentally sound method for long-term soil fertility restoration and sustained vegetable production.

Keywords: biochar, soil health, vegetable production, nutrient management, sustainable farming.

Introduction: the need for sustainable soil fertility in vegetable production

Sustainable vegetable production is severely hampered by soil deterioration and nutrient depletion, particularly in regions with intense agriculture. Declining soil fertility is caused by factors such as frequent cropping cycles, excessive fertiliser use, and poor management of organic matter. Many farmed soils have low levels of organic carbon, poor structure, and a diminished capacity to retain nutrients, which results in significant losses through gas emissions

and leaching. Maintaining yields and safeguarding the environment requires improving soil health through environmentally responsible management practices. As a carbon-rich amendment for increasing soil fertility, biochar, which is made from biomass pyrolysed in low-oxygen environments, offers significant advantages. By increasing total and plant-available nitrogen by approximately 36%, phosphorus by 34%, potassium by 15%, and cation exchange capacity by nearly 18%, it can improve crops ability to store and absorb nutrients. Additionally, by reducing nitrous oxide (N_2O) emissions by about 29% and nutrient leaching by about 38%, biochar lessens its negative effects on the environment. These results highlight the importance of biochar for long-term sustainability of vegetable production, nutrient-use efficiency improvements, and soil restoration strategies (Bekchanova *et al*.,2024).

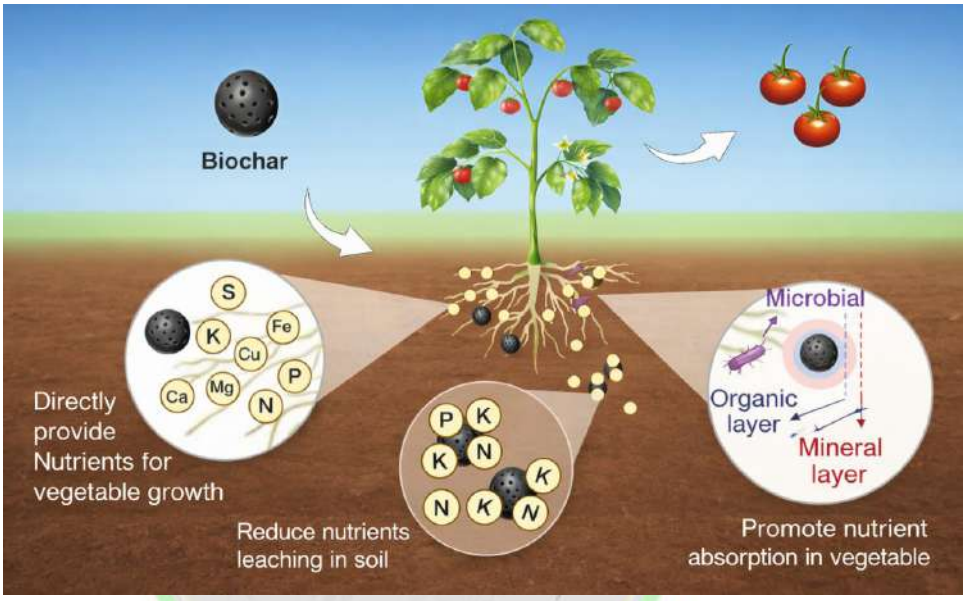
Biochar: a promising soil amendment for modern agriculture:

The thermochemical decomposition of biomass, such as crop residues, straw, wood chips, and farm waste, via pyrolysis under oxygen-scarce (anaerobic) environments, usually between 450–600 °C, produces biochar, a long-lasting carbon-rich material. Through this process, organic matter is converted into a long-lasting, extremely porous carbon structure with a large surface area and important functional groups like hydroxyl and carboxyl. By increasing aeration, water retention, and nutrient retention, its porous structure improves the physical, chemical, and biological characteristics of soil. According to research, nutrient levels in various biochars range between 0.2 and 1.36%, with ash concentration varying from 3.88 to 14.7%, depending on feedstock type and pyrolysis settings. These properties allow biochar to collect and store important nutrients like nitrogen, phosphate, and potassium, while also providing perfect conditions for beneficial soil bacteria. Given its longevity and versatility, biochar is an excellent soil conditioner for increasing fertility and developing sustainable vegetable cultivation (Xu *et al*.,2025).

How biochar improves soil fertility and nutrient availability:

Biochar improves soil fertility and nutrient delivery for vegetable crops by improving physical, chemical, and biological soil characteristics. Its porous structure increases surface area, facilitating better aggregation, aeration, and water retention to maintain moisture and nutrients over time. Biochar-treated soils have improved fertility indicators such as pH of 8.25, electrical conductivity of 0.79 dS m^{-1}, and organic carbon of 3.93%. They also have higher levels of critical nutrients such as nitrogen (1080.75 kg ha^{-1}), phosphorus (46.64 kg ha^{-1}), potassium

(985.6 kg ha^{-1}), sulfur (38.42 kg ha^{-1}), calcium (344.3 kg ha^{-1}), and magnesium (16.9 kg ha^{-1}). The material's porosity and high cation exchange capacity help to reduce leaching while increasing nitrogen, phosphorus, and potassium retention.Biochar also stimulates beneficial soil bacteria, which improves biological processes and nutrient cycling for overall soil health. These improvements in structure, hydration, microbial function, and nutrient access promote vigorous plant growth and yields, with vegetable fresh leaf production increasing by up to 63.7% and fresh weight gains reaching 126.1% in modified soils (Hussain *et al*.,2025).



(Xu *et al*.,2025).

Benefits of biochar application in vegetable crops:

Cow bone biochar applied to vegetable crops significantly improves soil fertility, plant vigour, and produce quality. In sandy loam soils, it increased organic matter by 130%, nitrogen by 33%, phosphorus by more than 300%, calcium by almost 90%, and magnesium by 288% compared to controls. Tomato plants responded strongly, with height gains of up to 76%, stem diameter gains of 72%, and fruit yields increasing by nearly 300% at peak application rates. Fruit nutrient absorption increased considerably, by 68%, 328%, 184%, and 143%, respectively. Protein levels in fruits increased by 147-217%, whereas lipids and carbohydrates decreased by up to 73% and 74%, respectively. Notably, shelf life increased by more than 70%, while post-harvest weight loss decreased by 42%. These findings show biochar's dual role in soil enrichment and the delivery of nutrient-dense, long-lasting veggies, establishing it as a valuable asset for environmentally conscious farming (Adekiya *et al*.,2025).

Conclusion

Biochar is gaining attention as a revolutionary soil conditioner for vegetable growing, increasing fertility, yields, and crop quality while reducing the need for chemical fertilisers. Its porous structure increases soil porosity by up to 16.7% while lowering bulk density by 11.3%, resulting in ideal root zones. In coarse-textured soils, water availability increases by 25.6%, whereas aggregate stability increases by 6% to 217%, depending on biomass source. Biochar is excellent at collecting nitrogen, phosphate, and potassium to reduce leaching and improve plant absorption. Tomato rhizosphere soils modified with biochar support growing microbial communities, fungi by 363%, bacteria by 82.5%, and actinomycetes by 63.7%, resulting in improved nutrient turnover and pathogen resistance. Rice husk and cottonseed husk biochars increased tomato output by 20% at 67.5 t ha^{-1}, with long-lasting soil benefits even without fertilisers in some instances. Biochar also improves vegetable resistance to drought and salt stress, reduces disease rates (for example, tomato wilt is reduced by 89% when combined with microorganisms), and increases nutritional content. As a result, it provides farmers with resilient, productive systems that promote soil health in the face of climate change while reducing dependency on synthetic inputs (Xu *et al*.,2025).

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SILENT THREATS IN SHRIMP FARMING IN INDIA: DISEASE IMPACTS AND ECO-FRIENDLY SOLUTIONS

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Summary

Shrimp aquaculture is vital to India's economy but is threatened by diseases such as EHP, White Feces Syndrome, and vibriosis, which reduce growth and productivity. These diseases are linked to poor water quality, stress, and farm mismanagement. While antibiotics were traditionally used, concerns over resistance and environmental impact have shifted focus toward sustainable approaches. Plant-based disease management using medicinal plants like garlic, neem, turmeric, and aloe vera enhances immunity, improves gut health, and reduces pathogen load. Farmer practices using natural products further support shrimp health. Combined with probiotics and biofloc systems, these eco-friendly strategies offer effective and sustainable solutions for disease control in shrimp aquaculture.

Key words: Shrimp aquaculture, EHP, WFS, Vibriosis, Medicinal plants, Immunostimulants

Introduction

Foods of animal origin play a crucial role in ensuring nutritional security, health, and livelihoods for the growing global population. Fish, in particular, is recognized as a vital source of essential micronutrients and is recommended in food security programs. India is the third-largest fish producer globally and the second-largest in aquaculture, contributing about 8% of global production. Shrimp aquaculture is a major contributor to India's fisheries sector, covering approximately 0.17 million hectares and supporting nearly 100,000 farming families, with total employment reaching 1.2 million. Shrimp production has increased from ~70,000 tonnes in 1994 to ~800,000 tonnes in 2023, contributing 6.2% of global output. Andhra Pradesh dominates

production, followed by West Bengal, Gujarat, Odisha, and Tamil Nadu (MPEDA, 2025). India's seafood exports reached 1.78 million metric tonnes (USD 7.38 billion), with shrimp contributing 40% of quantity and 66% of value. The whiteleg shrimp (Litopenaeus vannamei) accounts for over 90% of production.Despite rapid growth, shrimp aquaculture faces major challenges such as disease outbreaks, poor feed efficiency, and climate change. Diseases significantly affect production, livelihoods, and food security. Viral infections like White Spot Syndrome Virus (WSSV) and Early Mortality Syndrome (EMS), along with parasitic infections such as Enterocytozoon hepatopenaei (EHP), have caused severe economic losses (Tandel et al., 2017). Globally, shrimp diseases cause losses of up to USD 6 billion, with Asian aquaculture alone losing around USD 1 billion annually.

Major Diseases in Shrimp Aquaculture

1. Hepatopancreatic Microsporidiosis (HPM)

Aetiology and Distribution

HPM is caused by the intracellular microsporidian parasite Enterocytozoon hepatopenaei (EHP), which infects the hepatopancreas of shrimp, particularly L. vannamei. Unlike acute pathogens, EHP does not cause high mortality but leads to severe growth retardation. Initially reported in Malaysia (1989) and Thailand (2009), EHP is now widespread across major shrimp-producing countries, including India, causing production losses of 20–30%.

Clinical Signs: Slow or stunted growth**;** Uneven size distribution (growth disparity in pond)**;** Reduced growth rate**;** High Feed Conversion Ratio (FCR) (2.9–3.0)

Transmission

EHP spreads horizontally through ingestion of spores via contaminated feed, water, feces, cannibalism, and live feeds such as Artemia and polychaetes. It infects all life stages.

Diagnosis

EHP infection is often asymptomatic in early stages, making detection difficult until growth retardation becomes evident. Reliable and early diagnosis is therefore critical for effective farm management and biosecurity. Molecular diagnostics target specific virulence-associated genes, including: SSU rRNA (small subunit ribosomal RNA), SWP (spore wall proteins), PTP2 (polar tube protein 2), NFS1 (cysteine desulfurase 1). These markers are involved in key processes such as host cell attachment, spore invasion, and parasite survival, making them effective detection targets. A wide range of diagnostic techniques are available,

including: Microscopy (spore observation), Histopathology (tissue-level changes), Electron microscopy (ultrastructural analysis), Immunoassays. Advanced molecular methods include: PCR (Polymerase Chain Reaction), Nested PCR, qPCR (quantitative PCR), LAMP (Loop-mediated isothermal amplification), RPA (Recombinase polymerase amplification).Among these, PCR and qPCR are considered gold-standard techniques due to their high sensitivity and specificity.

Prevention and Control

EHP spreads through highly resistant spores that are ingested by shrimp and released back into the environment, enabling continuous reinfection. These spores can persist in pond sediments for weeks to months, making eradication difficult. Therefore, management relies primarily on strict biosecurity, early diagnosis, and continuous monitoring, especially when signs such as slow growth and reduced feed intake appear. An integrated approach involving hatchery, pond, feed, and water management is essential, including the use of certified EHP-free post-larvae, water disinfection, broodstock screening, and optimal stocking density. Environmental pH plays a key role in spore inactivation, as alkaline conditions promote spore germination and reduce infectivity. Accordingly, treatments such as sodium hydroxide application, quicklime to raise pond pH above 12, and disinfectants are effective. NACA also recommends the application of potassium permanganate (>15 ppm) or chlorine (>40 ppm) to control soil-borne spores. In addition, proper pond drying after harvest, along with the use of treated water and pathogen-free feed while avoiding live feeds, is critical for preventing reinfection.

2. White Feces Syndrome (WFS)

Causative Agents and Distribution

WFS is a multifactorial disease often associated with EHP and Vibrio spp. (V. parahaemolyticus, V. alginolyticus). First reported in Thailand (2009), it is now widespread in India, especially in Andhra Pradesh, Tamil Nadu, Gujarat, and West Bengal**.**

Clinical Signs

WFS-affected shrimp exhibit characteristic gross signs including an opaque white gut, a yellowish gelatinous layer surrounding the hepatopancreas, and white or yellow fecal strings floating on the pond surface. Infected shrimp also show lethargy, growth retardation, reduced feed intake, and a loose carapace. In severe cases, additional signs such as striated white muscles and black necrotic gills have been reported, particularly in *Penaeus monodon*. Pond-level signs

typically become evident around two months of culture, while early indications such as abnormal fecal matter may appear as early as 35 days.

Diagnosis

Diagnostic methods are divided into traditional and molecular methods. Traditional methods include applying serological techniques, histopathological assessment, morphological pathology, electron microscope, and bioassays. Molecular methods consist of using PCR/RT-PCR (Reverse transcriptase PCR), real-time PCR, transcriptome analysis, and gene sequencing.

Control Measures

White feces syndrome (WFS) in shrimp can be controlled through strict biosecurity and good management practices, including maintaining optimal water quality, proper disinfection, worker hygiene, and the use of high-quality feed. Avoiding overstocking, especially during summer, and regularly removing floating feces and sludge help reduce pathogen load, while reservoir ponds prevent contamination from untreated water. Feed-based interventions such as garlic additives, probiotics, β-glucans, and organic acids improve gut health, inhibit *Vibrio* growth, and enhance disease resistance. Probiotics like *Bacillus subtilis* act as bioremediators and growth promoters, improving survival and immunity. Additionally, biofloc technology provides a sustainable solution by improving water quality, reducing pathogen levels, and enhancing microbial balance, thereby lowering the risk of WFS outbreaks

3. Vibriosis

Aetiology

Vibriosis is caused by opportunistic bacteria such as *Vibrio parahaemolyticus*, *V. harveyi*, and *V. alginolyticus*. These bacteria proliferate under stress conditions like poor water quality and high stocking density.

Associated Diseases

Disease / Condition	Causative Agent(s)	Clinical Signs
Vibriosis	*Vibrio spp.* (*V. harveyi*, *V. parahaemolyticus*, etc.)	Necrosis, slow growth, melanization, bioluminescence, ulcers, reduced feeding
Early Mortality Syndrome (EMS) / AHPND	*V. parahaemolyticus*, *V. harveyi* (pirA & pirB toxins)	Lethargy, pale hepatopancreas, empty gut, loose shell, rapid mortality within 20–30 days of culture

Luminescent Vibriosis	*V. harveyi*	Body glow in dark, lethargy, slow growth, muscle opacity
Brown Spot Disease (Seagull Syndrome)	*V. harveyi, V. parahaemolyticus, V. vulnificus, V. alginolyticus*	Brown/black spots, stooped posture, necrosis, surface swimming
Bacterial Septicemia	*V. alginolyticus, V. anguillarum, V. parahaemolyticus*	Lethargy, abnormal swimming, reddish pleopods, melanized lesions, gill erosion
Necrosis (HP, muscle, appendages)	*Vibrio spp., Pseudomonas, Aeromonas, Flavobacterium*	Milky white body, melanization, white patches, tissue damage
Running Mortality Syndrome	*V. parahaemolyticus, V. azureus*	Carapace spots, mucus on hepatopancreas, antennal cut, cannibalism, mortality

Control Measures

Vibrio infections in shrimp are mainly triggered by poor water and soil quality, high organic load, overstocking, and low-quality feed. Since *Vibrio* cannot be completely eliminated from aquatic systems, prevention relies on good farm management practices such as maintaining water quality, using healthy broodstock, reducing stress, and proper feeding. Although antibiotics were traditionally used, their overuse has led to resistance and environmental concerns, prompting a shift toward sustainable alternatives. Probiotics and prebiotics improve gut health, enhance immunity, and suppress pathogens, while microalgae, macroalgae, and plant-based compounds (e.g., garlic and green tea extracts) provide natural antimicrobial and immunostimulatory effects. Biofloc technology further improves water quality and reduces pathogen load, enhancing growth and survival. Emerging approaches such as bacteriophages and nanoparticles offer targeted and effective control of *Vibrio*. Overall, strengthening shrimp immunity through natural and eco-friendly strategies is key to reducing disease impact and minimizing reliance on antibiotics.

Plant-based disease management in shrimp aquaculture

Plant-based disease management plays a vital role in shrimp aquaculture by enhancing the immune system through immunostimulants. Immunostimulants are commonly administered through feed due to their cost-effectiveness and ease of use. Among the various types studied, plant-derived compounds have gained significant attention in India because of their availability, eco-friendly nature, and broad-spectrum effectiveness in improving disease resistance.

Plant-Based Natural Products Used by Indian Farmers Against WFS in *Litopenaeus vannamei (*Palanikumar et al., 2019*)*

S.No	Natural Product	Plant Source	Dosage	Application Method
1	Lemon juice	Citrus limon	Fifty milliliters of squeezed and filtered lemon juice per 1 kg feed	Mixed with 1 kg of feed and allowed to dry at shadow place for 30 min before feeding
2	Garlic homogenate	Allium sativum	Twenty grams of garlic paste + 50 ml of feed binder per 1 kg feed	Garlic paste and feed binder are mixed with feed and allowed to dry at shadow place for 15 min before feeding
3	Ginger paste	Zingiber officinale	20 g of ginger paste + 50 ml of feed binder per 1 kg feed	Mixed with feed and allowed to dry at shadow place for 15 min before feeding
4	Palm jaggery (treacle)	Borassus flabellifer	30 ml of jaggery treacle per 1 kg feed	1 kg jaggery dissolved in 1 L water, boiled to treacle condition, cooled, mixed with feed and allowed to dry at shadow for 15 min before feeding (usable up to 5 days)
5	Black gram flour	Vigna mungo	50 g of grinded black gram + 30 ml of feed binder per 1 kg feed	Mixed with feed and allowed to dry for 30 min at shadow before feeding

Applications of medicinal plants in shrimp aquaculture (Bharathi et al., 2021)

S.No	Plant Name	Scientific Name	Key Function	Dosage / Level Used	Application / Observation in Shrimp
1	Aloe vera	Aloe vera	Antibacterial, antiviral, antioxidant, immunostimulant	Not specified (varies); 4% in diet (general)	Acts as protective agent against WSSV and *Vibrio parahaemolyticus* in cultured shrimp
2	Neem	Azadirachta indica	Antibacterial, antiviral, antifungal, immunostimulant	Not specified; pond application and extract-based usage	Neem extract inhibited *Vibrio* spp. and reduced disease incidence in shrimp culture systems
3	Turmeric	Curcuma longa	Antibacterial, antioxidant, immunostimulant	25% extract incorporation	Showed antibacterial activity against *Vibrio harveyi* and improved survival in Penaeus monodon
4	Garlic	Allium sativum	Antimicrobial, antiparasitic, immunostimulant	Not specified (used as extract/powder)	Controlled black gill disease in Penaeus indicus and improved disease resistance
5	False daisy	Eclipta alba	Antibacterial, antioxidant, immunomodulatory	1% incorporation	Improved growth, immunity and reduced viral load in Penaeus monodon
6	Veld grape	Cissus quadrangularis	Growth promoter, antioxidant, immunostimulant	Not specified	Improved growth performance, feed utilization and survival in Macrobrachium rosenbergii post larvae
7	Indian copperleaf	Acalypha indica	Antibacterial, antifungal, antioxidant, immunostimulant	Not specified	Improved immunity, growth, and survival against *Vibrio harveyi* in Penaeus indicus

Conclusion

The impact of diseases on aquatic animals is profound, influencing both the health of individual organisms and the broader aquaculture industry. The interplay between host, pathogen, and environmental conditions is critical in determining disease outcomes. The rapid expansion of aquaculture has intensified these challenges, with emerging diseases threatening both ecological balance and economic stability. Addressing these issues necessitates ongoing

research, improved surveillance, and the implementation of effective disease management strategies. By enhancing our understanding of the factors contributing to disease outbreaks and developing targeted interventions, we can better protect aquatic health and sustain the benefits of aquaculture for the future.

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NEMATODES: THAT CAN ATTACK ON AERIAL PLANT PARTS

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Introduction

Most people visualize plant-parasitic nematodes (PPN) as strictly subterranean microscopic worms, hidden in damp soil and gnawing exclusively at plant roots. This common perception often leads to the misconception that these pests cannot survive outside the soil or lack the ability to attack above-ground plant structures. However, a specialized group of these "hidden enemies" has evolved to transcend the soil boundary, colonizing aerial tissues such as stems, leaves, flowers, and even seeds. For college students and progressive farmers, understanding these aerial invaders is vital because they bypass traditional soil-based management practices. Furthermore, farmers frequently misidentify the resulting damage as being of insect or microbial origin, leading to the ineffective application of insecticides or fungicides rather than targeted nematicides. This article explores the biology of these unique PPNs, focusing on the five primary threats: foliar nematodes (*Aphelenchoides* spp.), wheat seed gall nematode (*Anguina tritici*), stem and bulb nematode (*Ditylenchus dipsaci*), red ring nematode (*Bursaphelenchus cocophilus*), and pine wilt nematode (*Bursaphelenchus xylophilus*).

1. EAR COCKLE DISEASE 2. STEM & BULB BLOAT 3. RED RING DISEASE 4. PINE WILTSYMPTOMS

To appreciate the threat posed by these species, we must first understand how these primarily aquatic organisms biologically adapted to move and survive far above the soil surface.

The "Climbing" Strategy: How Soil Worms Go Aerial

Nematodes are essentially aquatic animals; they need moisture to move and survive. To attack the above-ground parts of a plant, they have developed two fascinating requirements. First is the necessity of a thin film of water; these nematodes cannot "crawl" on dry surfaces and instead depend on microscopic layers of moisture provided by rain, heavy dew, or high humidity to swim up the stem and reach the foliage. Second is their sophisticated chemical weaponry; once they reach their target, they do not simply "eat" the plant but instead secrete specific pectinolytic enzymes. These enzymes dissolve the "pectin," the biological glue that holds plant cells together, allowing the nematodes to slip between cells or collapse the plant tissue entirely (Jones et al., 2013).

The Journey of the Aerial Invaders:

Foliar Nematodes (*Aphelenchoides* spp.)

The journey of the foliar nematode begins as J2 juveniles hatch from eggs nestled in crop debris or dormant buds. During periods of high humidity or rainfall, they swim upward in a film of water and enter the leaf through stomata (natural breathing pores). Once inside, they move through the leaf's internal spaces, feeding on the mesophyll cells. Because these nematodes are unable to cross the large, tough veins of a leaf, the damage they cause is strictly confined to the areas between these veins (Kohl, 2011). This leads to the hallmark symptom of angular, water-soaked spots that eventually turn brown or black, often resulting in premature leaf drop and stunted flowering in crops like strawberries and chrysanthemums.

Seed Gall Nematodes (*Anguina* spp.)

Perhaps the most resilient of the group, *Anguina tritici* (the wheat seed gall nematode) is famous for its ability to undergo cryptobiosis, a state of suspended animation where it can remain dried and dormant inside a seed for decades. When a contaminated seed is planted and meets moist soil, the nematodes revive, hatch, and crawl to the growing tip of the wheat seedling. As the plant grows, they hitch a ride upward, eventually entering the developing floral tissues. They transform the healthy grain into a dark, hard seed gall or "cockle." Inside these galls, the plant's reproductive tissues are replaced by thousands of dormant larvae, leading to the "Ear Cockle" disease which significantly reduces grain quality and yield (Nallathambi et al. 2020).

Stem and Bulb Nematodes (*Ditylenchus* spp.)

Commonly known as the "Stem Bloat" nematode, *Ditylenchus dipsaci* typically survives and infects plants during its fourth-stage juvenile (J4) phase. This specific stage is highly adapted for survival; the J4 juveniles can undergo anhydrobiosis, allowing them to remain dormant in dry plant debris for years. When moisture is present, these infective J4s migrate toward the "neck" of bulbs or leaf axils, entering through stomata or wounds. Using enzymes to break down the middle lamella, they cause cells to separate and undergo hypertrophy (abnormal enlargement). Externally, this results in "bloated" stems, twisted leaves, and "spikkels." In advanced stages, J4s may congregate in massive numbers to form "nematode wool," a visible white mass that appears as infested tissue dries out (Jones et al., 2013).

Red Ring Nematode (*Bursaphelenchus cocophilus*)

Formerly known as *Rhadinaphelenchus cocophilus*, this nematode is the causative agent of the devastating Red Ring Disease in coconut and oil palms. Unlike surface-swimmers, it relies on an insect vector, the South American Palm Weevil (*Rhynchophorus palmarum*), for transport. The weevil carries the third-stage dispersal juveniles (J3) and deposits them into the palm's soft tissue during feeding or egg-laying. Once inside, the nematodes multiply rapidly within the parenchyma tissue of the trunk and petioles, disrupting the plant's vascular system. This internal colonization creates a vivid red-to-brown ring visible in the cross-section of the trunk. As the infection progresses, the leaves turn bronze and wilt, and the internal degradation becomes so severe that the entire crown of the palm may eventually snap off and fall (Jones et al., 2013).

Pine Wilt Nematode (*Bursaphelenchus xylophilus*)

The Pine Wilt Nematode is a globally significant pest of pine forests, particularly in Asia and Europe. It is transported between trees by the Pine Sawyer Beetle (*Monochamus* spp.). The infective stage is the specialized fourth-stage dispersal juvenile (J4), also known as the "dauer" stage, which hitches a ride in the tracheal system of the beetle. When the beetle feeds on the bark of healthy twigs (maturation feeding) or lays eggs (oviposition) on stressed trees, the J4 juveniles enter the tree through the wounds. They rapidly colonize the resin canals and xylem, causing the tree to lose its ability to transport water. Symptoms include a rapid cessation of resin flow followed by the browning of needles, often leading to the death of a mature tree within a single season (Jones et al., 2013).

Unique Management Strategies

Modern nematode management has moved away from traditional soil fumigation, as most first-generation fumigants (such as methyl bromide and EDB) have been banned globally due to environmental and health risks. Today, management must be highly specialized and often focuses on internal plant protection and cultural prevention.

- **Certified Seed and Brine Treatment:** Since many of these species move via seeds, using nematode-free planting material is vital. For wheat farmers dealing with Ear Cockle, the **brine treatment** is a highly effective, low-cost method. By immersing seeds in a 20% salt solution (brine), the lighter, diseased "cockles" or galls float to the surface and can be skimmed off, while the healthy seeds sink to the bottom.
- **Hot Water Treatment:** For infested dormant materials like garlic bulbs or certain seeds, soaking at 43–49°C kills internal nematodes without damaging the plant embryo.
- **Moisture Control:** Transitioning from overhead sprinklers to drip irrigation can starve surface-climbing nematodes of the transport they need to reach the foliage.
- **Next-Generation Nematicides and Biopesticides:** Modern management utilizes safer, non-fumigant chemistries (e.g., fluopyram) or biological control agents (e.g., *Paecilomyces lilacinus*) which target nematodes specifically with minimal impact on soil health (Jones et al., 2013).
- **Vector Management:** For species like *Bursaphelenchus*, management shifts toward controlling the insect carriers through trapping and targeted insecticides.

Global Vigilance: Quarantine Importance to India

In the context of international trade, aerial nematodes pose a significant biosecurity risk. For India, several of these species are of high quarantine importance. While the Wheat Seed Gall nematode is already present in some northern states, species like the Pine Wilt Nematode (*B. xylophilus*) and the Red Ring Nematode (*B. cocophilus*) are classified as exotic pests not yet established in India. If introduced via imported timber or palm planting materials, they could devastate India's vast forest resources and coastal coconut plantations. Strict phytosanitary regulations and rigorous inspection of imported agricultural commodities are the nation's primary defense against the entry of these destructive aerial invaders.

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Volume: 06 Issue No: 04

IMPACT OF SOCIAL MEDIA ON OUR CONNECTION TO NATURE

Article ID: AG-VO6-I04-04

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Introduction

In the digital age, social media has become an inseparable part of everyday life, shaping how individuals communicate, learn, and interact with the world around them. Platforms such as Facebook, Instagram, YouTube, and TikTok have created new spaces for information sharing and virtual experiences. While these platforms provide opportunities to learn about environmental issues, appreciate natural landscapes, and participate in global conservation movements, they also influence how people physically and emotionally connect with the natural environment. As screen time increases and digital interactions replace outdoor engagements, concerns have grown about the weakening human–nature relationship, especially among younger generations. Understanding the dual nature of social media is important for recognizing both its potential to promote environmental awareness and its risks of distancing people from the real-world ecosystem on which life depends.

Advantages of social media and nature

Environmental Awareness and Education

Social media spreads information on climate change, biodiversity loss, pollution, and conservation efforts quickly and widely. Environmental organizations use social media to educate the public through campaigns, documentaries, posts, and webinars. Young people gain knowledge about sustainability and eco-friendly lifestyles.

Motivating Nature Protection and Activism

Platforms mobilize global participation in movements like climate strikes, tree-planting drives, and wildlife protection. Hashtags such as #SaveSoil, #FridaysForFuture, or

#BeatPlasticPollution strengthen collective action.

Showcasing Natural Beauty

Travel bloggers, photographers, and explorers share high-quality visuals of forests, oceans, and wildlife. These images inspire people to travel, explore, and appreciate natural environments.

Building Virtual Eco-Communities

People with similar interests (e.g., bird watching, hiking, home gardening) can connect and share experiences. Helps spread innovative ideas like organic farming, waste management, and green living.

Support for Environmental Research

Citizen science projects allow people to upload pictures of plants, animals, or weather patterns. Researchers use this data to track species distribution, climate changes, and environmental threats.

Disadvantages of social media and nature

Reduced Time Spent in Nature

Excessive screen time decreases outdoor activities. Children and adolescents spend more time scrolling than playing outside, reducing physical fitness and emotional well-being.

Superficial Connection to Nature

Many people experience nature only through images or videos, not real-life interactions. Virtual nature appreciation cannot replace sensory experiences like touch, smell, or sound.

Over-Tourism and Environmental Damage

Viral posts encourage mass tourism to fragile ecosystems. Local wildlife and natural landscapes are disturbed due to crowding, waste dumping, and commercialization.

Nature as a Backdrop for Social Status

Some people visit natural sites only for photos or popularity, not for appreciating biodiversity. This leads to irresponsible behavior like disturbing animals or damaging plants for better pictures.

Mental Health Issues

Constant digital exposure can increase stress, anxiety, and attention problems. Loss of nature connection reduces relaxation, creativity, and emotional balance.

Spread of Misinformation

Fake environmental news or exaggerated posts can mislead the public. Unverified remedies for plants, animals, or eco-farming practices may cause harm.

Use of Social Media in Strengthening Nature Connection

- **Environmental campaigns**: Encouraging recycling, tree planting, water conservation.
- **Online eco-learning**: Courses on ecology, nature photography, gardening, farming.
- **Disaster updates**: Real-time information on floods, forest fires, or cyclones.
- **Promotion of sustainable brands**: Eco-friendly products, green tourism, renewable energy.
- **Digital volunteering**: Reporting endangered species sightings, plastic waste locations, or illegal wildlife trade.

Negative Outcomes of Weak Nature Connection

- **Decline in Ecological Knowledge**: Younger generations lose skills like identifying plants, reading animal behavior, or understanding seasons.
- **Reduced Physical Health**: Less outdoor activity leads to obesity, vitamin deficiencies, and weak immunity.
- **Emotional and Psychological Effects**: Disconnection from nature increases stress, loneliness, irritability, and mood disorders.
- **Environmental Neglect**: If people experience nature only online, they may feel less responsible for conservation. Real-life environmental action decreases.
- **Loss of Cultural and Traditional Environmental Practices**: Many indigenous and rural practices connected to forests, rivers, and seasons fade as digital culture dominates.

Conclusion

Social media in the digital era presents a dual influence on the human-nature relationship. Platforms such as Facebook, Instagram, YouTube and TikTok offer powerful tools for spreading environmental awareness, encouraging global movements like #FridaysForFuture and building virtual eco-communities that promote sustainability and conservation. At the same time, excessive screen time, superficial virtual engagement with nature, over-tourism driven by viral content, misinformation and declining outdoor experiences weaken individuals' physical, emotional and cultural connections with the natural world.

Therefore, a balanced approach is essential using social media as a medium to educate, mobilize and inspire real-world environmental action, while consciously encouraging direct interaction with nature to preserve ecological knowledge, well-being and long-term environmental responsibility.

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THORNLESS CACTUS (*OPUNTIA FICUS-INDICA*) A SOURCE OF GREEN FODDER FOR DRY REGIONS

Article ID: AG-VO6-I04-05

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Introduction

Thornless cactus (*Opuntia ficus-indica*) commonly known as fodder cactus or prickly pear is one of the most important plants of Cactaceae family. It can be used both as a vegetable and valuable forage resource in arid / semi-arid areas. These areas are characterized with high water deficit, low and erratic rainfall, frequent drought along with long & dry spells and poor soil. Therefore, animal husbandry has come to the fore-front as a source of livelihood in such areas. In India, arid zone alone occupies about 19 per cent of total geographical area and supports 34 percent of the total livestock population. Generally, such areas have a significant deficit of feed & fodder resources and their adequate supply in terms of quality & quantity for livestock is a major challenge. Further, production and feeding of green fodder to livestock beyond rainy season is even more challenging. Fodder cactus originated in the deserts of Central and North America, cultivated as perennial crop for green fodder production in many arid and semi-arid areas of the world. It has potential to produce a large quantity of palatable and nutritious green fodder for the livestock. The entire plant can be used for green fodder consisting of 1-1.5 cm thick fleshy mass called cladode (oval stems).

Physiology

Thornless cactus has higher water use efficiency (WUE) and rain use efficiency (RUE) than any conventional fodder crop because it is CAM (Crassulacean Acid Metabolism) plant. The CAM plants are native to arid and semi-arid regions and characterized by nocturnal stomatal opening so that net CO2 uptake and water loss occurs during the cooler part of 24 –hour cycle, leading high WUE & RUE.

Nutrient Composition

Cactus fodder is rich in vitamin A and water soluble carbohydrates. Forage quality is comparable with several other cultivated fodder crops. It is highly digestible with 70 per cent dry matter digestibility. The average chemical composition of cactus cladode is given below:

Chemical composition (dry matter basis)	
Dry Matter	10 -11
Crude protein	11.81
Ether Extract	1.18
Fibre	8.12
Acid Insoluble Ash	2.55
Calcium	6.05 (%)
Phosphorus	0.30 (%)
Magnesium	3.15 (%)
Potassium	1.82 (%)
Sodium	0.05 (%)
Copper	6.13 (mg/kg)
Zinc	24.37 (mg/kg)
Manganese	98.17 (mg/kg)
Iron	257.54 (mg/kg)
Carotenoid	29 µg/100 gm
Ascorbic acid	13 mg / 100 g

Propagation

Cactus is successfully multiplied by vegetative propagation using oval stems known as cladodes or paddles. For planting in large area, it can be propagated by using saplings raised through tissue culture. Package of practices for cultivation

- Rainy or post rainy seasons (Mid-June to Mid-July and Mid-October to Mid-November) are ideal for cactus planting in arid and semi-arid climate.
- Cactus thrives best on sandy and sandy loam soils. However, well drained heavy soils and gravely or stony lands especially at foot hill slopes are also suitable.

- Recommended available accessions/cultivars of thornless cactus in India are No. 1270, No. 1271 and Texas 1308.
- Field should be well prepared with a chisel plough before planting up to depth of 60-80 cm in order to ensure good drainage. Apply well decomposed farm yard manure @ 15 ton/ha in field 20 days before planting of cactus.
- One week before planting, use disc plough, cultivator and harrow ploughs to get fine tilth in upper 30 cm soil layer and make soil free from weeds. At last ploughing, mix *Trichoderma viridae* bio-fungicide @ 1.5 kg/ha in soil to control root decaying fungal diseases.
- Use 90 kg nitrogen, 40 kg phosphorus, 30 kg potash and 10 kg Zinc sulphate per ha. Well mix 30 kg nitrogen and rest of fertilizers in soil before planting. As top dressing, apply 20 kg nitrogen in equal doses to plants at four months intervals during the year.
- Sowing has to be done at row to row distance of 100 cm and plant to plant of 40 cm. One foot high ridges (north-south direction) are formed in field for plantation of cladodes/ sapling to avoid water stagnation.
- One year old cladodes or 7-8 month old saplings raised through tissue culture are suitable for planting.
- Fresh seed cladodes are treated with copper based fungicide like copper oxychloride (50% WP) or copper hydroxide (77% WP) @ 5 gram per litre of water to control bacterial and fungal plant diseases. These fungicides may also be applied to thornless cactus plants if root decay, wilting and rotting symptoms appears during growing periods particularly during rainy season.
- After fungicide treatment cladodes are kept under the shade for 2 weeks before planting for better establishment.
- Cladodes are planted keeping one third portion below the soil and two-thirds portion above the soil surface. Press the soil well near the surface for firm establishment of cladodes or saplings in soil.
- Irrigate the cladodes and saplings immediately after planting. Control irrigations through drip coupled with mulching enhances the water use efficiency (WUE) and biomass production.

- Give light irrigation to crop as per need and soil moisture availability. Drain excess water from the fields. Harvesting /Pruning Take first harvest manually when plant attain one meter height. In first two years, remove inner cladodes and those oriented downward, horizontally or close to ground. Use clean tools for cutting cladodes from plants. Take regular harvest at the interval of 5 to 6 months. Well managed crop gives green fodder yield of 40-50 MT/ hectare/ year.

Feeding of Thornless Cactus

For animal feeding only large size, fleshy and 6 months old cladodes are cut from plants. Please note that whole plant is not to be uprooted. At a time, up to 1/3rd of total cladodes on plant may be harvested for feeding. Subsequent harvesting is done after 6 months.

- Before feeding, cladodes / paddles should be chopped in small pieces of 2-3 inches size by chopper or chaff cutter.
- After chopping, mix small pieces with some dry fodder like wheat, bajra or sorghum straw for feeding. 10-15 kg chopped thornless cactus may be fed to animals per day.

Other benefits of fodder cactus

- It is an excellent source of water too for livestock as it contains 90 per cent water.

- It has high water use efficiency (WUE) i.e. to produce 1 kg dry matter; it needs 267 kg of water against 400 kg required for pearl millet, a prominent drought tolerant cereal crop.
- Due to high rain use efficiency (RUE), it can produce 40 kg dry matter /mm/ year of rainfall against 25 kg in pearl millet.
- It also provides food to human beings.
- Thornless cactus is also suitable for saline soils, check soil erosion, combat desertification and reclaim degraded land.
- It has high potential to capture carbon both above and below the soil.

Fungicide treatment | Treated Cladodes | Regenerated cladodes

Thornless cactus cultivation with drip irrigation and plastic mulching

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CARBON SEQUESTRATION IN VEGETABLE CROPS

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Abstract

Climate change is one of the most urgent challenges facing humanity, driven largely by rising levels of atmospheric carbon dioxide (CO_2). Carbon sequestration is the process of capturing and storing atmospheric carbon, has emerged as a key strategy to mitigate climate change. While forests are often highlighted as major carbon sinks, agricultural systems, particularly vegetable crops, also play a vital but underappreciated role. Vegetable crops, with their rapid growth, high biomass production and frequent cultivation cycles, have a strong capacity to absorb carbon dioxide through photosynthesis and store it in plant tissues and soil organic matter. This article explores how vegetable cropping systems contribute to carbon sequestration, the underlying mechanisms and the sustainable practices that enhance their potential. By integrating approaches such as organic farming, biochar application and residue management, vegetable cultivation can become a powerful tool for improving soil health, increasing productivity and addressing climate change simultaneously.

Keywords: Carbon sequestration, vegetable crops, soil organic carbon, climate change, biochar, sustainable agriculture

Introduction: A Climate Challenge Rooted in Carbon

The rising concentration of greenhouse gases, especially carbon dioxide (CO_2), has significantly altered the Earth's climate system. Human activities such as industrialization, deforestation and intensive agriculture have accelerated the release of carbon into the atmosphere, disrupting the natural carbon cycle. As global temperatures continue to rise, there is an urgent need for effective strategies to reduce atmospheric carbon levels.

Carbon sequestration offers a promising solution. It involves capturing carbon dioxide from the atmosphere and storing it in stable forms within plants, soils or other reservoirs. While forests and oceans are widely recognized for their role in carbon storage, agricultural lands - particularly those used for vegetable production, are increasingly being recognized as important contributors.

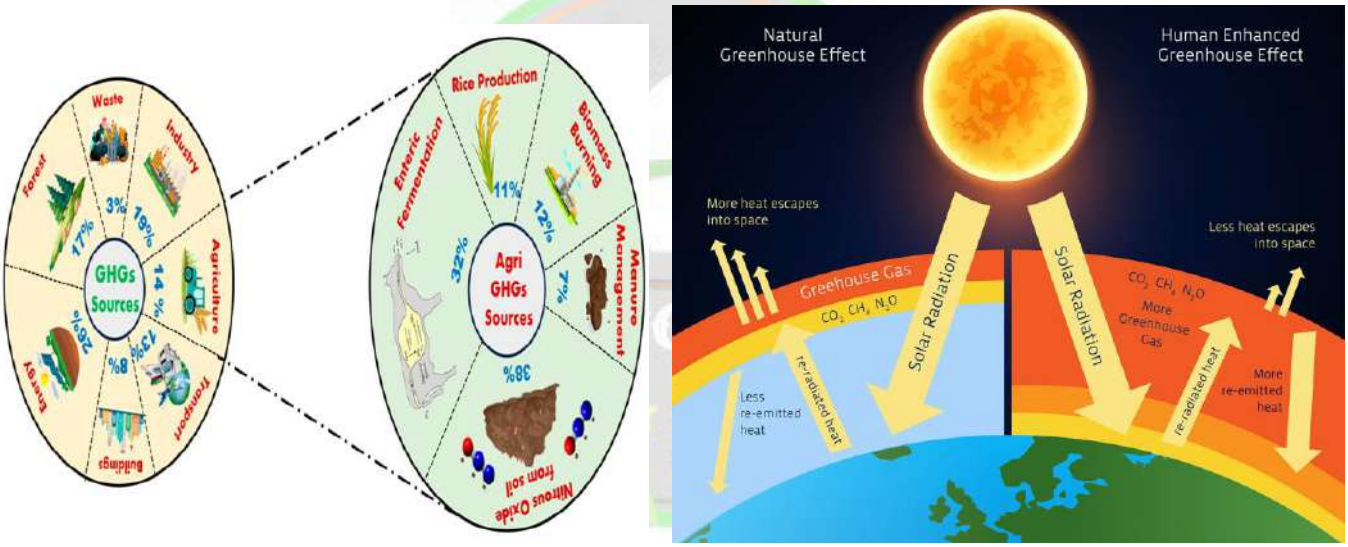

Fig.1. Sources and effects of greenhouse gases

Vegetable crops may seem small compared to trees, but their impact is far from insignificant. With rapid growth cycles and continuous cultivation, they act as dynamic carbon absorbers, capturing carbon dioxide repeatedly throughout the year.

How Vegetable Crops Capture Carbon

At the heart of carbon sequestration lies the process of photosynthesis. Vegetable plants absorb carbon dioxide from the atmosphere and convert it into organic compounds using sunlight and water. This process not only fuels plant growth but also locks carbon into plant tissues such as leaves, stems and roots.

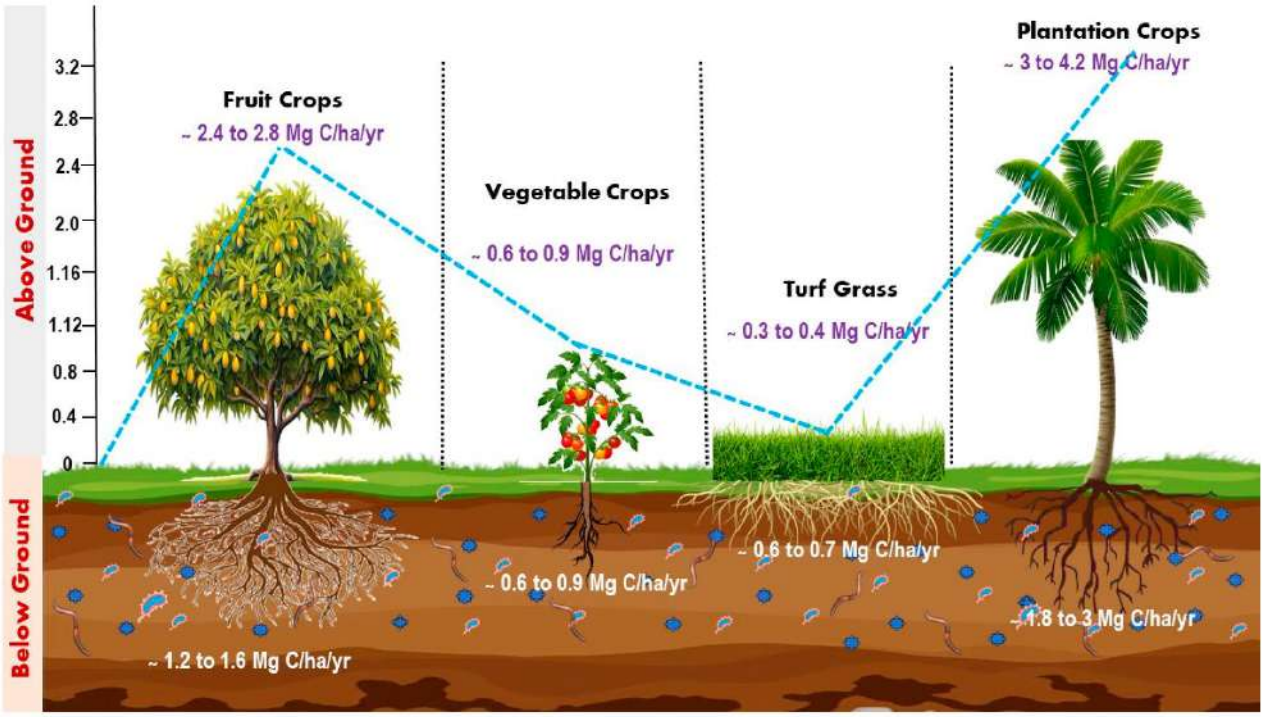

Fig.2. Trends in different horticulture crops for carbon sequestration

Unlike many field crops, vegetables are often grown multiple times a year. This means the process of carbon capture is repeated frequently, making vegetable systems highly efficient at short-term carbon absorption. Each planting cycle contributes fresh biomass, which eventually becomes part of the soil. A significant portion of captured carbon is transferred below ground. Roots release organic compounds known as root exudates, which feed soil microorganisms and contribute to the formation of soil organic matter. When crop residues such as leaves and stems are returned to the soil after harvest, they further enhance carbon storage. Horticultural crops are more profitable than field crops. 2.2 metric tonnes of wood can sequester one tonne of carbon in the atmosphere. Perennial fruit trees, plantation crops, vegetable crops etc., have 25–100 times higher biomass of carbon compared to agricultural lands.

Soil: The Hidden Carbon Bank

Soil plays a crucial role in carbon sequestration. It acts as a major reservoir, storing more carbon than the atmosphere and vegetation combined. A 1% increase in SOC - raise soil water-holding capacity up to 20,000 gallons acre^{-1}. According to the Global soil carbon sequestration map, global soils - potential to sequester 0.14–0.57 Pg C year^{-1}. According to IPCC, agricultural soils- sequester up to 1.2 billion metric tonnes of carbon every year.

In vegetable cropping systems, soil organic carbon is continuously replenished through plant residues, root biomass and organic amendments. Healthy soils rich in organic carbon are not just beneficial for climate mitigation, they are also essential for agriculture. They improve soil structure, enhance water retention and support microbial life, all of which contribute to better crop productivity. The vegetable crops with higher biomass production, such as potato, cauliflower and brinjal, have greater potential for carbon storage. These crops produce more plant material, which translates into higher organic matter input into the soil.

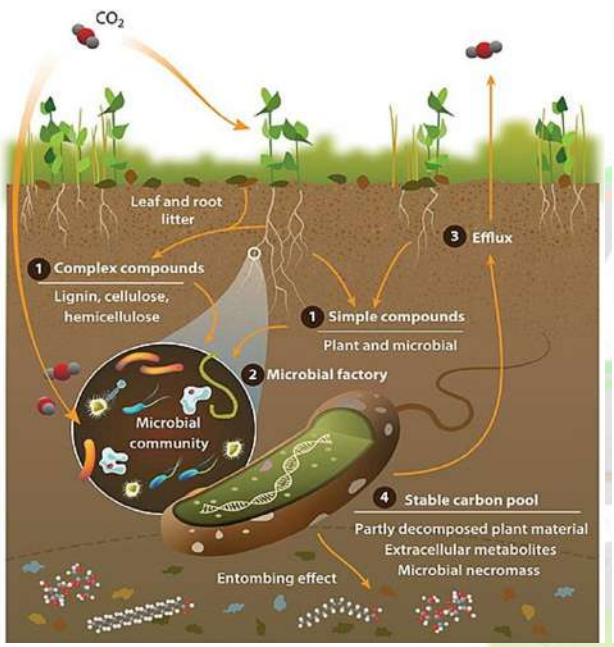

Fig. 3. Soil carbon sequestration

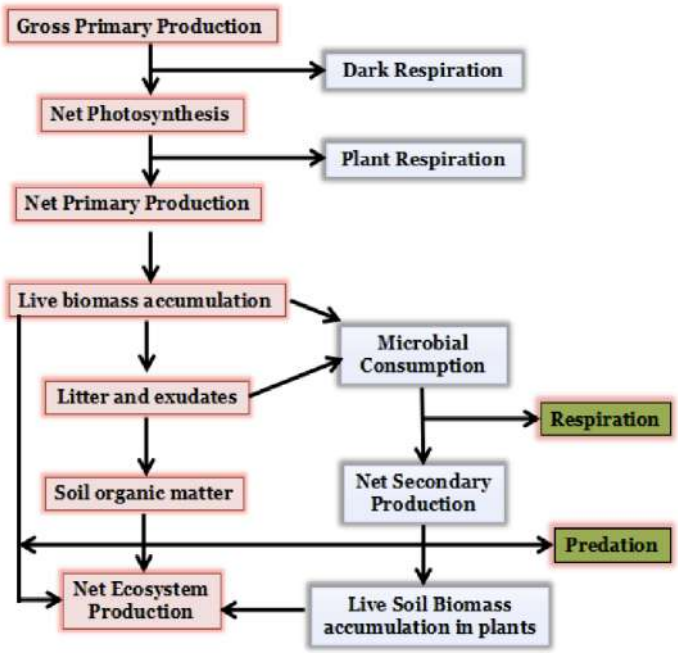

Fig.4. Mechanism of carbon sequestration

The Role of Sustainable Farming Practices

The carbon sequestration potential of vegetable crops can be significantly enhanced through sustainable agricultural practices. These practices not only increase carbon inputs but also reduce carbon losses from the soil.

1.Organic Farming

Organic farming relies on natural inputs such as compost, manure and crop residues. These materials are rich in carbon and help build soil organic matter over time. Gattinger *et al*. (2012), SOC in upper 20 cm soil was 3.50 ± 1.08 Mg C ha^{-1} higher in organic systems than non-organic (14-year study). Sardiana *et al*. (2020), ecological farming showed +1.13 t C ha^{-1} yr^{-1} carbon sequestration compared to conventional farming.

A case study from Bali by Sardiana (2021) Organic farming: 24.52 % higher soil carbon stocks than conventional farming, 49.02 % higher labile carbon, indicating better soil fertility. At a soil depth of 10 cm, organic vegetable farming increase carbon sequestration by 1.18 Mg ha^{-1} $year^{-1}$, compared to conventional farming systems. This highlights the long-term benefits of organic practices in enhancing soil health and carbon storage.

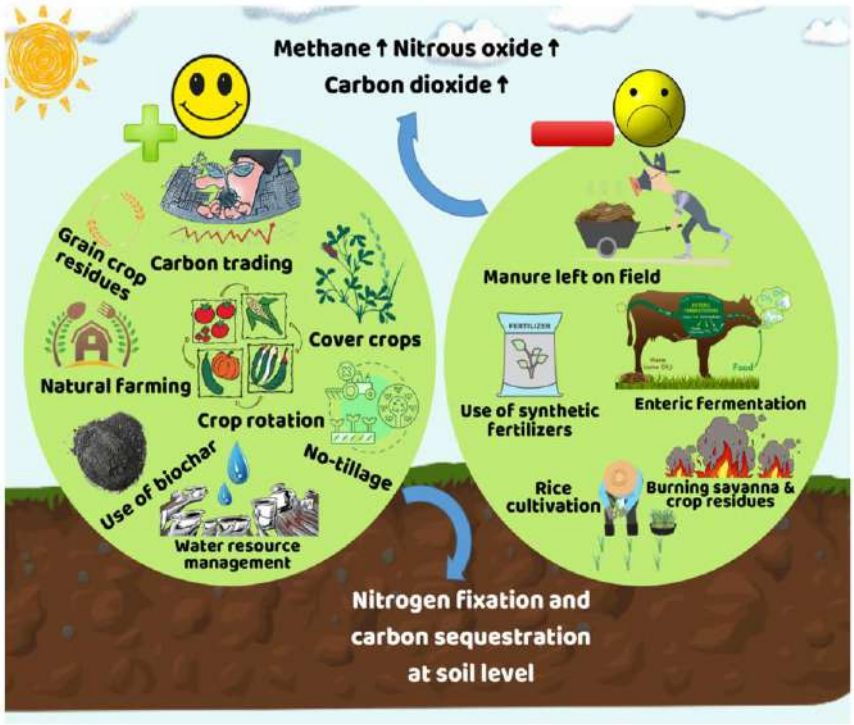

Fig.5. The influence of carbon farming recommended management practices compared to the main agricultural polluters

2. Biochar Application

Biochar is a stable, carbon-rich material produced by heating organic biomass in the absence of oxygen. When added to soil, biochar acts as a long-term carbon storage medium because it resists decomposition. In vegetable cultivation systems, biochar has been shown to increase soil organic carbon, improve soil structure and enhance nutrient retention. A field study in Eastern China by Zhang *et al*. (2022) found that applying wheat straw biochar significantly increased soil carbon levels in vegetable fields. SOC increased by 8.5–47.5% immediately after biochar application. After 3 years, SOC decreased by 4.8- 35.8 % because biochar owned the labile carbon fraction. Biochar enhanced aggregate-protected carbon, especially in micro-aggregates. DOC/SOC reduced by 11.1–22.5%. EOC/SOC reduced by 5.3–6.3% - Indicates

improved long-term carbon stability. 20 Mg ha^{-1} biochar (C20) - identified as the best rate for: Carbon storage, Nutrient retention and Sustainable vegetable production.

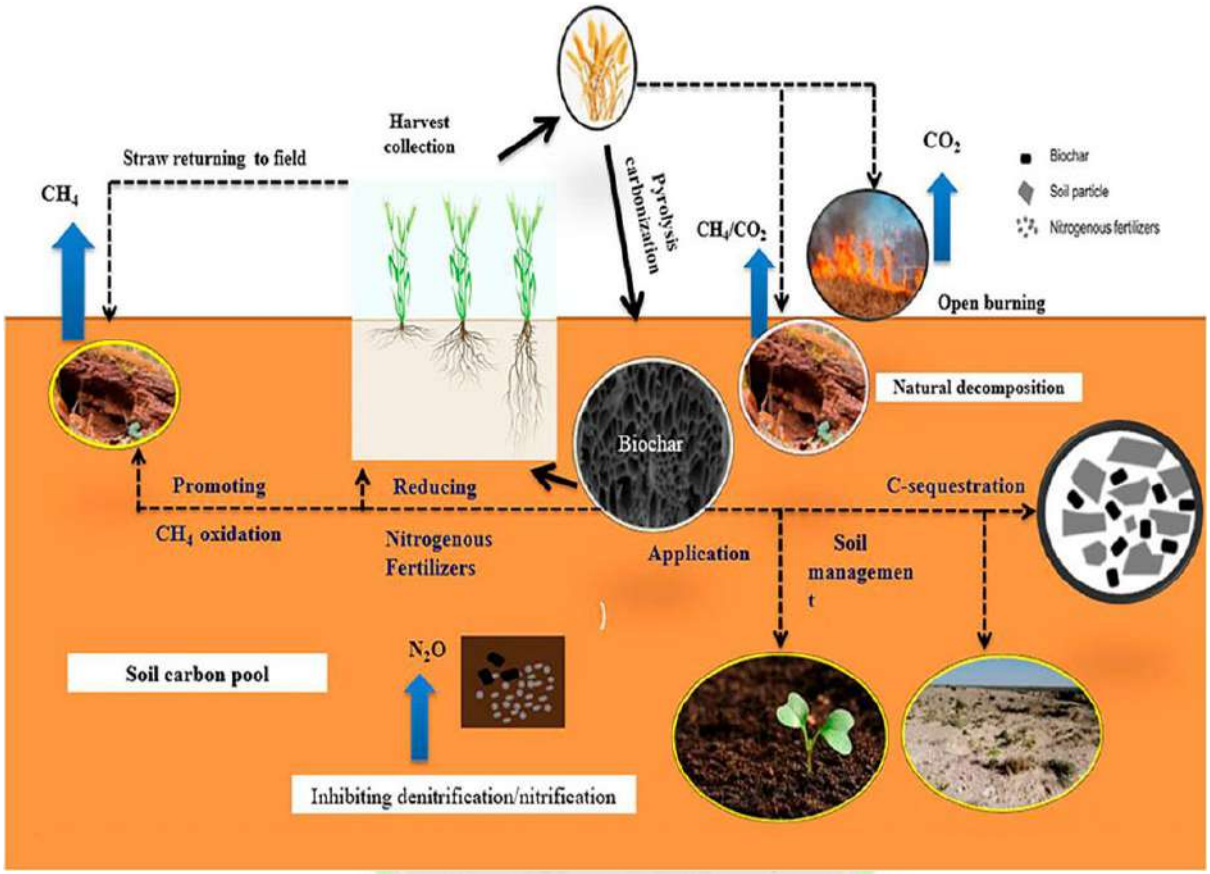

Fig. 6. Mechanism of greenhouse gas reduction and soil carbon sequestration through biochar application

3. Conservation Tillage

Reducing soil disturbance is another effective way to enhance carbon sequestration. Conventional tillage exposes soil organic matter to oxygen, accelerating its decomposition and releasing carbon dioxide into the atmosphere. Conservation tillage minimizes this disturbance, helping retain carbon in the soil. It also improves soil structure and reduces erosion, further supporting sustainable agriculture.

4. Crop Rotation and Cover Crops

Diverse cropping systems contribute to greater carbon inputs. Crop rotation introduces different types of plant residues into the soil, enhancing microbial activity and promoting carbon stabilization. Cover crops protect the soil surface and add additional biomass, further increasing soil organic matter.

Organic Amendments: Feeding the Soil

Organic amendments such as compost, poultry manure and cow dung are valuable tools for carbon sequestration. They not only provide essential nutrients but also add significant amounts of organic carbon to the soil. In a study on spinach cultivation by Rashid *et al*. (2025), the application of organic amendments resulted in increased soil organic matter and improved carbon storage. Soil organic matter was appreciably increased (1.21% to 2.23%) and organic carbon content also increased (0.63% to 1%). These findings highlight the importance of integrating organic inputs into vegetable production systems.

Understanding the Carbon Cycle

To appreciate the role of vegetable crops in carbon sequestration, it is important to understand the carbon cycle. Carbon continuously moves between the atmosphere, plants, soil, oceans and geological formations. The "fast carbon cycle" involves processes such as photosynthesis, respiration and decomposition, which occur over short time periods. Vegetable crops actively participate in this cycle by capturing carbon dioxide and transferring it into biomass and soil. The "slow carbon cycle," on the other hand, operates over geological timescales, storing carbon in rocks and sediments. While vegetable crops primarily influence the fast cycle, their contribution to soil carbon can have long-term impacts.

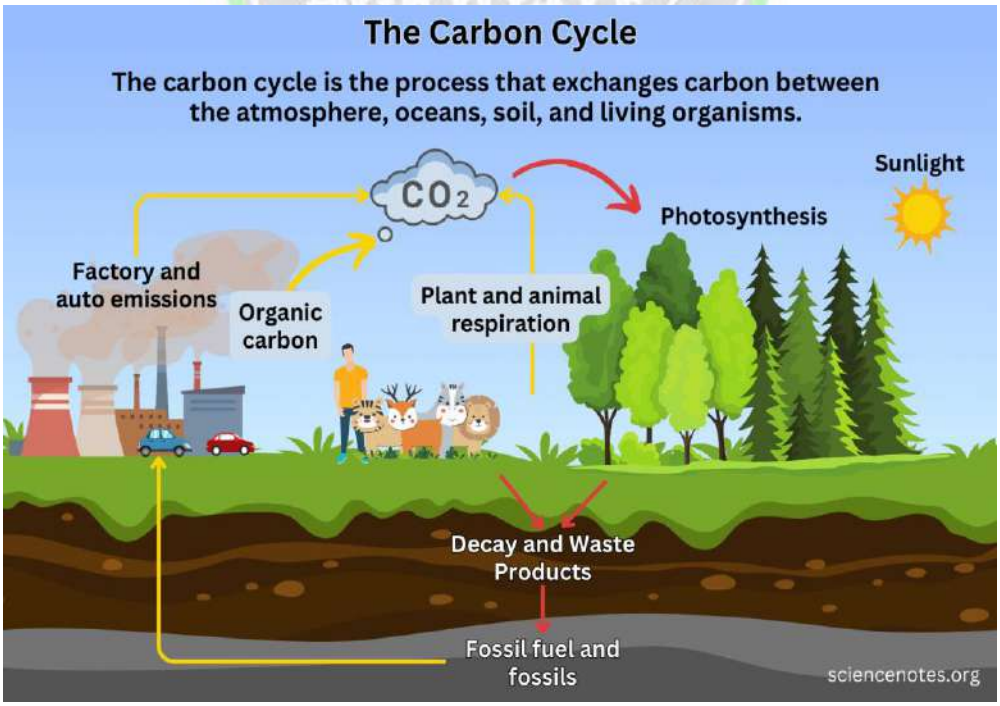

Fig. 7. Carbon cycle

Benefits Beyond Climate Change: Carbon sequestration in vegetable crops offers a wide range of benefits beyond reducing atmospheric carbon dioxide.

Improved Soil Health - Increased soil organic carbon enhances soil fertility, structure and water-holding capacity. This leads to healthier crops and higher yields.

Enhanced Resilience - Soils rich in organic matter are more resistant to drought, erosion and extreme weather conditions. This makes vegetable farming systems more resilient to climate change.

Sustainable Productivity - By improving soil quality, carbon sequestration supports long-term agricultural productivity without relying heavily on chemical inputs.

Challenges to Overcome

Despite its potential, carbon sequestration in vegetable systems faces several challenges.

One major limitation is the finite capacity of soils to store carbon. Once soils reach saturation, additional carbon inputs may not lead to significant increases in storage.

Environmental factors such as temperature, rainfall and soil type also influence carbon sequestration. High temperatures, for example, can accelerate the decomposition of organic matter, reducing carbon storage.

Unsustainable agricultural practices, including excessive tillage and overuse of chemical fertilizers, can further reduce soil carbon levels. Economic constraints and lack of awareness may also limit the adoption of sustainable practices among farmers.

The Way Forward

The future of carbon sequestration in vegetable crops lies in innovation, awareness and policy support. Research should focus on identifying crop varieties and farming practices that maximize carbon capture. Integrating biochar, organic amendments and conservation agriculture into vegetable systems can significantly enhance their carbon sequestration potential. At the same time, government policies and incentives can encourage farmers to adopt these practices. Promoting carbon farming initiatives and educating farmers about sustainable practices will be crucial in scaling up these efforts.

Conclusion

Vegetable crops, often overlooked in discussions on climate change, have immense potential to contribute to carbon sequestration. Through rapid growth, repeated cultivation cycles and significant biomass production, they capture atmospheric carbon dioxide and store it in plant

tissues and soil. When combined with sustainable practices such as organic farming, biochar application and conservation tillage, vegetable cropping systems can become powerful tools for climate change mitigation. At the same time, they improve soil health, enhance agricultural productivity and support environmental sustainability. Harnessing the potential of vegetable crops for carbon sequestration represents a practical and accessible approach to addressing one of the most pressing challenges of our time. Small plants, when managed wisely, can indeed make a big difference.

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CRISPR GENOME EDITING IN PLANT PATHOLOGY

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Introduction

CRISPR-Cas9 is a revolutionary, precise, and accessible gene-editing technology that acts as "molecular scissors" to cut, add, or remove DNA sequences. By using a customizable guide RNA to direct the Cas9 enzyme to a specific genomic site, it enables targeted modifications, transforming fields like medicine (gene therapy) and agriculture (crop enhancement).

How CRISPR-Cas9 Works

- **Targeting:** A guide RNA (gRNA) is designed to recognize a specific sequence of DNA that needs to be edited.
- **Cutting:** The Cas9 enzyme (or other enzymes) binds to the gRNA and scans the DNA to find the target. Once found, Cas9 cuts both strands of the DNA helix.
- **Repairing/Editing:** The cell's natural repair mechanism kicks in to fix the cut. Researchers can use this process to deactivate a gene or insert a new, corrected sequence of DNA.

Applications of CRISPR

- **Medical Therapeutics:** Treating genetic diseases (such as sickle cell disease) by correcting mutations, and developing cancer-fighting immune cells.
- **Agriculture:** Modifying crops to be more resilient against diseases and environmental stressors.
- **Molecular Biology Research:** Modifying DNA in organisms to study gene function.

Key Concepts and Future Directions

- **Efficiency:** CRISPR is known for its high accuracy, efficiency, and relatively low cost compared to older gene-editing technologies like TALENs.

- **Safety Considerations:** Concerns exist regarding "off-target" edits (accidental edits elsewhere in the genome).
- **Advanced Techniques:** Beyond simple cutting, techniques like base editing and prime editing allow for more precise modifications without double-stranded breaks.
- **Ethics:** Gene editing in human germline cells (sperm/eggs) carries risks of permanent, inheritable changes to the human genome.

Genome editing the precise and targeted modification of the genetic material of living organisms represents one of the most significant advancements in molecular biology. It has far-reaching applications, from unraveling fundamental biological processes to driving advancements in medicine, agriculture, and biotechnology. With the approval of the first CRISPR-based human therapy in late 2023,[1] CRISPR genome editing is entering a new era. In this review, we aim to provide a panoramic view of the CRISPR genome editing landscape, emphasizing its current state, potential future developments, and the hurdles that must be overcome to fully realize its promise for human medicine.

The past: Development and limitations of CRISPR genome editing

Genome editing originally arose from advancements in the field of eukaryotic DNA repair. Pioneering studies in the early 1990s using homing endonucleases such as I-SceI, which recognizes 18-bp DNA sequences, showed that induction of a targeted double-strand break (DSB) in mammalian cells stimulated homologous recombination at the target site.[2] This established the concept of genome editing using DSB-generating nucleases. The need for diverse nucleases with long recognition sites, which would be capable of targeting single sites in eukaryotic genomes, spurred the subsequent development of engineered nuclease enzymes based on complex fusions of non-specific DNA endonucleases with tandem arrays of sequence-specific DNA binding modules. These were initially zinc-finger nucleases (ZFNs), introduced in the early 2000s, and later transcription activator-like effector nucleases (TALENs) in 2010–2011.[3,4] These developments set the stage for genome editing, but the laborious design and generation of ZFNs and TALENs limited their use. The discovery and development of RNA-guided, CRISPR-associated (Cas) nucleases marked a revolutionary shift due to their simplicity of programming, specificity, and versatility.

In 2007, prokaryotic CRISPR-Cas systems were shown to function as adaptive genome defense mechanisms that recognize and target foreign nucleic acids associated with viruses

(phages) and other mobile genetic elements.[6] In these systems, fragments of invader DNA are acquired and stored in repetitive arrays, whose transcription and subsequent processing yields CRISPR RNAs (crRNAs). crRNAs function as molecular guides and program molecular machineries composed of Cas proteins to recognize invading nucleic acids and target them for destruction.[7] Subsequent research revealed that so-called type II CRISPR-Cas systems site-specifically cleaved phage DNA, that the activity was dependent on the protein Cas9,[9] and that an additional RNA component, *trans*-activating crRNA (tracrRNA), was essential for crRNA maturation.[10] Finally, biochemical studies published in 2012 demonstrated that Cas9 functioned as a DNA cleaving endonuclease, whose specificity was determined by a dual-RNA guide structure composed of crRNA and tracrRNA.[12] The CRISPR-Cas9 system was further streamlined by integrating tracrRNA and crRNA into a single guide RNA (sgRNA), thus providing a fully programmable one-nuclease-one-guide-RNA design. This became the basis for the development of CRISPR genome editing technologies, whereby targeting Cas9 to a specific genomic site could thus be achieved by designing an sgRNA with a matching sequence.[12] The discovery of the RNA-guided DNA cutting activity of Cas9 set off a race to repurpose it for genome editing, which culminated in several studies published in early 2013 reporting that expression of Cas9 and specific sgRNAs in eukaryotic cells led to the introduction of genetic modification at target genomic loci.

CRISPR nuclease-based genome editing

The programmab ility of CRISPR-Cas nucleases to generate site-specific double-strand DNA breaks has enabled their rapid adaptation for genome editing technologies.The archetypical Cas9 protein originating from *Streptococcus pyogenes* (SpCas9), the first Cas nuclease to be repurposed for genome editing, remains the most widely used gene editor due to its intrinsically high activity and specificity. Cas9 forms an active nuclease in association with either crRNA-tracrRNA complexes or sgRNA guides. To direct the Cas9 nuclease to the genomic locus of interest, the 20-nt guide sequence on the 5′ end of the crRNA can be altered to enable canonical base pairing with the DNA target. Target binding is additionally dependent on the presence of a short protospacer adjacent motif (PAM) located on the non-target strand (NTS) of the DNA, immediately downstream of the target site. Initial recognition of the PAM results in local unwinding of the target DNA, whereas the guide RNA base pairs with the target strand (TS) of the DNA in a 5′-3′ directional manner starting at the PAM-proximal end of the target site,

triggering conformational changes in Cas9 that lead to nuclease domain activation.[19,20,21] Cas9 subsequently cleaves the double-stranded DNA (dsDNA) substrate three nucleotides upstream of the PAM sequence, generating DSBs with either blunt ends or single-nucleotide 5′ overhangs.[12] DSB formation is catalyzed by the Cas9 HNH and RuvC domains, which cleave the TS and NTS, respectively.[11,12] Selective inactivation of either nuclease domain converts Cas9 into RNA-guided nickases, whereas inactivation of both domains results in an RNA-guided DNA binding protein that can serve as a platform for delivery of fused proteins to specific genomic loci

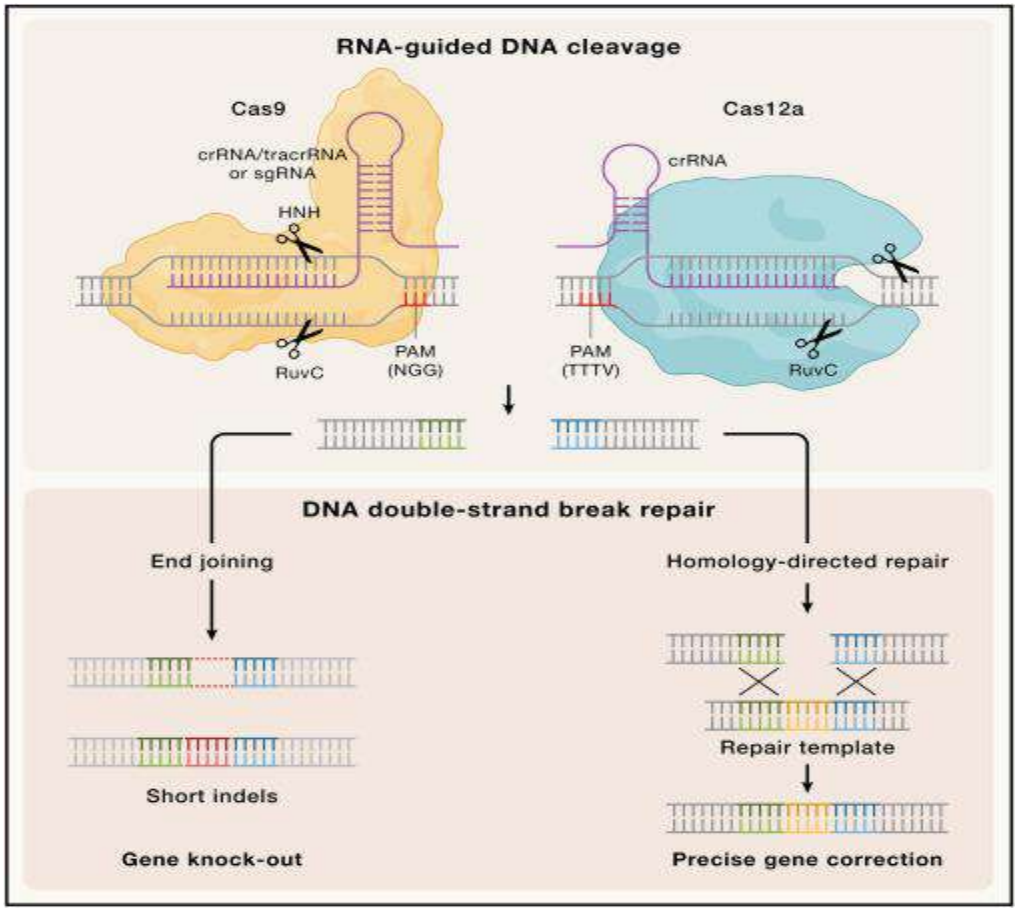

Fig 1.CRISPR genome editing

CRISPR gene editing (/ˈkrɪspər/; pronounced like "crisper"; an abbreviation for "clustered regularly interspaced short palindromic repeats") is a genetic engineering technique in molecular biology by which the genomes of living organisms may be modified. It is based on a simplified version of the bacterial CRISPR-Cas9 antiviral defense system. By delivering the Cas9 nuclease complexed with a synthetic guide RNA (gRNA) into a cell, the cell's genome can

be cut at a desired location, allowing existing genes to be removed or new ones added *in vivo("within the living").*The technique is considered highly significant in biotechnology and medicine as it enables *in vivo* genome editing and is considered exceptionally precise, cost-effective, and efficient. It can be used in the creation of new medicines, agricultural products, and genetically modified organisms, or as a means of controlling pathogens and pests. It also offers potential in the treatment of inherited genetic diseases as well as diseases arising from somatic mutations, such as cancer. However, its use in human germline genetic modification is highly controversial. The development of this technique earned Jennifer Doudna and Emmanuelle Charpentier the Nobel Prize in Chemistry in 2020. The third researcher group that shared the Kavli Prize for the same discovery, led by Virginijus Šikšnys, was not awarded the Nobel Prize.

Working like genetic scissors, the Cas9 nuclease opens both strands of the targeted DNA sequence to introduce the modification by one of two methods. Knock-in mutations, facilitated via homology-directed repair (HDR), are the traditional pathway of targeted genomic editing approaches. This allows for the introduction of targeted DNA damage and repair. HDR employs the use of similar DNA sequences to drive the repair of the break via the incorporation of exogenous DNA to function as the repair template. This method relies on the periodic and isolated occurrence of DNA damage at the target site in order for the repair to commence. Knock-out mutations caused by CRISPR-Cas9 result from the repair of the double-stranded break by means of non-homologous end joining (NHEJ) or POLQ/polymerase theta-mediated end-joining (TMEJ). These end-joining pathways can often result in random deletions or insertions at the repair site, which may disrupt or alter gene functionality. Therefore, genomic engineering with CRISPR-Cas9 enables researchers to generate targeted random gene disruption. While genome editing in eukaryotic cells has been possible using various methods since the 1980s, the methods employed have proven to be inefficient and impractical for large-scale implementation. With the discovery of CRISPR and specifically the Cas9 nuclease molecule, efficient and highly selective editing became possible. Cas9, derived from the bacterial species *Streptococcus pyogenes*, has facilitated targeted genomic modification in eukaryotic cells by enabling a reliable method of creating a targeted break at a specific location as designated by the crRNA and tracrRNA guide strands. Researchers can insert Cas9 and template RNA with ease in order to silence or cause point mutations at specific loci. This has proven invaluable for

quick and efficient mapping of genomic models and biological processes associated with various genes in a variety of eukaryotes. Newly engineered variants of the Cas9 nuclease that significantly reduce off-target activity have been developed.

- **High Precision and Efficiency:** CRISPR allows for specific, targeted modifications to DNA.
- **Cost-Effective and Simple:** It is cheaper and easier to use than previous methods like ZFNs or TALENs, requiring fewer specialized resources.
- **Versatility:** It is applicable across many organisms (bacteria, plants, animals) for research, disease treatment, and agricultural improvement.
- **Agricultural Advances:** It can create crops with increased yields, higher nutritional value, and better resistance to diseases or drought, as noted in this Automata article.
- **Rapid Research Deployment:** The ability to design guide RNAs (sgRNAs) quickly makes it an ideal tool for rapid scientific discovery, according to Integrated DNA

Future Applications

- To harness the full potential of CRISPR/Cas9 to modify the mouse genome, an intriguing option is to take a step back and use it to genetically engineer ES cells rather than embryos. Compared to traditional gene targeting approaches, the main advantage of using CRISPR/Cas9 in ES cells is that Cas9-induced DNA damage increases the frequency of homologous recombination events by many orders of magnitudes.
- Consequently, there is no need to identify ES cell clones carrying the modified allele, which streamlines procedures for generating the targeting vector, ES cell screening, and validation.

  By isolating clonal populations of cells, it is possible to avoid mosaicism and perform in-depth quality control procedures to verify that the modified allele does

Conclusion

CRISPR/Cas9 genome engineering technology has provided researchers with an invaluable tool to accelerate the generation of mouse models for biomedical *in vivo* research. The furious pace of CRISPR development, its versatility, and ease of use have already left a mark in the field of molecular genetics. Its combination with established technologies will significantly expand opportunities for generating new and valuable genetically engineered mouse models for basic and translational research.

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MULTIPLE VOICES, BETTER CHOICES: PLURALISM IN EAS (EXTENSION AND ADVISORY SERVICES)

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Abstract

Agricultural Extension and Advisory Services (EAS) in India have transitioned from centralized public systems to pluralistic, multi-actor frameworks involving public institutions, private enterprises, and civil society organizations. This approach enhances the effectiveness of knowledge dissemination by combining research-based guidance, market-driven solutions, and participatory, community-oriented support. Key actors such as KVKs, ATMA, agritech firms, NGOs, and Farmer Producer Organizations contribute to improved service coverage, innovation diffusion, and demand-driven advisory delivery. Pluralistic EAS promotes inclusivity, adaptability, and farmer empowerment while strengthening linkages between research and practice. However, challenges such as coordination gaps, overlapping roles, and unequal access for small and marginalized farmers persist. This article examines the evolution, structure, and effectiveness of pluralistic extension systems, highlighting their role in fostering sustainable, resilient, and inclusive agricultural development.

Keywords: Pluralistic extension, Agricultural advisory services (AAS), Public-private partnerships, Farmer Producer Organizations (FPOs), India, Knowledge dissemination, Participatory extension

Introduction

India has witnessed unpredictable population growth over the past six decades, expanding from around 450 million in 1960 to over 1.4 billion in 2025, with nearly half of the population reliant on agriculture for their livelihoods. This demographic pressure, combined with the demands of globalization, has intensified the need for adaptive and innovative agricultural

practices to ensure food security and sustainable rural development. Agricultural extension services, which facilitate the transfer of research-based knowledge, technologies and management practices to farming communities, play a critical role in bridging the gap between scientific research and field-level application. Historically, India's extension system has evolved through multiple phases, from early rural development experiments before independence, such as the Sevagram and Shri Niketan projects, to post-independence programmes including the Training and Visit (T&V) system, Intensive Agricultural Area Programme, and Krishi Vigyan Kendras (KVKs). While these initiatives contributed to enhancing productivity and knowledge dissemination, their impact was often constrained by limited coordination, resource shortages, and centralized, top-down approaches. These limitations underscored the need for more flexible, inclusive, and diversified extension mechanisms. In this context, pluralism in agricultural advisory services (AAS) has emerged as a key strategy, emphasizing collaboration among public agencies, private enterprises, cooperatives, and civil society organizations to provide a diverse range of services, expertise, and resources. Globally, pluralistic advisory systems have been linked to improved innovation, competitiveness, and sustainability, although challenges remain in ensuring equitable access, particularly for smallholder and marginalized farmers. Recent studies highlight that understanding the diversity, institutional arrangements, and interactions among extension service providers is essential for designing effective policies and interventions.

Evolution of pluralism in EAS:

The evolution of pluralism in agricultural extension represents the shift from centralized, public-sector systems to multi-actor advisory frameworks. In the early to mid-20th century, extension services were largely government-led and top-down, focusing on the dissemination of research-based technologies. While this system established the foundation for formal advisory services, it lacked flexibility and often failed to meet the diverse, localized needs of farmers.By the mid-20th century through the 1970s, the limitations of public-only extension became evident. Resource constraints, workforce shortages, and poor coordination hindered effective outreach, while farmers increasingly demanded practical, context-specific guidance suited to their socio-economic and agro-ecological conditions.

In the late 20th century, non-public actors such as NGOs, cooperatives, private enterprises, and farmer organizations began participating in extension activities. This period marked the emergence of pluralism, emphasizing collaboration among multiple actors and

integration of diverse knowledge sources to address complex agricultural challenges.Between the 1980s and 2000s, pluralistic systems became more formalized. In India, initiatives such as the Agricultural Technology Management Agency (ATMA) and Krishi Vigyan Kendras (KVKs) facilitated decentralization, partnerships, and knowledge sharing. Globally, privatization, decentralization, and policy reforms in Europe, Africa, and Latin America reinforced the trend toward multi-actor advisory services, highlighting pluralism as a key strategy for responsive, inclusive, and sustainable agricultural extension.

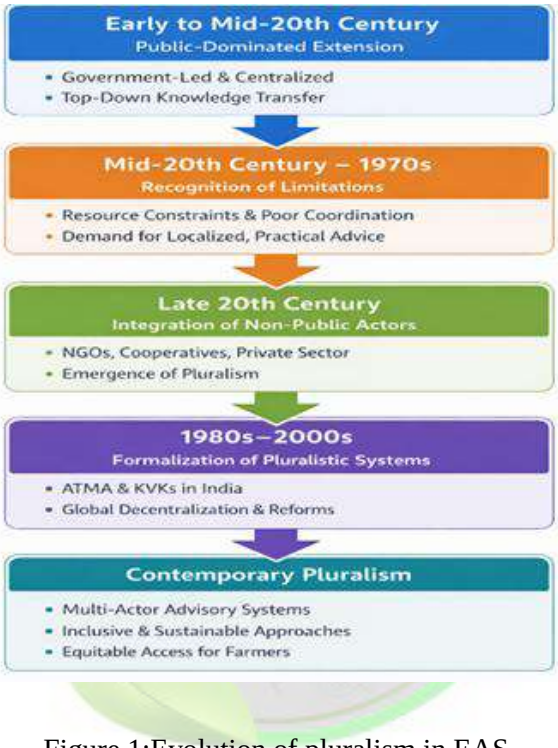

Figure 1:Evolution of pluralism in EAS

Actors in pluralistic extension and advisory services:

The pluralistic EAS system in India is built on the coordinated involvement of multiple stakeholders, ensuring farmers receive timely information, technology, and support to enhance productivity, sustainability, and livelihoods. These actors can be categorized broadly into **Public Sector, Private Sector, and Civil Society Organizations (CSOs)** each contributing uniquely to extension services.

1. Public Sector Actors

The **public sector** forms the core of agricultural extension, providing research-based guidance, policy support, and capacity-building initiatives. Key actors include,

- **Department of Agriculture and Cooperation (DAC):** The DAC, through its Directorate of Extension, serves as the central policy and coordinating body at the national level. It develops extension policies, oversees programs, and conducts training for extension functionaries. Programs such as **ATMA (Agricultural Technology Management Agency)**, Mass Media Support for Agricultural Extension, and Agri-Clinics and Agri-Business Centres facilitate decentralized advisory services across districts.
- **Krishi Vigyan Kendras (KVKs):** Managed under the **Indian Council of Agricultural Research (ICAR)**, KVKs are district-level hubs that provide training, demonstrations, and technology transfer to farmers. They act as resource centers bridging research institutions and the farming community.
- **State Agricultural Universities (SAUs) and State Line Departments:** SAUs integrate education, research, and extension at the state level, delivering localized knowledge and training. State Line Departments assist in implementing extension programs and often collaborate with KVKs and ATMA.
- **State Agricultural Management and Extension Training Institutes (SAMETIs):** SAMETIs provide specialized training for extension personnel on technology, gender issues, market-led approaches, and modern extension methods.
- **National Institute of Agricultural Extension Management (MANAGE):** MANAGE focuses on professional development of extension personnel, promoting innovative practices and capacity building for effective service delivery.

2. Private Sector Actors

The **private sector** complements public services by offering market-oriented solutions, technologies, and advisory support. Key actors include,

- **Agro-input companies and agritech startups:** These provide innovative products, tools, and advisory services directly to farmers or through partnerships with cooperatives or public agencies.
- **Independent consultants and contract farming organizations:** They deliver specialized guidance on crop management, value chains and market linkages. Contract farming enables direct collaboration between farmers and private enterprises without intermediaries.

- **Input Dealers:** Serving as informal advisory agents, input dealers supply agricultural inputs while offering guidance on usage. Programs like MANAGE's **Diploma in Agricultural Extension Services for Input Dealers (DAESI)** have strengthened their capacity to disseminate knowledge and novel technologies to farmers.

The private sector's involvement increases competition, encourages innovation, and facilitates farmer access to diverse technologies and market-driven solutions.

3. Civil Society Organizations (CSOs)

Civil society actors play a crucial role in participatory extension, community engagement, and empowerment.Key actors include,

- **Non-Governmental Organizations (NGOs):** NGOs such as **PRADAN, BAIF, and BASIX** facilitate knowledge transfer, capacity building, and link farmers to government and private resources. They focus on sustainable development, social empowerment, and inclusion of marginalized groups.
- **Farmer Producer Organizations (FPOs) and Cooperatives:** These organizations support collective action, market access, resource pooling, and adoption of modern practices. India has approximately **580,000 cooperatives** and **375,000 agricultural cooperatives** serving over 280 million farmers.
- **Self-Help Groups (SHGs):** SHGs assist in women empowerment, financial literacy, and collective decision-making, integrating social development with agricultural productivity.

Civil society actors ensure that extension services are participatory, inclusive, and tailored to the specific needs of local farming communities.

4. Supporting and Emerging Actors

In addition to these core actors, **International development agencies, research institutions, and digital advisory platforms** are increasingly influencing pluralistic extension. They provide technical expertise, funding, and ICT-based advisory solutions that enhance the reach and efficiency of extension services, particularly in remote and marginalized farming areas.

PLURALISTIC EXTENSION AND ADVISORY SERVICES IN INDIA:

The pluralistic structure of agricultural extension in India, where farmers are at the center, receiving advisory services from multiple actors. The public sector, including Krishi Vigyan Kendras (KVKs) and Agricultural Technology Management Agencies (ATMA), provides research-based knowledge, training, and policy support. The private sector, comprising advisory

firms, input suppliers, and agri-tech companies, delivers market-oriented services, innovative technologies, and specialized expertise. Civil society organizations such as NGOs, cooperatives, self-help groups, and Farmer Producer Organizations (FPOs) offer community-level support and capacity building. Arrows indicate the bi-directional flow of knowledge and resources, highlighting collaboration, coordination, and information sharing, which ensures inclusivity, responsiveness, and sustainability in agricultural development.

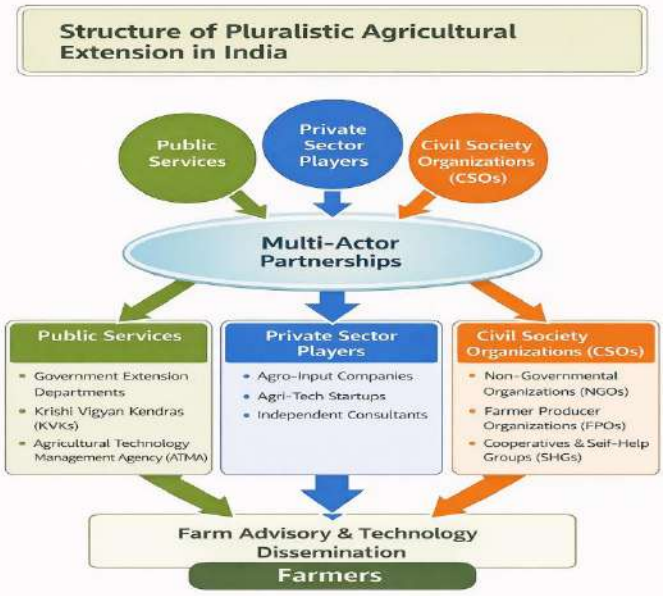

Figure 2:Pluralistic Agricultural extension in India

Effectiveness of pluralistic EAS:

1. Broader Service Coverage- The presence of multiple service providers expands the reach of advisory services to more farmers across diverse regions and contexts, increasing overall coverage.
2. Improved Responsiveness- Pluralistic systems are more responsive to farmer demands compared to singular public models, as multiple actors can tailor services to local needs.
3. Diverse Knowledge Sources- Combining public research with private and civil society insights enriches the quality and relevance of advisory content.
4. Participatory Approaches- Inclusion of farmers and stakeholders in decision-making enhances adoption of innovations and relevance of services.

5. Flexibility and Adaptability- Pluralistic systems can respond more dynamically to changing agricultural and market conditions.
6. Enhanced Innovation Diffusion- Multiple providers contribute to faster dissemination of new technologies, including climate-smart practices.
7. Reduced Public Burden- Sharing advisory responsibilities with private and NGO actors relieves pressure on under-resourced public extension systems.
8. Capacity Building- Training and collaboration among varied actors strengthen overall advisory capacity across sectors.
9. Competitive Quality Improvement- Competition among providers can lead to improvements in service quality and efficiency.
10. Contextualized Advisory Delivery- Local and civil society actors often deliver context-specific and culturally relevant advice.

Conclusion

Pluralistic agricultural extension and advisory services (EAS) have become a cornerstone for addressing the diverse and dynamic needs of India's farming population. The transition from centralized, public-sector approaches to multi-actor systems has enhanced inclusivity, responsiveness, and adaptability in the delivery of agricultural advisory services. By integrating public institutions, private enterprises, and civil society organizations, pluralistic extension leverages complementary strengths to expand outreach, improve knowledge dissemination, and foster participatory decision-making.Public actors, including the Department of Agriculture and Cooperation (DAC), Krishi Vigyan Kendras (KVKs), State Agricultural Universities (SAUs), and SAMETIs, provide research-backed guidance, policy support, and capacity-building programs. Private sector participants, such as input suppliers, agritech companies, and contract farming organizations, contribute market-oriented services, innovative solutions, and technology access. Civil society actors, including NGOs, cooperatives, Farmer Producer Organizations (FPOs), and Self-Help Groups (SHGs), enhance community engagement, empowerment, and context-specific advisory support.

The pluralistic approach has been effective in broadening service coverage, facilitating the rapid diffusion of innovations, and ensuring contextually relevant and demand-driven advisory services. Nevertheless, challenges remain, including coordination difficulties, potential duplication of efforts, and the risk of unequal access for smallholder and marginalized farmers.

Addressing these issues through improved governance, capacity building, and collaborative frameworks is essential. Overall, pluralistic EAS offer a promising pathway toward sustainable, inclusive, and resilient agricultural development, enabling farmers to meet emerging challenges, enhance productivity, and strengthen rural livelihoods.

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POPULAR AND PROMISING VARIETIES AND HYBRIDS OF OKRA

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Introduction

Okra or Bhendi improvement focuses on developing high-yielding hybrids and varieties with better fruit quality and uniformity. Priority is given to breeding for resistance against major biotic stresses such as Yellow Vein Mosaic Virus (YVMV), powdery mildew, and fruit and shoot borer. Efforts are also directed towards incorporating tolerance to abiotic stresses like drought, salinity, and high temperatures through both conventional and molecular breeding approaches. The utilization of wild species and landraces is crucial for broadening the genetic base and introducing novel traits. There is a growing interest in developing parthenocarpic varieties suitable for off-season and protected cultivation. Enhancing the nutritional quality of by increasing protein, fiber, vitamins, and antioxidants is also a key area. Emphasis is being placed on promoting sustainable and organic cultivation practices. Biotechnological interventions, including marker-assisted selection and genetic engineering, are expected to play a significant role in future breeding programs. In addition, standardization of hybrid seed production techniques and the development of value-added and processed products from offer significant potential for improving crop utility and farmer income.

I. Indian Agricultural Research Institute, New Delhi

1. Pusa Makhmali: This variety was developed in 1955 by H.B. Singh and S.M. Sitka at IARI, New Delhi, from a local selection collected from West Bengal. It is an early type, producing smooth, straight, five-ridged green pods measuring about 15–20 cm. It was one of the early improved varieties introduced in India.

2. Pusa Sawani: Bred in 1957–58 at IARI, New Delhi, this variety is a cross between IC-1542 and Pusa Makhmali. The plants are medium tall, growing 120–150 cm with dark green, five-ridged pods that are 18–20 cm long. It can be identified by a purple patch at the base of the yellow petals on both sides. Initially resistant to YVMV, it was recommended for cultivation across India in 1969 due to its high adaptability and yield potential of about 100 q/ha.

3. Selection 2: Developed by H.B. Singh and colleagues at IARI, New Delhi, between 1973 and 1974, this variety is a derivative of the cross Pusa Sawani Best-1 × Pusa Sawani × IC 7194. The plants grow up to 110 cm with purple petal base colour and occasional branching. Pods are green, five-ridged, tender, and become harvestable 50 days after sowing. It yields about 100 q/ha and shows tolerance to YVMV.

4. Pusa A 4: Released by IARI in 1994 as a substitute for Pusa Sawani, this variety has dark green leaves, short internodes (2–4 cm), and occasional purple pigmentation on stem and petiole. The pods are attractive, dark green, 12–15 cm long, and exhibit excellent shelf life. It is resistant to YVMV and gives good yields.

5. Harbhajan: The original 'Perkins Long Green' or Sel-6 has been named as Harbhajan in the memory of the most dedicated Vegetable Scientist, Dr. Harbhajan Singh of IARI, New Delhi by T.A. Thomas and R. Prasad. Plants are very tall, thick and prolific bearer. Leaves are large, moderately lobed with rough surface and prominent veins. Fruits are long, tapered, bright green, spineless and mostly 8-edged. It is notified by the central variety release committee.

II. Tamil Nadu Agricultural University, Coimbatore

1. CO 1 (1976): Released by Tamil Nadu Agricultural University, Coimbatore in 1976, CO 1 is a selection from a population of Red Wonder collected from Hyderabad. The plants are medium tall (90–120 cm) with 5–8 branches. The stem and leaves have a reddish tinge, and the first fruit appears on the 5th node. The pods are long, slender, scarlet red, and smooth with 5 ridges. While it is tolerant to yellow vein mosaic virus (YVMV), it is susceptible to fruit borer and powdery mildew.

2. CO 2 (1987): It is a F_1 hybrid between A.E. 180 x Pusa Sawani. Fruit surface is less hairy with a better consumer's appeal and market preference. Fruits are very long with 7-8 ridges. It has a yield potential of 15-16 tonnes/ha in 90 days.

3. CO 3 (1991): It is a F_1 hybrid between Parbhani Karanti x MDU.1. Yields about 16-18 tonnes/ha. Moderate resistance to Yellow Vein Mosaic disease.

4. MDU 1 (1978): This variety was developed at TNAU, Coimbatore, as a mutant of Pusa Sawani and released in 1985. It has green stems with light purple pigmentation and bears medium-long pods of about 20 cm. Fruiting starts from the 4th node, and it takes about 45 days for the first picking. It is suited for cultivation in all three seasons in Tamil Nadu.

5. Okra hybrid COBH H 1 (2007): It is a cross between Varsha Uphar selection and PA 4 (T). It has resistance to yellow vein mosaic virus disease with high level of market preference. The fruits are dark green, slender, less fibrous and sparsely pubescent. Yields about 22.1 /ha under normal conditions.

6. COBh H 3: Slender, dark green colour fruit, yield 25.7 t ha-1, 25-29 fruits per plant, Resistance to Yellow Vein Mosaic Virus (YVMV) disease.

7. Okra Hybrid CO 4 (2016): BHD 9/Karamadai local, 110 days duration, yield 25.60 t/ha, 19.6 and 23.1% increase over COBhH1 and Sakthi respectively 32.40 t/ha; Suitable for all the districts of Tamil Nadu except hilly regions; 22 harvests in 110 days starting from 39 days after sowing; resistant to Okra Yellow Mosaic Virus disease.

8. Okra hybrid CO(H) 5 (2025): It is a high-yielding variety developed from a cross between AE-CBE-92 and AE-CBE-921. It has a crop duration of 110 to 120 days and is suitable for cultivation during the Aadi pattam and Thai pattam seasons. This hybrid is early in flowering, initiating between 33 to 36 days after sowing, and allows for up to 23 harvests within its growth period, beginning from 38 days after sowing. It records a yield of 28.85 tonnes per hectare, which is 15.77 per cent higher than CO 4. Additionally, CO(H) 5 exhibits moderate resistance to Yellow Vein Mosaic Virus (YVMV) and Enation Leaf Curl Virus (ELCV), making it a reliable choice for Okra cultivation.

III. Punjab Agricultural University, Ludhiana

1. Punjab Padmini: This variety is a cross involving *Abelmoschus esculentus* and *A. manihot spp. manihot*, followed by backcrossing with Pusa Sawani. The plants are tall, bearing dark green pods 18–20 cm long. Fruits are smooth, tender, and glossy, and picking begins around 45–50 days after sowing. It is resistant to YVMV and tolerant to jassids, giving a yield of about 125 q/ha.

2. P7: P7 is another YVMV-resistant hybrid developed from *A. esculentus* and *A. manihot* spp. *manihot.* The plants have sparse branching and produce green, five-ridged fruits from the 4th–5th node. It yields 95 q/ha and is suited for both summer and rainy seasons.

IV. Indian Institute of Vegetable Research, Varanasi

1. Kashi Mohini (VRO 3): It has tall plants (110–140 cm) and produces 11–12 cm long green pods. Fruiting begins from the 4th–5th node. It gives a green pod yield of 130–150 q/ha and is tolerant to YVMV.

2. Kashi Pragati (VRO 6): This variety has tall plants (130–175 cm) with good branching and early flowering at 4th node. It produces smooth, tender, 8–10 cm long green pods. The yield is 150–180 q/ha, and it is tolerant to YVMV

3. Kashi Mangali (VRO-4): Developed through pure line selection, plants tall, height 120-125 cm, flowers at 4th to 5th node after 40-42 days after sowing, fruits five ridged, light green, yield 130-150 q/ha, resistant to YVMV under field conditions.

4. Kashi Vibhuti (VRO-5): A variety with dwarf growth habit, plant height 60-70 cm during rainy and 45-50 cm during summer season, bears 2-3 branches with short-inter-nodal length, flowering starts on 4th to 5th node after 38-40 days after sowing, plant bears 18-22 fruits of 8-10 cm length at marketable stage, yield 170-180 q/ha, resistant to YVMV.

5. Kashi Satdhari (IIVR-10): Plant height 130-150 cm with 2-3 effective branches, flowering at 42 days after sowing at 3rd to 4th node, 18-25 fruits/plant with seven ridges, fruit length 13-15 cm at marketable stage, yield 110-140 q/ha, resistant to YVMV under field conditions.

6. Kashi Lila (IIVR-11): Medium plant height (110-130 cm), flowering at 30-34 days after sowing, suitable for cultivation during rainy and summer seasons as early crop due to low temperature tolerance, fruits have five ridges, green and 13-15 cm long, resistant to YVMV, yield 150-170 q/ha.

7. Shitla Uphar (DVR-1): Plants medium tall, (110-130 cm), flowering at 38-40 days after sowing at 4th-5th node, fruits green, 11-13 cm long at marketable stages, yield 150-170 q/ha, resistant to yellow vein mosaic virus

8. Shitla Jyoti (DVR-2): Plants medium tall, (110-150 cm), flowering at 30-40 days after sowing at 4th-5th node, fruit green, 12-14 cm long at marketable stage, yield 180-200 q/ha, resistant to YVMV.

9. Kashi Bhairav (DVR-3): Plants medium tall with 2-3 branches, fruits dark green, 10-12 cm long at marketable stage, yield 200-220 q/ha, resistant to YVMV under field conditions.

10. Kashi Mahima (DVR-4): Plants tall, height 130-170 cm, flowering at 36-40 days after sowing at 4th-5th node, fruits green, 12-14 cm long at marketable stage, yield 200-220 q/ha

V. Marathwada Agricultural University, Parbhani

1. Parbhani Kranti: This YVMV-resistant variety was developed by Marathwada Agricultural University, Parbhani in 1985 through an interspecific cross involving Pusa Sawani and an African species. The plants have deeply lobed leaves and green fruits with narrow tips. Fruits begin to mature around 48 days after sowing. It yields about 100 q/ha and is suitable for summer and rainy season cropping.

VI. Haryana Agricultural University, Hisar

1. Hisar Unnat (HRB 55): This variety from HAU, Hisar is a cross between Sel 1-2-2 and Parbhani Kranti. It is YVMV resistant, short in height (90–120 cm), and begins fruiting 45–47 days after sowing. The pods are medium green and 15–16 cm long with a high yield potential of 120–150 q/ha.

2. Varsha Uphar (HRB 9-2): This variety has been developed by Haryana Agricultural University, Hisar from the cross, Lam Selection 1 x Parbhani Kranti following pedigree selection method. It was released in 1992 and notified in 1995 by the Central Sub-Committee on Crop Standards. It has resistance to YVMV and field tolerance to leaf hopper and suits to disease prone rainy as well as disease-free spring- summer season. Average fruit yield of 10 tonnes/ha.

VII. Indian Institute of Horticultural Research, Bengaluru

1. Arka Abhay (Sel 4): Developed by IIHR, Bangalore, Arka Abhay is a sister line of Arka Anamika and is resistant to YVMV. The plants resemble Arka Anamika and also show resistance to fruit borer. It is suitable for ratoon cropping due to its pruning adaptability.

2. Arka Anamika: Developed by interspecific hybridization of (*Abelmoschus esculentus* × *A. manihots spp. tetraphyllus var. tetraphyllus*) followed by back cross method of breeding. Fruits lush green, tender and long. Fruits free from spines having 5-6 ridges, delicate aroma. Good keeping and cooking qualities. Field tolerant to YVMV. Yield 20 t/ha.

3. Arka Abhay: Developed by interspecific hybridization of (*Abelmoschus esculentus* × *A. manihot spp. tetraphyllus* var *tetraphyllu*s) followed by back cross method of breeding. Fruits lush green, tender and long. Fruits free from spines having delicate aroma. Good keeping and cooking qualities. Field tolerant to yellow vein mosaic virus (YVMV). Yield 18 t/ha.

4. Arka Nikitha: Hybrid between GMS-4 X IIHR-299-14-11-585, has been identified for release by the Institute VTIC during 2017. It is developed through genetic male sterile line.

Early flowering and first female flower appear at 9th node from the base of the vine. Takes 39 days for the first flower appearance and 43 days for first picking of fruits. Produces dark green, medium, smooth and tender fruits. Excellent cooking quality, nutritionally rich in antioxidant activity, high mucilage content (1.08% FW) and high edible fiber content (8.85% DW). It is rich in minerals like potassium (3.7%), calcium (997 mg/100 g) and magnesium. Rich in iodine content (33.31 µg/kg). Yields 21–24 t/ha in 125–130 days duration.

VIII. Gujarat Agricultural University, Junagadh

1. Gujarat Bhindi 1 – (1983): This variety was developed by the Gujarat Agricultural University in 1983 through pure line selection from local material. It has medium tall plants (90 cm in summer and 120 cm in rainy season) with purple pigmentation on stems. Fruits are green, five-ridged, and 14–15 cm long, with a yield of 70 q/ha. It was released for general cultivation by the central variety release committee.

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MECHANISM GOVERNING EVOLUTION OF NEW GENES AND ITS IMPORTANCE IN ORGANISM'S EVOLUTION AND ADAPTATION

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Introduction

A gene is a segment of DNA that contains information required to produce a functional molecule, usually a protein or RNA. Proteins carry out the majority of cellular functions, including metabolism, structural support, signaling and regulation of gene expression. Therefore, the origin of new genes is closely linked to the origin of new biological functions. The evolution of new genes is one of the most fascinating processes in evolutionary biology and genetics, because it explains how organisms acquire novel traits and adapt to changing environments. In evolutionary terms, the creation of new genes contributes to biodiversity, enabling organisms to adapt to new environments, exploit new resources and develop new physiological capabilities. The emergence of novel genes has been linked to major evolutionary transitions such as the development of multicellularity, immune systems and specialized organs.

For many years scientists believed that most genes were ancient and simply modified over time. However, modern genomic studies have revealed that entirely new genes can emerge through several mechanisms. These processes include gene duplication, exon shuffling, horizontal gene transfer, retroposition and *de novo* gene formation. Together they demonstrate that genomes are dynamic systems capable of generating genetic novelty throughout evolutionary history.

The fundamental principle underlying gene evolution is variation. Mutations introduce changes in DNA sequences, and natural selection filters these variations by favoring those that improve survival or reproduction. Over long periods of time, these processes can transform existing genes or create entirely new ones.

Most Common Mechanism of new gene evolution

Below is a detailed explanation of the major mechanisms of new gene evolution along with examples that illustrate how they operate in nature.

1. Gene Duplication

One of the most important mechanisms for the evolution of new genes is **gene duplication**. In this process, a segment of DNA containing a gene is copied during replication or through recombination errors. As a result, an organism gains an extra copy of a gene. Initially, both gene copies perform the same function. However, because one copy can still maintain the original role, the other copy is free to accumulate mutations without harming the organism. Over time, this duplicated gene may evolve a new function.

There are several evolutionary outcomes of gene duplication:

a. Neofunctionalization - one gene copy retains the original function while the other evolves a completely new function through mutation and natural selection.

b. Subfunctionalization - the duplicated genes divide the original functions between them. Each gene becomes specialized in performing part of the ancestral role.

c. Pseudogenization - the extra copy accumulates harmful mutations and becomes inactive, forming a pseudogene.

Gene duplication has played a major role in the evolution of complex organisms. For example, many gene families in vertebrates - such as those involved in immunity and development - arose through multiple duplication events.

Example

- The globin gene family in vertebrates - the hemoglobin and myoglobin genes arose through multiple rounds of duplication and divergence, allowing different globin proteins to specialize in oxygen transport and storage.
- Another example is the Hox gene clusters, where gene duplications have contributed to the complexity of body plans in animals.

2. Whole Genome Duplication

A more dramatic form of duplication is **whole genome duplication**, where the entire set of chromosomes is duplicated. This process creates two copies of every gene in the genome. Whole genome duplication events have occurred multiple times during evolution, particularly in plants and some vertebrates. These events provide enormous opportunities for evolutionary innovation

because thousands of genes suddenly become available for modification. After such duplications, many genes are lost over time, but others diversify and acquire new functions. Some scientists believe that genome duplication contributed significantly to the complexity of vertebrates.

Example

Whole genome duplication is very common in plants. Bread wheat, for instance, has undergone multiple genome duplication events that resulted in a large and complex genome. These duplications helped plants evolve traits such as improved environmental tolerance and metabolic diversity.

In vertebrates, ancient genome duplication events are believed to have contributed to the evolution of complex organ systems, including the nervous system and immune system.

3. Exon Shuffling

Another mechanism for creating new genes is exon shuffling. Genes in eukaryotic organisms are often composed of segments called exons, which encode portions of proteins. During recombination events, exons from different genes can be rearranged and combined to form new gene structures. This process allows evolution to generate new proteins by mixing and matching functional modules. Because many protein domains perform specific biochemical tasks, combining them in different ways can produce proteins with novel properties.

Exon shuffling is particularly important in the evolution of multidomain proteins, which are common in complex organisms. These proteins often contain multiple functional regions that evolved through recombination of existing exons.

Example

- The tissue plasminogen activator (tPA) gene in humans is believed to have arisen through exon shuffling, combining domains from different ancestral genes to create a gene important in blood clot breakdown.
- Immunoglobulin genes also exhibit exon shuffling contributing to antibody diversity.

4. Retroposition

Retroposition is another mechanism that generates new genes. In this process, a gene is first transcribed into RNA. This RNA molecule is then reverse-transcribed back into DNA and inserted into a new location in the genome. Because the new copy originates from processed RNA, it usually lacks introns and regulatory sequences present in the original gene. However, if it integrates near active regulatory elements, it can become functional and evolve independently.

Retroposed genes are common in mammals and have contributed to the evolution of new gene families. Some of these genes have acquired important roles in reproduction and development.

Example

- One well-known example is the Jingwei gene found in fruit flies. This gene originated from a retroposed copy of another gene and later fused with additional DNA sequences. The resulting gene evolved a new enzymatic function involved in metabolism. This example demonstrates how retroposition can generate completely new genes with novel functions.
- The PGK2 gene in mammals originated by retrotransposition from the X-linked PGK1 gene. PGK2 is expressed specifically in testes and plays a role in sperm development.
- Many processed pseudogenes are retrotransposed copies, although most are non-functional.

5. Horizontal Gene Transfer

While gene duplication mainly occurs within a lineage, genes can also move between different species through **horizontal gene transfer**. This process involves the transfer of genetic material between unrelated organisms rather than through traditional reproduction.

Horizontal gene transfer is especially common in bacteria, where genes can be exchanged through mechanisms such as transformation, transduction and conjugation. These transfers can rapidly introduce new metabolic capabilities, antibiotic resistance or virulence factors.

Although less common in multicellular organisms, horizontal gene transfer has still played a role in their evolution. For example, some genes in plants and animals appear to have originated from microbial sources.

Example

- The transfer of the antibiotic resistance genes among bacteria, such as the beta-lactamase gene, which allows bacteria to degrade penicillin and related antibiotics.
- Another example includes the transfer of genes from bacteria to eukaryotes, such as the gene for carotenoid biosynthesis in aphids, which was acquired from fungi.

6. *De Novo* gene birth

One of the most surprising discoveries in modern genomics is *de novo* gene birth, where entirely new genes arise from previously noncoding DNA sequences.

For a long time scientists believed that new genes could only evolve from existing genes. However, research has shown that random mutations can create new open reading frames in

noncoding regions of the genome. If these sequences are transcribed and translated, they may produce new proteins.

Most newly formed proteins are likely nonfunctional or unstable. However, occasionally a sequence may confer a beneficial effect and become preserved by natural selection. *De novo* gene birth highlights the creative potential of genomes, demonstrating that genetic novelty can arise even from sequences that previously had no function.

Example

A well-studied example is the antifreeze proteins found in Antarctic fish. These proteins prevent ice crystals formation in the blood, allowing fish to survive in extremely cold waters. Some antifreeze protein genes appear to have evolved from previously noncoding DNA sequences. Through mutation and natural selection, these sequences acquired the ability to produce functional proteins.

In humans, genes like FLJ33706 and others have been proposed as *de novo* genes based on comparative genomics.

7. Transposable elements and gene innovation

Another contributor to gene evolution is **transposable elements**, often called "jumping genes." These DNA sequences can move from one location to another within the genome. Transposable elements can influence gene evolution in several ways:

- Creating mutations when they insert into genes
- Providing regulatory sequences that affect gene expression
- Contributing coding sequences that become part of new genes

Over evolutionary time, many transposable elements have been incorporated into functional genes and regulatory networks.

Example

- The human RAG1 and RAG2 genes, essential for adaptive immunity, are thought to have originated from a transposable element that was domesticated by the host genome.
- In plants, the Ac/Ds transposon system in maize has contributed to gene rearrangements and new gene formation.

8. Gene fusion and gene fission

New genes can also arise through structural rearrangements such as gene fusion and gene fission.

- **Gene fusion** occurs when two separate genes join together to form a single gene encoding a combined protein.
- **Gene fission** happens when one gene splits into two independent genes.

These processes can alter protein architecture and create new functional possibilities. Gene fusion, in particular, is common in metabolic pathways where enzymes may combine to improve efficiency.

Example

- Gene Fusion: the TRIM5 - Cyclophilin A fusion gene in some primates arose by fusion and provides resistance to certain retroviruses.
- Gene Fission: the split of the ancestral bacterial RNA polymerase gene into multiple subunits in eukaryotes is an example of gene fission, allowing more regulatory control.

9. Role of Natural Selection

The fate of newly formed genes depends largely on **Natural Selection**. Most mutations are neutral or harmful, and many new genes disappear over time. However, if a gene provides an advantage - such as improved metabolism, immunity, or environmental tolerance - it may spread through the population. In contrast, genes essential for basic cellular processes tend to evolve slowly because changes may disrupt vital functions.

Example

Genes involved in immune responses often evolve rapidly because organisms must constantly adapt to new pathogens. For example, many immune-related genes in humans show signs of rapid evolution due to interactions with viruses and bacteria.

This evolutionary “arms race” drives the emergence of new gene variants.

10. Evolution of gene families

Repeated duplication and diversification events can produce gene families, groups of related genes with similar sequences but different functions. Gene families illustrate how evolution builds complexity gradually. Starting from a single ancestral gene, duplication and mutation can generate dozens or hundreds of specialized genes.

Example

A well-known example is the **Olfactory Receptor** gene family responsible for detecting odors. Humans possess hundreds of olfactory receptor genes, while some animals such as dogs

have even more. These genes evolved through duplication and diversification, allowing organisms to detect a wide range of chemical signals.

These examples illustrate how diverse genetic mechanisms contribute to the origin and evolution of new genes, fueling biological innovation and diversity.

New genes and species evolution

New genes can contribute to the emergence of new species by generating novel traits. For instance, changes in developmental genes can alter body structures, while new metabolic genes may allow organisms to exploit different ecological niches. The evolution of species-specific genes is particularly interesting. Some genes exist only within a single lineage and may contribute to unique biological characteristics. Comparative genomics has revealed that every species possesses a set of lineage-specific genes that evolved relatively recently in evolutionary history.

Methods for studying new gene evolution

Scientists use several approaches to study gene evolution:

1. **Comparative genomics** – comparing genomes from different species to identify gene origins and duplication events.
2. **Phylogenetic analysis** – reconstructing evolutionary relationships between genes.
3. **Functional experiments** – determining how new genes affect organismal biology.
4. **Transcriptomics and proteomics** – studying gene expression and protein production.

Advances in DNA sequencing technology have greatly expanded our understanding of gene evolution. The availability of whole-genome sequences from thousands of species allows researchers to track how genes originate, diversify, and sometimes disappear.

Importance of new genes in adaptation

The evolution of new genes plays a critical role in adaptation. For example:

- Microorganisms evolve new metabolic enzymes to break down novel compounds.
- Plants develop genes that help them resist pests or tolerate drought.
- Animals acquire genes that improve immunity or reproduction.

These innovations enable organisms to survive environmental challenges and exploit new ecological opportunities.

Importance of new genes in evolution

The evolution of new genes plays a critical role in biological diversity and adaptation. New genes allow organisms to:

- Adapt to new environments
- Develop new physiological functions
- Improve immune defenses
- Exploit new ecological niches

For example, the evolution of antifreeze proteins allowed Antarctic fish to survive freezing temperatures, while gene duplication in hemoglobin genes improved oxygen transport in vertebrates.

Without the evolution of new genes, life would lack the genetic innovation necessary for complex biological systems.

Conclusion

The evolution of new genes is a fundamental driver of biological innovation. Through processes such as gene duplication, exon shuffling, retroposition, horizontal gene transfer and *de novo* gene birth, genomes continually generate new genetic material. Natural selection then determines which of these innovations persist.

Over millions of years, these mechanisms have produced the enormous diversity of life on Earth. From simple microorganisms to complex multicellular organisms, the evolution of new genes has enabled life to adapt, diversify and thrive in countless environments. As genomic research continues to advance, scientists will gain an even deeper understanding of how new genes arise and how they shape the evolutionary history of living organisms.

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FROM FIELD TO FORK: THE MANY FACES OF RICE

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Introduction

Various types of rice have been used for centuries to create nutritious, flavourful, and functional foods that are rich in essential biomolecules such as proteins, healthy fats, carbohydrates, vitamins, and minerals. These foods contribute to good health, energy, and overall well-being. Mineral-rich rice varieties have always been highly valued, particularly for their believed therapeutic properties. Many traditional red rice types, grown organically, were used both as food and medicine. The husk of these varieties is also nutritious and flavourful. (Sala1 *et al*., 2024).

Rakthashali is regarded as one of the rarest and most prized types of red rice. Other notable red rice varieties include Karuppu Kavuni, Poongar, Kattuyanam, Mookil, and Karunkuruvai rice, all known for their distinct flavours. Thooyamalli, a white rice, is famous for its delicate taste and medicinal benefits. Additionally, Mappillai Samba is another traditional rice variety with unique qualities. (Arsha RS *et al*., 2021).

Health Benefits

Rice varieties are beneficial for pregnant women, help eliminate unpleasant body odour, strengthen the immune system, support diabetes management, promote healthy digestion, and are high in antioxidants.

Raktashali Red Rice

Raktashali is one of the rarest and most valued types of red rice. Ancient Ayurvedic texts highlight its healing properties. This rice is believed to support the production of blood cells, making it especially beneficial for women with anemia. Rich in Vitamin B5, Raktashali aids in

red blood cell formation and is considered helpful for women and individuals experiencing high stress or undergoing intensive medical treatments.

Raktashali has held a special position since time immemorial and is highly valued for its reputed ability to cure diseases. In the past, many traditional red rice varieties with specific qualities were grown organically for use as both food and medicine. This red rice is specifically used to increase milk secretion in lactating mothers. It is often offered along with fenugreek and salt or sugar to promote lactation. (Sala1 *et al*., 2024).

Raktashali Red Rice

Rakthashali is also acknowledged for its therapeutic value in the treatment of allergies, skin ailments, uterine problems, gastrointestinal issues, and disorders of the liver, kidney, and nerves. It is even known to combat cancer. This red rice variety improves blood circulation and has recently been recommended by doctors to boost immunity against COVID-19. Also it is a powerhouse of antioxidants (selenium and polyphenols), as well as zinc, calcium, and iron, all of which play a crucial role in strengthening the body. Studies have shown that certain elements in Raktashali rice reduce the risk of cancer, anemia, and diabetes. It also helps relieve constipation naturally and nourishes the skin, keeping it clear and glowing.

Karuppu Kavuni Rice

Karuppu Kavuni, also known as Black Rice or Forbidden Rice, is a traditional variety native to southern India, particularly Tamil Nadu. Its dark colour and rarity have made it highly prized. This rice is packed with antioxidants, fiber, and protein. It has a nutty flavour and chewy texture, making it ideal for savoury dishes. (Bhardwaj *et.al*., 2023).

Karuppu Kavuni Rice

Key benefits include:

1. Rich in antioxidants: Contains high levels of anthocyanins, natural compounds that protect the body from harmful free radicals and prevent chronic diseases.
2. Low glycemic index: Releases energy slowly, preventing sudden spikes in blood sugar levels—beneficial for people with diabetes or weight management goals.
3. Good for digestion: High in dietary fiber, which aids digestion and prevents constipation.
4. Gluten-free: A safe alternative for people with celiac disease or gluten intolerance.
5. Boosts immunity: Anthocyanins help strengthen the immune system and protect against infections.

Karuppu Kavuni is also rich in essential nutrients like iron, zinc, magnesium, and B vitamins, supporting healthy blood cells, brain function, and energy production. Its high fiber content promotes fullness and may help with weight management. (Harini *et.al*., 2024).

Poongar Rice (Women's Rice)

Poongar rice, also known as Women's Rice, is traditionally cultivated and consumed in southern India, especially Tamil Nadu.

Poongar Rice

It is valued for its ability to alleviate women's hormonal issues and is particularly beneficial for pregnant and lactating women. This rare rice variety has a dark reddish-brown colour and high nutritional value. It is rich in iron, fiber, antioxidants, and other essential nutrients. (Sala1 *et al*., 2024).

Health benefits include:

1. High antioxidant content, which protects cells from free radicals and reduces the risk of chronic illnesses such as cancer and heart disease.
2. High fiber content, which supports digestion, lowers cholesterol levels, and reduces heart disease risk.
3. Low glycemic index, making it suitable for diabetics.
4. Rich in iron, necessary for red blood cell production and anemia prevention.
5. Naturally gluten-free, suitable for people with celiac disease or gluten intolerance.

Helps with weight management by promoting fullness and reducing calorie intake. (Arsha *et al*., 2021).

Bamboo Rice

Bamboo rice is a distinct variety obtained from the seeds of a dying bamboo shoot, which flowers only once every 12 years. These seeds are collected and used as rice. It has a sweet, strong, and slightly pungent flavor, similar to wheat. Traditionally, tribal communities in Kerala and Tamil Nadu have used bamboo rice to treat joint pain due to its high calcium and phosphorus content. (Sebastian *et al*., 2023).

Bamboo Rice

Nutritional and health highlights:

1. Rich in protein and essential nutrients.
2. Beneficial for bone health and joint pain relief.

3. Low glycemic index, making it suitable for diabetic patients.
4. Low in fat and rich in Vitamin B.
5. Moist and sticky when cooked, pairing well with curries.

Bamboo rice is both highly nutritious and medicinal, making it a unique addition to traditional diets. (Das *et al*., 2021).

Conclusion

Incorporating nutrient-rich rice varieties such as Karuppu Kavuni, Poongar, Kattuyanam, Mookil, Karunkuruvai, Thooyamalli, White Rice, and Mappillai Samba into our daily diet is a proactive step toward enhancing overall health and reducing the risk of various diseases. Nature provides an abundant source of plant-based compounds that play a vital role in protecting against numerous ailments. By adopting a plant-centric diet that includes these colourful and traditional rice varieties, we can effectively harness nature's healing power to promote long-term health and well-being.

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CLASSIFICATION OF CULTIVATED CAPSICUM PUBESCENS AND CAPSICUM BACCATUM CHILI PEPPERS

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1. INTRODUCTION

Chili is grown throughout the country and is used in almost all dishes. Chilies are of numerous varieties and their degree of pungency varies. Dry and fresh Chilies are used in various dishes. Dry chilly gives a red colour and makes the dish attractive. This spice is grown throughout the year and so there is no scarcity and a good quantity is exported. Kashmir chillies are known for its colour and pungency. The highly pungent chilly is 'Sannam' and slightly pungent chilly is 'Mundu'. Sannam has international popularity. Chilies are used with or without stalks. To make good quality of chilli powder the stalks should be removed. It is variously called capsicum, paprika, pimento, sweet pepper, red pepper, cayenne pepper and bird pepper, depending on the type of chili and the manner in which it is prepared and used. The chili (*Capsicum* spp.) pepper is an important condiment of high commercial value and also medicinal values containing antioxidant properties, anti-cancerous and many other properties capsicum belongs to the family Solanaceae possessing 10 species. Chilli (*Capsicum annuum* L.) is one of the most cultivated vegetable spice crops in tropical and subtropical climates. India is the largest consumer and exporter of chilies in the international markets and exports dry chili, chili powder and oleoresins to over 90 countries Major capsicum-producing countries include China, Mexico, India, Turkey, the United States, Spain, and the Netherlands. In India, capsicum is predominantly cultivated in states like Andra Pradesh, followed by Karnataka, Himachal Pradesh, Maharashtra Odisha and Tamil Nadu, especially under protected environments. Indian chilies are mainly exported to USA, Sri Lanka, Bangladesh, the middle and the Far east. It is grown in several parts

of India, though it has a larger area; its productivity is very low as compared to other countries. Hence, there is an urgent need to produce and identify new varieties combining with high level of disease resistance, besides increased yield and capsaicin content in chili.

2. CLASSIFIATION OF CAPSICUM PUBESCENS PEPPERS

***Capsicum pubescens* (Pubescens, Downy Pepper or Downy Capsicum)**: This species is native to Central and South America This chili pepper species is characterized by large, rugose, pubescent leaves; stem has mixed green with purple pigments, giving striped appearance. Flowers are large rotate, purple or white flowers with five to eight lobes. The fruits are pungent with cucumber aroma. This species of cultivated chili is further classified into two botanical varieties *viz*.,

a. Rocoto peppers: These are apple or pear-shaped peppers, native to Peru and other parts of South America, similar in appearance to a small bell pepper. The peppers have a thick wall similar to a bell pepper, with black seeds, and can found in a variety of colours from vibrant red to yellow and orange. It is 40 times hotter than Jalapeno peppers, having SHU ranging from 30,000 to 1,00,000 units.

A B C D E

Fig. 1. Rocoto Peppers (*Capsicum pubescens* var. *rocoto*). A. Plant, B. Flower, C. Red fruits, D. Yellow fruits and F. Fruit in Longitudinal section

b. Manzano Peppers or Apple Peppers: These are native to Andes and are mainly cultivated in Mexico and South America. The fruits are from green to a vibrant yellowish orange or sometimes beautiful red, resembling miniature apple and hence the name Manzano pepper.

A B C D E

Fig. 2. Manzano Peppers (*Capsicum pubescens* var. *manzano*). A. Plant, B. Flower, C. Red fruits, D. Yellow fruits and F. Fruit in Longitudinal section

The fruit wall are thicker and juicy with bright crispy earthiness flavour having a tempting medium heat of 12,000 to 30,000 SHU.

03. CLASSIFICATION OF CAPSICUM BACCATUM PEPPERS

Capsicum baccatum* var. *pendulum: This species originated from *Capsicum baccatum* var. *baccatum* and is characterized by cream-coloured flowers with paired gold or green markings. The fruits are elongated in shape with cream-coloured seeds. The calyx is with elongated teeth, corolla off white (cream) with a pair of yellow, greenish or tan markings at the base of each corolla. The anthers are long and yellow in colour. This cultivated species is further classified into the following botanical varieties *viz*.,

a. Aji Peppers or Peruvian Hot Peppers: Aji peppers refers to Peruvian chili peppers of Capsicum baccatum species, native to South America and the Caribbean region. Aji peppers are celebrated not just for their heat but also for their distinctive fruit-forward flavor and bright colors. These peppers are a staple in traditional Latin American cooking, particularly in countries like Peru, Bolivia, and Colombia. Because of their wide culinary appeal, they've become increasingly popular among chefs and home cooks worldwide. Aji peppers are further classified into the following groups *viz*.,

i. Aji Amarillo or Aji Yellow or Yellow Chile Peppers: The most common peppers cultivated and consumed in Peru. The fruits are 3-4 inches or even 6-7 inches long with colour changing from green to deep orange when mature. It has a pungent taste and mildly hot with SHU of 40,000 to 50,000 and are mostly used in Peruvian and Bolivian dishes.

ii. Aji Panca Peppers: These are the second most common chili peppers of Peru and are cultivated in the coastal regions of Peru. The fruits are deep red to burgundy, measuring 3-5 inches. The shape of the fruit is similar to Aji Amarillo, but less spicy and has a sweet berry like and a smoky flavour.

iii. Aji Criolla Sella Peppers: These are small, short, and slender pods, averaging 4 to 5 centimeters in length and 1 to 2 centimeters in diameter, and have a conical shape that tapes to a distinct point on the non-stem end. The bullet-shaped pods ripen from green, yellow-orange, to deep orange when mature and the skin is smooth, taut, thin, and waxy. Underneath the surface, the semi-thick flesh is crisp and orange, encasing a narrow central cavity filled with a few round and flat, cream-colored seeds. Criolla Sella chile peppers are tangy-sweet with aromatic notes of citrus and mango and offer a moderate to hot level of spice that lingers on the back of the tongue. Thes are an excellent source of vitamin A and potassium and contain essential minerals like calcium and iron.

The peppers are also a good source of vitamins C and D, dietary fiber, and flavonoids, which provide antioxidant benefits.

iv. Aji Cito Peppers: These are possibily the hottest of *Capsicum baccatum* chilies, having an SHU of 1,00,000 value. They mature from green to a beautiful yellowish-orange with a somewhat citrusy flavor, excellent when used fresh in salad or salsa, and delicious when dried or powdered.

v. Aji Cristal Peppers: These are small spicy chili peppers native to Curico Chile. The fruit is 4 inches long and start light green in color, then ripen to yellow and finally a vibrant orange-red color.

vi. Aji Fantasy Peppers: These are sweet peppers with mild heat level with SHU of 5,000 to 10,000 and highly falvourful.

vii. Aji Limo or Lemon Drop or Hot Lemon Peppers: These are super hot chili peppers that are yellow, orange, red or even purple to white, providing a great colour to different dishes. The fruits are 2-3 inches long, thin and waxy with SHU of 50,000 to 1,00,000.

viii. Aji Pineapple Peppers: These are gorgeous yellow baccatum peppers, with elongated fruits measuring 2-3 inches. They begin with green and ripen to vibrant yellow and has a fruity taste with 20,000 SHU.

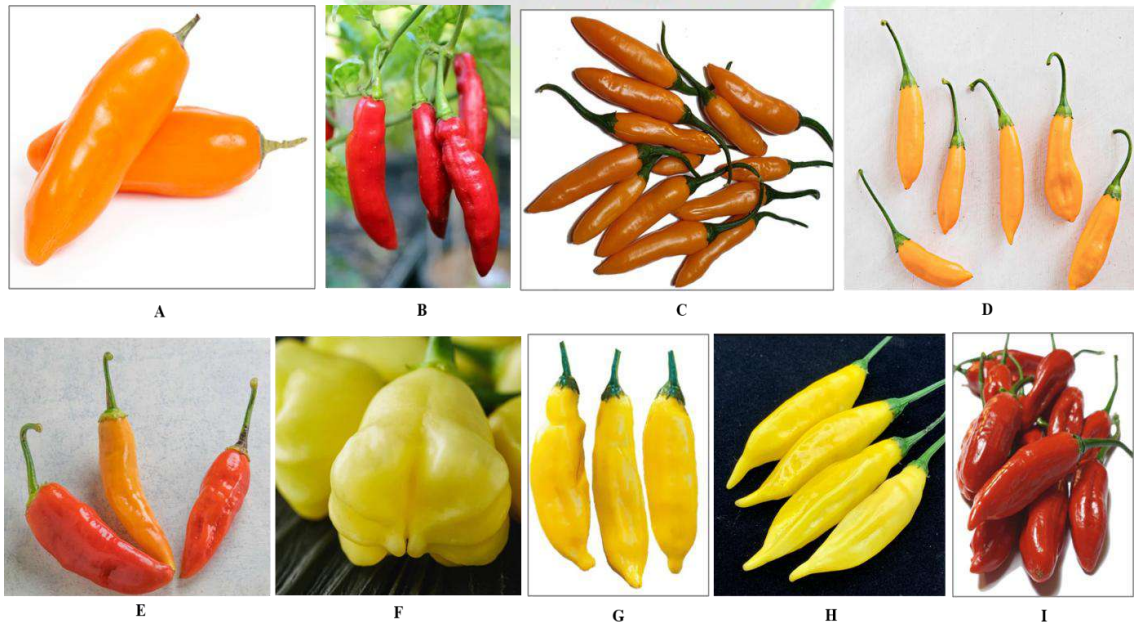

Fig. 3. Different cultivated types of Aji Peppers. A. Aji Amarillo Peppers, B. Aji Panca Peppers, C. Aji Criolla Sella Peppers, D. Aji Cito Peppers, E. Aji Cristal Peppers, F. Aji Fantasy Peppers, G. Aji Limo Peppers, G. Aji Pineapple Peppers and H. Aji Norteno Peppers

ix. Aji Norteno Peppers: These are popular in Northern Coastal valley of Peru. The fruits are 3-4 inches long with a tapering end. They start from green to yellow, orange or red. They have a fruity flavour and moderate pungency with SHU 45,000 to 75,000.

b. Bishop's Crown or Christmas Bell or Napalese Bell or Joker's Hat Peppers: These are native to South America. They are named for its distinct three sidedshape resembling Bishop's crown. The plant grows up to 3-4 feet. The fruits have fyling saucer like three or four flat wings. They are green that turns red on maturity. They are very little heat and the wings are sweet in taste.

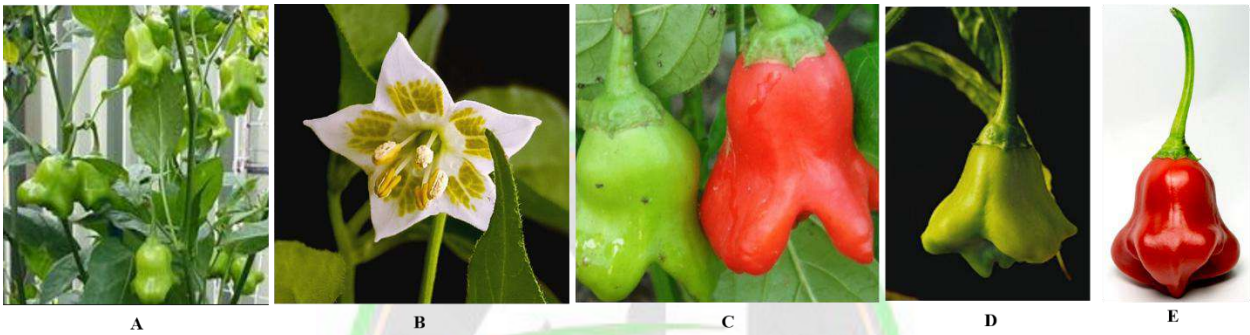

Fig. 4. Bishop's Crown Peppers. A. Plant, B. Flower, C. Unripe green and matured red fruit, D. Unripe green fruit, and E. Matured Red fruit

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ROLE OF IPR IN AGRICULTURAL RESEARCH COLLABORATIONS AND PROTECTION OF PUBLIC INSTITUTE INVENTIONS

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01. INTRODUCTION

The expansion of intellectual property rights (IPRs) within agriculture has fostered new avenues for research collaboration between public institutions and private sector entities; however, it also presents complex challenges. Public universities and research institutions must navigate the decision to protect innovations not only based on economic benefits but also their mission to serve the public good. Unlike commercial enterprises, public institutes prioritise generating broad societal benefits from their research outputs. Thus, protecting intellectual property solely to maximise royalty income may conflict with institutional responsibilities. Nonetheless, in certain cases, granting exclusive or non-exclusive licensing rights to private firms is essential to stimulate utilisation and ensure that innovations make tangible impacts on agricultural productivity and sustainability.

02. PRINCIPLES OF PROTECTING PUBLIC INSTITUTE INVENTIONS

Protecting inventions developed within public institutions involves balancing transparency with commercial viability. A fundamental legal requirement is that inventors disclose sufficient information about inventions, enabling replication, improvement, and further innovation. The nature of an invention often dictates the appropriate form of protection that a university like Tamil Nadu Agricultural University (TNAU) might seek. For example, inventions that do not meet patent or PPVFR standards may be protected using trademarks or brand names. This multi-faceted approach safeguards research outputs while enabling flexible commercialization strategies.

03. CHALLENGES UNIQUE TO AGRICULTURAL INNOVATIONS

Breeding new plant varieties or developing agricultural technologies entails significant time, resource investment, and patience. Yet, many new plant varieties can self-reproduce, allowing widespread dissemination of their progeny from limited initial releases. Without legal protection conferring exclusive exploitation rights, breeders lack sufficient economic incentives to invest in developing new varieties—especially given high research costs and the ease of replication in agricultural settings. Thus, in many countries—including India—legal mechanisms like the Protection of Plant Varieties and Farmers' Rights (PPV & FR) Act grant breeders' rights crucial for encouraging private investment in plant breeding.

04. METHODS OF IP PROTECTION IN AGRICULTURAL RESEARCH

Agricultural research outputs may be protected through a variety of intellectual property frameworks. The choice of protection depends on factors such as market potential, innovation type, and commercialisation economics.

- **Plant Variety Protection (PVP)*:*** For new crop varieties fulfilling distinctness, uniformity, and stability criteria.
- **Patenting*:*** For inventions meeting patentability criteria, including plant patents and utility patents.
- **Licensing*:*** Permits controlled use of IP-protected technologies by private entities.
- **Trademarks and Brand Names*:*** To protect product identity and ensure consumer confidence.
- **Copyrights*:*** For software or documentation related to agricultural technologies.

05. DECISION-MAKING IN PROTECTION AND TECHNOLOGY TRANSFER

Protection decisions often hinge on the expected market demand and ability to attract private licenses. While public institutions avoid monopolistic motives, the economic feasibility of protecting an innovation requires market interest sufficient to cover protection costs and generate revenue. Additionally, control over technology usage is frequently a critical motivator for protection, even where market size is limited. For example, TNAU patented certain gene sequences for research applications despite limited market demand, ensuring inventor rights and control over further use. Varieties developed with niche market potential have successfully attracted private seed companies through PPVFR protection, enabling the university to grant licensing rights that strategically manage market entry and expansion.

06. LICENSING AGREEMENTS: EXCLUSIVE *VS*. NON-EXCLUSIVE

Universities typically enter into licensing agreements to transfer protected technologies to private firms. Selection of exclusive or non-exclusive licenses depends on technology nature and intended usage.

1. **Exclusive Licenses**: Exclusive licenses often include termination clauses, giving the university rights to retake control if contractual obligations are unmet. This is suitable when,
    - The technology involves high commercialisation costs.
    - Target markets are narrow or regionally restricted.
    - Close supervision and quality control are required.
2. **Non-Exclusive Licenses**: Encourage broader dissemination, especially for inputs such as bio-fertilisers, ensuring widespread adoption and maximising public benefit.

07. RESEARCHER CONTROL AND LONG-TERM INTERESTS

Researchers often maintain an enduring interest in the trajectory of their innovations. The transfer of IP rights must balance licensing freedoms with researchers' desire to influence future development, ensuring ongoing input without relinquishing all control. This dynamic requires thoughtful contract design involving confidentiality stipulations and governance of research use.

08. ADVANTAGES OF IP PROPERTY PROTECTION FOR PUBLIC INSTITUTES

1. Institutional IP protection brings multiple benefits

- Generates alternative revenue streams through royalties, compensating for stagnant government grants.
- Incentivises researchers by securing economic benefits from their innovations.
- Enhances institutional reputation and increases the commercial value of research outputs.
- Facilitates public-private partnerships, accelerating product development and market introduction.
- Reduces redundant research by publicizing findings, fostering collaborative advancements.

2. Promoting Partnerships through Intellectual Property Rights

Protecting IP is essential to attracting the private sector investment required for commercialisation. Universities often lack the financial resources or infrastructure to market

technologies at scale. Exclusive or non-exclusive licenses legally empower private companies to invest in the development, certification, and distribution of technologies.

For instance, TNAU's maize hybrid development demonstrates this dynamic. The complex technology involved proprietary seed procurement techniques, which TNAU licensed exclusively to a private firm. The partnership ensured large-scale production and quality control, thereby making high-quality maize hybrids available to farmers and consumers.

09. RECENT EXAMPLES OF TNAU COLLABORATIONS IN AGRICULTURE RESEARCH

- **TNAU & Michigan State University (MSU), USA**: Collaboration on supply chain management in fruits and vegetables under a USAID-funded program through a Liaison Office Association. This partnership aims to address emerging supply chain challenges, leveraging international expertise for Indian agriculture.
- **TNAU & ICAR Institutes**: Multiple joint projects focusing on developing climate-resilient crop varieties and precision agriculture technologies, combining resources to enhance research impact and societal benefits.
- **TNAU & Private Seed Companies**: Licensing agreements for commercialization of improved pulses and cereal varieties developed through extensive breeding programs, ensuring both farmer benefits and royalty revenues to TNAU.

Table 1. Decision factors in protecting public Agricultural Innovations

Factor	Considerations
Nature of Innovation	Crop variety, machinery, biotech, software, *etc.*
Market Size and Commercial Demand	Potential licensees, adoption scale
Type of Protection	Patents, PVP, trademarks, or copyrights
Researcher Control	Degree of oversight desired post-licensing
Licensing Strategy	Exclusive, non-exclusive, joint commercialisation
Public Benefit	Access, affordability, social impact
Financial Feasibility	Protection costs vs. anticipated royalties

10. EXAMPLES OF LEGAL AGREEMENTS AND INTELLECTUAL PROPERTY MANAGEMENT PRACTICES IN INDIAN AGRICULTURAL INSTITUTES

Indian agricultural institutes, including Tamil Nadu Agricultural University (TNAU) and several Indian Council of Agricultural Research (ICAR) bodies, have developed a range of legal agreements and best practices to manage intellectual property effectively while fostering research collaboration and commercialisation.

1. Technology Transfer Agreements (TTAs)

Technology Transfer Agreements are the primary legal instrument governing the licensing and commercialisation of agricultural innovations. They specify:

- The scope of licensed technology use (e.g., geographic area, fields of use).
- Financial terms including license fees, royalties, and milestone payments.
- Obligations regarding quality control, confidentiality, and reporting.
- Termination clauses allowing the institute to rescind licenses in case of non-performance.

Example: TNAU's licensing of its drought-tolerant rice variety to a private seed company includes strict provisions on seed quality maintenance and periodic reporting on sales and farmer impact, ensuring both quality assurance and revenue tracking.

2. Material Transfer Agreements (MTAs)

Material Transfer Agreements regulate the sharing of biological material such as seeds, breeding lines, or genetic resources between research institutions and external collaborators. MTAs typically govern:

- Conditions of use limited to research or breeding.
- Restrictions on further dissemination to third parties.
- Intellectual property rights arising from derivatives or improvements.

Example: ICAR institutes collaborating with international partners often sign MTAs that stipulate joint ownership of future innovations and capacity-building components to support local research.

3. Collaborative Research Agreements (CRAs)

CRAs define the terms of joint research projects between institutions and private sector partners. They address:

- Ownership of data, inventions, and copyrights.

- Sharing of funding, resources, and responsibilities.
- Publication rights and confidentiality agreements.

Example: The ongoing partnership between TNAU and Michigan State University for supply chain research operates under a CRA detailing shared IP rights and joint dissemination of research outcomes, balancing open scientific inquiry with commercial interests.

4. Institutional IP Policies and Management Practices

Several Indian agricultural institutes have institutionalised IP management by establishing dedicated Technology Transfer Offices (TTOs) or Intellectual Property Management Cells (IPMCs). Their functions include,

- Identifying and evaluating patentable inventions and varieties.
- Coordinating IP protection applications (patents, PVP, trademarks).
- Negotiating licenses and monitoring compliance.
- Training researchers in innovation disclosure and IP rights.

Example: ICAR institutes have developed standardised procedures ensuring timely IP disclosure, decision-making on protection routes, and active licensing strategies. Training programs have also improved researchers' awareness of the benefits of IP protection as a means of enhancing innovation impact.

Table 2. Common Legal Agreements in Agricultural Research IP Management

Agreement Type	Purpose	Key Provisions	Typical Use Cases
Technology Transfer Agreement	Commercialises IP technologies	Licensing terms, fees, quality control	Licensing of seed varieties, agrochemicals
Material Transfer Agreement	Governs the exchange of biologicals	Usage limits, ownership rights	Sharing germplasm with collaborators
Collaborative Research Agreement	Frames' joint research projects	IP ownership, funding, publication	Multi-institutional supply chain or crop improvement projects
Institutional IP Policy	Guides internal IP management	Innovation disclosure, licensing roles	TTO operations, researcher education

Case Study: ICAR-National Research Centre on Plant Biotechnology

The ICAR-NRCPB has developed a successful model combining research collaboration, IP protection, and commercialisation. The institute employs strict IP policies for protection and has entered into multiple licensing agreements for genetically enhanced crop varieties and molecular diagnostic tools. Proceeds from the licensing fund further research, demonstrating a sustainable cycle of innovation funding.

Conclusion

By legally codifying research collaborations and managing intellectual property strategically, Indian agricultural institutes have enhanced both public and private sector engagement, encouraging technology dissemination and fulfilling their mandate for societal benefit. The examples from TNAU, ICAR, and allied organisations illustrate how robust IP management frameworks and tailored legal agreements are critical for optimising the impact of agricultural innovations.

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INTELLECTUAL PROPERTY AND INTERNATIONAL TREATY ON PLANT GENETIC DIVERSITY

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01. Introduction

Plant genetic diversity forms the foundation for global food security, sustainable agriculture, and climate resilience. Recognising the critical importance of preserving and promoting access to this genetic variability, the international community has established legally binding frameworks to govern its conservation, use, and equitable benefit-sharing. The cornerstone of these efforts is the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), often referred to simply as the Plant Treaty. Adopted in 2001 under the aegis of the Food and Agriculture Organisation (FAO) of the United Nations and effective since 2004, this treaty represents a landmark global agreement dedicated exclusively to plant genetic resources critical to food and agriculture.

This treaty addresses fundamental challenges related to accessing, conserving, and sustainably using plant genetic materials while ensuring fair and equitable sharing of benefits arising from their use. The treaty's implementation has important implications for farmers, breeders, researchers, and countries worldwide, particularly in adapting agriculture to emerging challenges such as climate change and biodiversity loss.

02. OBJECTIVES AND SCOPE OF THE TREATY

The primary objectives of the International Treaty on Plant Genetic Resources for Food and Agriculture are threefold:

1. To conserve the world's plant genetic resources essential for food and agriculture.

2. To promote their sustainable use to improve agricultural productivity, resilience, and diversity.
3. To ensure the fair and equitable sharing of benefits arising from the utilisation of plant genetic resources, recognising the immense contributions of farmers and indigenous communities in conserving and enhancing crop diversity.

The scope of the treaty covers Plant Genetic Resources for Food and Agriculture (PGRFA), which includes seeds, plant propagating materials, and wild relatives of crops relevant to food production and nutrition.

03. MULTILATERAL SYSTEM OF ACCESS AND BENEFIT-SHARING

At the heart of the treaty lies its innovative Multilateral System (MLS), designed to facilitate the exchange of 64 key food and forage crops critical to global food security. This system provides a standardised, internationally agreed framework granting access to plant genetic materials for research, breeding, and training.

Countries that are parties to the treaty agree to make their collections of these essential crops available via the MLS, operating under the terms of a Standard Material Transfer Agreement (SMTA). The SMTA governs access to plant genetic materials and ensures that all users share the benefits derived from these resources. These benefits include the exchange of information, access to and transfer of technology, capacity-building in developing nations, and monetary benefits from commercialisation.

The MLS covers approximately 80% of globally used plant-based food and forage crops often referred to as the "life insurance policy" for food production—thereby acknowledging and facilitating the interdependence of countries in conserving and using genetic diversity.

04. CONSERVATION AND SUSTAINABLE USE

Implementation of the treaty emphasises both in situ (on-farm and natural habitat) and ex situ (gene banks and seed vaults) conservation methods, recognising their complementary roles. Article 5 of the treaty focuses on conservation actions, including the exploration, characterisation, evaluation, documentation, and conservation of PGRFA, vital for maintaining diversity and usable traits.

Article 6 promotes the sustainable use of genetic resources by encouraging diverse and participatory agricultural practices that reduce genetic erosion while improving production and resilience. This includes support for traditional farming systems, plant breeding approaches that

consider farmers' needs, and adaptation in response to climate change pressures. National governments are urged to develop policies, legal frameworks, and active programs addressing conservation and sustainable use, a reflection of the treaty's importance in global agricultural and environmental strategies.

05. FARMERS' RIGHTS

One of the most significant features of the treaty is the recognition and promotion of Farmers' Rights (Article 9). These rights acknowledge the role of farmers, especially in developing countries, as custodians and innovators of crop diversity over millennia.

Farmers' Rights encompass the protection of traditional knowledge relevant to plant genetic resources, equitable benefit-sharing, participation in decision-making processes, and the ability to save, use, exchange, and sell farm-saved seeds. Countries are encouraged to implement these rights through national legislation and policies that balance farmers' interests with commercial and intellectual property rights considerations.

06. BENEFIT-SHARING FUND (BSF)

The Benefit-Sharing Fund (BSF) was established to operationalise the core principle of equitable benefit-sharing enshrined in the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). Managed by the treaty's Governing Body, the BSF finances projects aimed at enhancing the conservation and sustainable utilisation of plant genetic resources for food and agriculture (PGRFA). These projects support a variety of activities, including technology transfer, capacity-building, and strengthening local seed systems, particularly in developing countries and among smallholder farmers.

Recent BSF-funded initiatives have successfully promoted improved seed networks in regions such as Africa and Asia. These projects help farmers adapt crop varieties to changing climatic conditions and emerging pest and disease threats, thereby enhancing food security and farmer livelihoods. For example, drought-tolerant maize varieties developed and disseminated through BSF support have empowered farmers in East Africa to sustain yields despite erratic rainfall patterns. Similarly, in South Asia, local rice seed systems have been strengthened with new flood-resistant varieties, reducing crop losses during monsoon variability. These efforts not only improve agricultural productivity but also contribute towards empowering vulnerable farming communities, promoting biodiversity, and ensuring resilient food systems.

07. GOVERNANCE STRUCTURE OF THE TREATY

The Governing Body is the highest decision-making organ of the ITPGRFA, composed of representatives from all contracting parties that have ratified the treaty. This body regularly convenes to set policies, approve budgets, supervise the implementation of the treaty's provisions, and negotiate amendments. Through these sessions, the Governing Body provides strategic guidance on critical components such as the Multilateral System (MLS) of access and benefit-sharing, Farmers' Rights, and funding mechanisms like the BSF.

Since its first meeting in 2006, the Governing Body has overseen the treaty's evolution as an autonomous entity under the Food and Agriculture Organisation (FAO) umbrella. It is supported administratively by the Treaty Secretariat, which organises meetings, facilitates communication among parties, and ensures implementation of decisions. The Secretariat also liaises with other international organisations to harmonise treaty activities with broader biodiversity and agricultural frameworks.

In recent governance cycles, the Governing Body has prioritised expanding the MLS to cover more crops and to enhance benefit-sharing through revised Standard Material Transfer Agreements (SMTAs). Financial sustainability and increased resource mobilisation have been key agenda items, with the Governing Body actively seeking partnerships with NGOs, donors, and multilateral institutions to scale up conservation efforts. For example, the 2025 Governing Body session focused extensively on improving transparency and accountability in BSF-funded projects to maximise impact.

In addition, the Governing Body has strengthened the emphasis on Farmers' Rights and promoted inclusive dialogue among indigenous and local community representatives to ensure their perspectives shape treaty implementation. This inclusivity ensures that the treaty remains responsive to the evolving challenges in agricultural biodiversity conservation, food security, and climate adaptation.

08. RECENT DEVELOPMENTS AND CHALLENGES

The ongoing evolution of the treaty involves significant debates on expanding the MLS to include all plant genetic resources, not just the 64 crops currently listed. Developing and developed countries have voiced different positions on this expansion, with concerns about national sovereignty, benefit-sharing fairness, and compliance with national biodiversity laws.

Efforts to negotiate a revised Standard Material Transfer Agreement (SMTA) seek to enhance payment structures from users of plant genetic materials, increasing financial resources available for conservation and sustainable use. These negotiations reflect the treaty's attempt to balance open access with sustainable financing.

Table 1. Key Features of the International Treaty on Plant Genetic Resources for Food and Agriculture

Aspect	Description
Date of Adoption	November 3, 2001
Effective Date	June 29, 2004
Administered by	Food and Agriculture Organisation (FAO)
Key Objectives	Conservation, sustainable use, fair and equitable benefit-sharing of plant genetic resources
Multilateral System (MLS)	Covers 64 major food and forage crops, facilitates access on standardised terms (SMTA)
Farmers' Rights	Recognition and protection of farmers' contributions and traditional knowledge
Benefit-Sharing Fund (BSF)	Finances projects for conservation, capacity building, and sustainable use, mainly in developing countries
Governing Body	Comprising member states, supervises treaty operations and policy

Global geopolitical shifts, climate change impacts, and emerging biotechnologies continue to present challenges and opportunities for the treaty. For instance, CGIAR gene banks, key players in conservation, recently secured USD 26 million to support the maintenance of treaty-backed genetic collections.

09. IMPORTANCE AND GLOBAL IMPACT

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) stands as a ground-breaking multilateral framework uniquely dedicated to the conservation, sustainable use, and equitable sharing of benefits arising from plant genetic resources vital for food and agriculture. Its importance transcends mere legal codification,

positioning the treaty as a global mechanism essential to present and future food security in the face of mounting environmental and socio-economic challenges.

One of the critical strengths of the treaty lies in fostering international cooperation among its member countries, currently numbering over 140. This extensive participation enables the collective management of plant genetic diversity, facilitating the free exchange of seeds and genetic materials necessary for crop improvement across geographic and political boundaries. Such global collaboration ensures that breeding programs benefit from a diverse gene pool critical for developing hardy crop varieties.

Recent evidence highlights the treaty's role in enabling resilience against climate variability and environmental degradation. For example, by facilitating access to diverse plant genetic resources adapted to different agro-climatic conditions, the treaty empowers breeders and farmers to develop crop varieties capable of withstanding drought, salinity, emerging pests, and diseases intensified by climate change. A 2023 report by the Crop Trust underscored how multilateral germplasm exchange accelerated the development of heat-tolerant wheat and flood-resistant rice varieties, directly contributing to food security in vulnerable regions such as South Asia and Sub-Saharan Africa.

Beyond its scientific and environmental impacts, the treaty strongly emphasises the recognition of farmers' contributions as custodians of agrobiodiversity. Unlike conventional intellectual property instruments, the ITPGRFA explicitly acknowledges that farmers have evolved and conserved plant genetic resources for millennia. Article 9 of the treaty enshrines Farmers' Rights, including the protection and preservation of traditional knowledge, access to seeds, and equitable benefit-sharing. This acknowledgement aligns the treaty closely with the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land) by promoting food sovereignty, conservation, and resilience in rural communities.

The treaty's benefit-sharing mechanisms integrate monetary and non-monetary benefits to support global agricultural development, especially in developing countries. For instance, revenue collected through access and benefit-sharing agreements funds the Benefit-Sharing Fund (BSF), which invests in capacity-building projects, participatory breeding programs, and sustainable agriculture initiatives. Notably, several BSF-funded projects from 2020 to 2024 have

improved local seed systems and enhanced smallholder farmers' livelihoods in Africa, Asia, and Latin America, according to recent UN reports.

Importantly, the treaty complements and enhances broader international biodiversity agreements, particularly the United Nations Convention on Biological Diversity (CBD) and the Nagoya Protocol. While the CBD focuses on genetic resources more broadly, the ITPGRFA specialises in the plant genetic resources vital for food security, providing a harmonised mechanism to address access and benefit-sharing at a global scale. This convergence strengthens international governance and ensures countries can collaboratively address challenges posed by genetic erosion, climate change, and global food demand.

Conclusion

The International Treaty on Plant Genetic Resources for Food and Agriculture is a ground-breaking global agreement dedicated to conserving and sustainably using the genetic diversity of crops vital to feeding the world. By enabling open access to genetic resources, honouring the rights and knowledge of farmers, and distributing benefits fairly, the treaty supports a more food-secure, equitable, and environmentally sustainable future. Its achievements and ongoing adaptations exemplify the vital role of multilateralism in tackling 21st-century global challenges related to nutrition, poverty, and ecosystem preservation.

Its holistic recognition of Farmers' Rights and emphasis on conservation and sustainable use of plant genetic resources position it as a key international policy instrument in the face of escalating food security challenges, biodiversity loss, and climate change. Ongoing negotiations and amendments strive to adapt the treaty to emerging scientific, ethical, and geopolitical realities, maintaining its relevance and effectiveness well into the future.

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TINY WASP, MIGHTY WARRIOR: *TETRASTICHUS HOWARDI* (HYMENOPTERA: EULOPHIDAE) AS A GAME CHANGER IN ECO-FRIENDLY PEST MANAGEMENT

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Abstract

The increasing concern over excessive pesticide use and its harmful effects on the environment has led to the growing importance of eco-friendly pest management strategies. Among biological control agents, *Tetrastichus howardi* has emerged as a highly effective parasitoid for managing several economically important Lepidopteran pests. This gregarious pupal parasitoid can parasitize a wide range of host species and produce multiple offspring from a single host, thereby ensuring rapid population buildup and efficient pest suppression. This parasitoid plays a significant role in integrated pest management (IPM) by reducing pesticide dependency, conserving beneficial organisms, and promoting sustainable agriculture. It can be successfully integrated with other biointensive approaches, such as trap crops, botanical pesticides, and microbial agents. Recent studies have highlighted its high parasitization efficiency, adaptability to varying temperature conditions, compatibility with modern agricultural practices, and advancements in mass-rearing techniques using alternative hosts. Despite certain limitations, such as sensitivity to chemical pesticides and the need for proper release timing, *T. howardi* remains a promising tool for sustainable pest management. Its adoption can contribute significantly to environmentally safe, cost-effective, and climate-resilient agricultural systems in the future.

Keywords: *T. howardi*, biological control, parasitoid, eco-friendly pest management, integrated pest management, sustainable agriculture, mass rearing, climate resilience, biointensive strategies.

1. Introduction

The increasing reliance on chemical pesticides in modern agriculture has raised serious concerns regarding environmental safety, human health, and sustainability. Although synthetic pesticides provide rapid control of insect pests, their excessive and indiscriminate use has led to several problems, including pesticide resistance, pest resurgence, soil and water contamination, and negative effects on beneficial organisms. These issues highlight the urgent need for eco-friendly and sustainable pest-management approaches. In this context, biological control using natural enemies has emerged as an effective and reliable alternative (Smith, 1996; Van Lenteren, 2012). Among natural enemies, parasitoids play a unique role owing to their specialized mode of action. In contrast to predators, parasitoids develop within or on a single host and ultimately kill it, making them efficient regulators of pest populations. One such important parasitoid is *T. howardi* (Hymenoptera: Eulophidae), a gregarious endoparasitoid known for its effectiveness against several lepidopteran pests (Paron and Berti Filho, 2000). It mainly targets the pupal stage, thereby preventing adult emergence and disrupting the pest life cycle (Barbosa *et al.* 2022). The parasitoid has a broad host range, including major pests such as *Spodoptera litura*, *Helicoverpa armigera*, and *Chilo partellus*, which cause significant crop losses in bhendi, maize, cotton, and sugarcane (Kumar *et al.*, 2015). Its high reproductive potential, with 20–80 individuals emerging from a single host, enables rapid population buildup and effective pest suppression. Additionally, it uses chemical cues, such as kairomones, to locate hosts efficiently in the field (Vet and Dicke, 1992).

Recent studies (2024–2025) have demonstrated its adaptability to varying environmental conditions and improved mass rearing using alternative hosts, enhancing its practical applications (Bermúdez *et al.*, 2024; Yan *et al.*, 2024). Despite its limitations, *T. howardi* remains a promising tool for sustainable pest management and reducing pesticide dependence.

2. Distribution and Agricultural Importance

T. howardi is widely distributed across the tropical and subtropical regions of the world, including Asia, Africa, and parts of South America. In India, it is commonly recorded in diverse agroecosystems, ranging from irrigated crop fields to rainfed farming systems. The parasitoid thrives under varying environmental conditions and has been reported in crops such as bhendi (okra), maize, sugarcane, cotton, pulses, and several vegetable systems. Its ability to survive and perform under different climatic conditions makes it particularly suitable for Indian agriculture,

where temperature fluctuations and seasonal variability are common challenges (Kumar *et al.*, 2015). The wide geographical distribution of *T. howardi* is closely linked to the availability of suitable host insects and favorable environmental conditions in the area. Since it parasitizes a broad range of lepidopteran pests, its presence is often associated with cropping systems that are prone to caterpillar infestation. This adaptability allows it to establish and persist in different habitats, including field and storage ecosystems. In agricultural systems, the presence of *T. howardi* plays a crucial role in maintaining a natural pest balance. By targeting the pupal stage of pests, it prevents the emergence of adult insects, thereby reducing the buildup of pest populations over time. This contributes to long-term pest suppression and minimizes the frequency of pest outbreaks. Consequently, farmers can reduce their dependence on chemical pesticides, leading to lower production costs and safer agricultural produce. Furthermore, the activity of this parasitoid supports sustainable farming by conserving beneficial organisms and enhancing biodiversity in agroecosystems. Its integration into pest management programs not only improves crop protection but also promotes environmentally responsible agricultural practice. With the increasing emphasis on eco-friendly farming, *T. howardi* holds significant potential as a reliable biological control agent in diverse cropping systems.

2.1 Host Range and Pest Suppression

T. howardi is an efficient gregarious pupal parasitoid known for its ability to parasitize a wide range of economically important lepidopteran pests. It primarily targets the pupal stage, which is a crucial transitional phase in the insect life cycle. By attacking this stage, the parasitoid prevents adult emergence and disrupts reproduction, leading to a gradual decline in pest population over time (Barbosa *et al.*, 2022). The host range of *T. howardi* is relatively broad, making it a versatile biological control agent in different cropping systems. It has been reported to parasitize several key pests affecting field crops, vegetables, and storage products. This adaptability allows parasitoids to persist in agroecosystems even when the availability of a single host species fluctuates (Kumar *et al.*, 2015).

2.2 Major Pests Suppressed by *T. howardi*

- *Spodoptera litura* (tobacco caterpillar) – a major polyphagous pest damaging vegetables and field crops
- *Helicoverpa armigera* (gram pod borer) – causes severe losses in pulses, cotton, and vegetables

- *Chilo partellus* (maize stem borer) – an important pest of maize and sorghum
- *Corcyra cephalonica* (rice moth) – a serious pest in stored grains
- *Diatraea saccharalis* (sugarcane borer) – damages sugarcane crops
- *Sesamia inferens* (pink stem borer) – affects rice and maize

These pests are responsible for significant yield reductions across various agricultural systems, and their management is crucial for ensuring crop productivity (Paron and Berti Filho, 2000; Kumar *et al.*, 2015). The mechanism of pest suppression by *T. howardi* is highly effective. After locating the host pupa using chemical cues, the female lays eggs inside it. The larvae develop internally by feeding on host tissues, ultimately killing the host before adult emergence. As multiple parasitoids can develop within a single pupa, the reproductive output is high, often resulting in 20–80 adults emerging from one host. This gregarious development enables rapid population buildup and enhances the pest suppression efficiency (Barbosa *et al.*, 2022). In addition to direct mortality, repeated parasitism across generations leads to the long-term regulation of pest populations. This reduces the frequency of pest outbreaks and minimizes the reliance on chemical pesticides. Therefore, its broad host range and efficient mode of action make *T. howardi* a valuable component of sustainable pest management programs.

3. Biology and Life Cycle

The biology of *T. howardi* is characterized by an efficient reproductive strategy and rapid developmental cycle, which contribute significantly to its effectiveness as a biological control agent. It is a gregarious endoparasitoid, meaning that multiple individuals develop within a single host, specifically targeting the pupal stage of lepidopteran insects (Paron and Berti Filho, 2000). The life cycle begins when the adult female locates a suitable host pupa using chemical cues, such as kairomones released by the host or herbivore-induced plant volatiles. Upon finding a suitable host, the female inserts her ovipositor and lays several eggs inside the host pupa. The number of eggs laid depends on the size and quality of the host, with larger pupae generally supporting higher progeny production (Barbosa *et al.* 2022). After oviposition, the eggs hatch into larvae that develop completely within the host body. These larvae feed on the internal tissues of the pupa, gradually consuming it while initially avoiding vital organs to keep the host alive during early development. As development progresses, the host is completely consumed and eventually killed before emerging as an adult moth. This internal feeding habit ensures effective destruction of the pest at a critical stage of its life cycle (Godfray, 1994). The larval

stage is followed by pupation within the host. As *T. howardi* is gregarious, multiple parasitoid pupae are formed inside a single host. After completing their development, adult parasitoids emerge by creating exit holes in the host pupal case. The total developmental period varies depending on environmental conditions, such as temperature, but is generally short, allowing for rapid population growth (Barbosa *et al*., 2022). Adult parasitoids are small, active, and capable of locating their hosts efficiently. Females typically have a longer lifespan than males and are responsible for host searching and oviposition (egg-laying). The reproductive potential is high, with a single host pupa producing 20–80 adult parasitoids under favorable conditions. This high fecundity, combined with a short life cycle, enables the quick establishment and effective suppression of pest populations in the field (Paron and Berti Filho, 2000). Overall, the biology and life cycle of *T. howardi* are well adapted for efficient parasitism and rapid multiplication, making it a valuable component in sustainable pest management programs.

Figure 1. Female and Male *T. howardi* (Adapted from *Gallego et al.*, 2013)

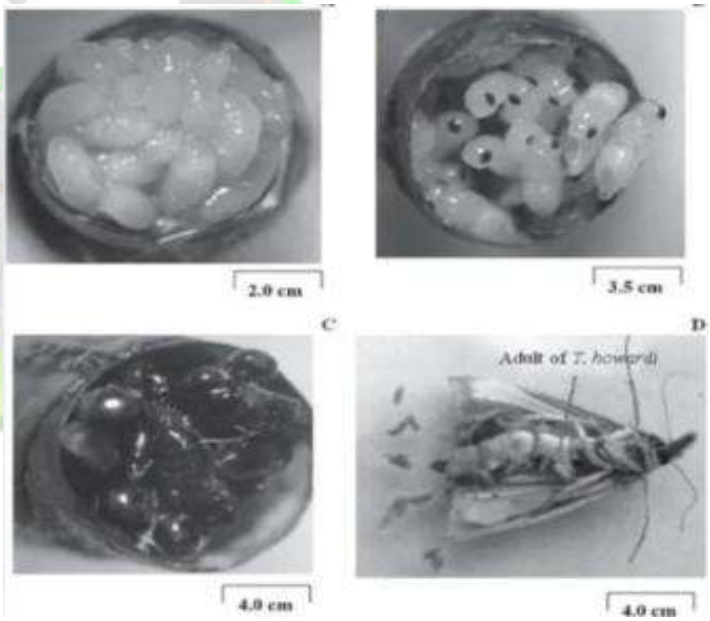

Figure 2. Larvae, pupae and adults of *T. howardi* (Hymenoptera: Eulophidae in pupae of Diatraea saccharalis(Lepidoptera: Crambidae) (A, B, C); D. saccharalis adult parasitized by *T. howardi.* (Adapted from *Pereira et al.*, 2015)

4. Behaviour and Host Location Mechanism

The success of *T. howardi* depends largely on its ability to locate suitable hosts in the wild. It uses chemical cues, such as kairomones released by host insects and herbivore-induced plant volatiles to identify infested plants. Host selection is influenced by several factors, including host size, age, and nutritional quality. Larger and healthier pupae are preferred because they provide better resources for developing offspring. Such selective behavior ensures higher survival and reproductive success (Godfray, 1994; Vet and Dicke, 1992).Understanding these behavioral mechanisms is important for improving their application in field conditions.

3.1 Role in Eco-Friendly Pest Management

T. howardi plays a significant role in eco-friendly pest management by naturally regulating the populations of destructive lepidopteran pests. Unlike chemical pesticides, they do not leave harmful residues, pollute the environment, or adversely affect non-target organisms, such as pollinators and other beneficial insects. Its use helps maintain ecological balance while ensuring effective pest suppression, making it an important component of sustainable agriculture (Smith, 1996). Parasitoids contribute to pest control mainly by targeting the pupal stage, thereby preventing adult emergence and breaking the reproductive cycle of pests. This stage-specific action is particularly advantageous because it reduces future pest generations, rather than providing only temporary control. Over time, repeated parasitism leads to a gradual decline in pest populations and minimizes the chances of pest outbreaks in the future. In addition, its gregarious nature allows multiple individuals to develop from a single host, resulting in rapid population buildup and enhanced control efficiency of the pest. In practical pest management, *T. howardi* is used in **augmentative biological control**, where laboratory-reared parasitoids are released into the field.

For effective control, releases are usually timed to coincide with the peak pupal stage of the target pest species. The parasitoids actively search for hosts, parasitize them, and establish their populations in the field. Once established, they can continue to reproduce and provide long-term suppression without requiring repeated external input. The success of this parasitoid in the field depends on its proper integration with other eco-friendly practices. It performs well when combined with trap crops, pheromone traps, light traps, and botanical pesticides, such as neem-based formulations. However, the indiscriminate use of chemical pesticides should be avoided, as it can negatively affect parasitoid survival. Selective and need-based pesticide application can

help conserve the population. Overall, the self-perpetuating nature, host specificity, and compatibility with other biointensive strategies make *T. howardi* a reliable and effective tool in integrated pest management programs. Its adoption not only reduces pesticide dependency but also promotes environmentally safe and sustainable crop production.

3.2 Integration with Biointensive Strategies

The effectiveness of *T. howardi* can be enhanced when it is integrated with other biointensive pest management strategies. It works well in combination with trap crops, light traps, pheromone traps, botanical pesticides such as neem, and microbial agents such as Bacillus thuringiensis. Such integration improves the overall pest control efficiency while maintaining ecological balance. This approach is particularly useful in sustainable and organic farming systems (Van Lenteren, 2012; Copping and Menn, 2000).

3.3 Ecological and Climate Resilience

Parasitoids, such as *T. howardi*, play a vital role in maintaining ecological balance by naturally regulating pest populations. Their activity supports biodiversity and helps to stabilize agroecosystems (Altieri, 1999).

Recent studies have indicated that this parasitoid can adapt to a wide range of temperatures, making it suitable for changing climatic conditions. It can survive and perform effectively between 18 and 34°C, with optimum performance at approximately 26°C. This adaptability makes it a reliable biological control agent in climate change scenarios (Yan *et al*., 2024).

3.4 Recent Advances (2024–2025)

Recent research has further strengthened the importance of *T. howardi* in modern agriculture. Studies conducted in 2024 have shown that parasitoids can achieve very high parasitization rates, even under laboratory conditions, when suitable hosts are available. Alternative hosts, such as *Galleria mellonella* and *Tenebrio molitor*, have been successfully used for mass rearing without loss of efficiency, which is a major advancement for large-scale production (Bermúdez *et al.*, 2024). Research in 2025 also highlighted that parasitoids maintain high reproductive efficiency and favorable sex ratios, ensuring long-term population stability. Furthermore, compatibility studies have indicated that it can be safely integrated with Bt crops and certain selective insecticides, although indiscriminate pesticide use should be avoided (De Sousa *et al.*, 2025; Liu *et al.*, 2022). Another important finding is that host age significantly

influenced parasitism success, with pupae aged 24–96 h being the most suitable. These advancements provide valuable insights for improving the field application strategies.

3.5 Importance to Farmers

For farmers, *T. howardi* offers a practical and cost-effective pest management solution. Its use reduces the need for chemical pesticides, lowers production costs, and ensures safer produce with minimal residue. This is particularly beneficial for crops such as bhendi, maize, and sugarcane, where caterpillar pests cause significant damage. The adoption of such biological control agents can improve profitability while promoting sustainable agriculture.

4. Mass Rearing and Field Application

The mass rearing of *T. howardi* is essential for its effective utilization in large-scale biological control programs. The parasitoid is commonly reared using laboratory hosts such as *Corcyra cephalonica* (rice moth), which is preferred because of its ease of culture, low cost, and availability throughout the year. The host insect is maintained on cereal-based diets, such as broken maize or sorghum, under controlled conditions of temperature and humidity to ensure uniform development. Fresh pupae, usually 1–3 days old, are collected and exposed to adult parasitoids in rearing containers for a specific period to allow parasitism. After exposure, the parasitized pupae are kept under suitable environmental conditions for development, during which the parasitoid larvae grow inside the host and complete their life cycle. Adult parasitoids emerge from the host pupae after a short developmental period and can be collected for further multiplication or field release. Recent advancements have explored alternative hosts, such as *Galleria mellonella* and *Tenebrio molitor*, which support continuous rearing and improve production efficiency (Bermúdez *et al.*, 2024). This systematic rearing process ensures a steady supply of healthy parasitoids, enabling timely field releases and effective pest suppression.

The field application of *T. howardi* involves the release of laboratory-reared adult parasitoids at the appropriate stage of pest development. For effective control, releases should be timed to coincide with the pupal stage of the target pest, as this is the most suitable stage for parasitism. Parasitoids are usually released in the field during early morning or late evening to avoid high temperatures and ensure better survival. It is important to maintain a sufficient host population in the field to support the establishment of parasitoids. Chemical pesticide application should be avoided for at least a few days before and after release, as it can negatively affect parasitoid activity and survival. In cases of high pest infestation, repeated releases at regular

intervals may be necessary to achieve effective pest control. Once released, the parasitoids actively search for host pupae, parasitize them, and multiply in the field, thereby providing sustained pest suppression over time. Proper timing, favorable environmental conditions, and integration with eco-friendly practices enhance the success of field applications (Van lenteren, 2012).

5. Limitations and Challenges

Despite its advantages, certain challenges must be addressed. The parasitoid is sensitive to chemical pesticides, and its effectiveness depends on the proper timing of release. Limited awareness among farmers also restricts their adoption. Addressing these constraints through training, extension services, and policy support is essential to maximize their potential.

6. Future Prospects

The future of *T. howardi* in pest management is highly promising. Advances in mass rearing, molecular biology, and precision agriculture are expected to enhance their effectiveness. Emerging technologies, such as artificial intelligence and drone-based release systems, can further improve the application of biopesticides in large-scale farming. With the increasing emphasis on sustainable agriculture, this parasitoid is likely to play a major role in future pest management strategies.

Conclusion

T. howardi is a highly efficient, eco-friendly, and sustainable biological control agent. Its ability to parasitize multiple pest species, reproduce rapidly, and adapt to diverse environmental conditions makes it a valuable tool in the field of modern agriculture. Promoting the use of biopesticides through research, awareness, and integration with other eco-friendly practices can significantly reduce pesticide dependence and contribute to environmentally safe and sustainable farming systems.

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A CALL FOR CONSERVATION: OF EXISTING & ENDANGERED SPECIES OF INDIA

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Introduction

Have you ever witnessed the beauty of Indian wildlife? If not so, lets travel deep within. Starting from habitat types, The Tropical jungles remain lively at night with the buzzing cicadas, crickets and howler monkeys. The lands are blessed with immense forest cover and primates of covering several genera. Deciduous forests are hidden in fallen leaves and twigs that act as sneaky spots for predatory tigers and leopards. Furthermore we have Thar deserts featuring camels glistening in the sunny daylight.

Sundar bans (the mangroves)

The Sundar bans (the mangroves) where plants and wildlife ensure that even they could flourish in stagnant, salty waters (where muds and swamps form the soil cover).And to the extremes the Alpine meadows and Snow-capped mountains where snow leopards breed in and provide a kingship to the mighty snowline

In terms of fauna lets start with the Mighty Asian elephants with rich tusks and great demeanour, Roars of the great Asiatic lions, unique one-horned rhinoceros, leaping Indian leopards, gigantic and ferocious Bengal tigers and finally the icon of beauty and pride, the great Indian peacock.

The list do extend long and deep yet their numbers vary dramatically within their habitats. The once conquering king of forests, Asiatic lions shrunken to numbers as just to exist sorrowfully within the Gir forests of Gujarat.

What really happened to this once dominated mighty creature of the forests? Do they really practiced any forms of self population control with use of practices like food chains &

webs? But it is figured out that external causes have immensely led to their widespread destruction and shamefully to say, we are the main reason for their gradual demise.

Practices like Poaching, Illegal trade, habitat fragmentations, land use, overgrazing, and invasion of forests have highly led to decrease in the number and population of wildlife species.

Many animals like lion-tailed macaque, snow leopard, one-horned rhinoceros etc are moving towards Extinction. Many more have already entered to list of vulnerable & endangered species.

Conclusion

So what measures can we take so to compromise for the ill deeds that we have done? In Global sense In-situ conservation methods like National Parks, Biosphere reserves and wildlife sanctuaries are in great use, strengthening of rules and norms have controlled practices of poaching, overgrazing, hotspots have resulted in conserving both Endemic flora and fauna. And further more Ethical rights and lessons should be followed for valuing life of co-species which would lead to strengthening biodiversity.

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HOW FARMERS NAVIGATE MULTIPLE SOURCES OF AGRICULTURAL ADVICE: INSIGHTS FROM FIELD INTERACTIONS

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Abstract

Agricultural advisory systems have evolved into multi-source environments where farmers interact with a range of formal and informal information providers. In practice, decision-making is rarely linear, as farmers continuously compare, interpret, and adapt advice based on their specific farming conditions. Field-level interactions indicate that choices are shaped not only by the availability of information but by its practical relevance, timeliness, and ease of application. Farmers often rely on a combination of sources, including extension personnel, input dealers, and peer networks, to support day-to-day decisions. This highlights the need to move beyond viewing advisory services as one-directional information delivery systems and instead understand how farmers actively navigate and evaluate multiple sources. Recognizing these real-world decision processes is essential for making agricultural advisory systems more responsive and effective in diverse farming contexts.

Keywords: Agricultural advisory, farmer decision-making, input dealers, extension services

Introduction

Agricultural decision-making has become increasingly complex in recent years, driven by factors such as climate variability, market fluctuations, and evolving production practices. Farmers now access a wide range of advisory sources, including input dealers, fellow farmers, and digital platforms[1]. Based on field interactions, farmers today rarely rely on a single source of agricultural advice, instead drawing from multiple channels to guide their decisions. They engage with multiple advisory providers, comparing and interpreting recommendations before making decisions. Understanding how farmers navigate and use this diverse pool of information

is important for appreciating real-world decision-making processes and improving the effectiveness of advisory support in agriculture.

The Changing Advisory Landscape

Agricultural advisory systems have undergone a significant transformation, moving from single-source, institution-led models to more diverse and interconnected systems. Farmers today have access to a wide range of advisory sources, including extension agents, input dealers, fellow farmers, and increasingly, digital platforms such as mobile applications and social media. Each of these sources provides different types of information, varying in technical depth, accessibility, and immediacy[2].

This shift has created a multi-source advisory environment in which information flows through multiple channels rather than a single, centralized system. Farmers are no longer passive recipients of advice but active participants who engage with different sources depending on their needs and situations. As a result, the advisory landscape is now characterized by overlapping sources of information, where decisions are shaped through a combination of formal guidance and practical, experience-based inputs.

How Farmers Approach Advisory Decisions

In practice, farmers do not treat advisory information as fixed instructions to be followed directly. Instead, they actively engage with the information they receive by comparing recommendations from different sources. Advice obtained from extension personnel, input dealers, or fellow farmers is often cross-checked before any decision is made. Farmers rarely follow a single recommendation without evaluation. Rather than relying on one source, they combine information with their own experience and understanding of local conditions. Advice is filtered through practical feasibility, taking into account factors such as available resources, crop stage, labour availability, and expected outcomes. For example, when facing a pest outbreak, a farmer may seek immediate advice from an input dealer, cross-check it with a progressive farmer's experience, and adapt the decision based on crop stage and affordability. This evaluative approach reflects a decision-making process that is adaptive and context-specific, where farmers act as active decision-makers rather than passive recipients of information.

Role of Informal Advisory Sources

Within the multi-source advisory environment, informal advisory actors play a prominent role in farmers' day-to-day decision-making. It is commonly observed that input dealers are

often among the first points of contact for farmers, largely due to their easy accessibility and immediate availability. Farmers frequently approach dealers for guidance related to input use, pest management, and crop protection, especially when quick decisions are required. The ability of these actors to provide timely responses makes them particularly relevant in situations where delays can affect crop outcomes[3].

Similarly, progressive farmers serve as important sources of experience-based advice within local communities. Their recommendations are often grounded in practical field experience, which makes them relatable and easier to interpret. Farmers tend to value such insights because they are directly linked to similar agro-ecological conditions and farming practices. These commonly observed patterns indicate that informal advisory sources contribute significantly to everyday farm decisions by offering accessible, timely, and context-specific guidance.

Interaction with Formal Advisory Systems

Formal agricultural advisory systems, including extension departments and research institutions, continue to play an important role in providing scientifically validated and technically sound recommendations. These systems are typically structured, with organized programs, training activities, and scheduled field visits aimed at improving farmers' knowledge and practices.

At the same time, interactions with formal advisory systems tend to occur less frequently compared to informal sources. Engagement is often limited to specific occasions such as field visits, training programmes, or organized meetings. In some cases, follow-up support after the initial advisory interaction may also be limited, particularly in situations where resources and manpower are constrained. These patterns suggest that while formal advisory systems provide valuable technical guidance, their interaction with farmers is more periodic in nature compared to the continuous engagement observed with informal sources.

What Influences Farmers' Decisions

Farmers' decisions are shaped by a combination of practical, experiential, and relational factors rather than a single source of information. It is commonly observed that farmers tend to prefer advice from sources they trust and have interacted with over time. Trust is often built through repeated engagement, successful outcomes in the past, and familiarity with the advisor's approach.

Recommendations that have previously worked under similar conditions are more likely to be considered reliable and are often given greater weight during decision-making[4].

Decisions are also influenced by considerations of cost and risk. Farmers tend to evaluate whether a recommended practice is affordable, feasible within their available resources, and unlikely to result in significant losses. In addition, the fit of the recommendation to specific farm conditions plays a critical role. Advice that aligns with the local environment, crop stage, and management capacity is more likely to be accepted and implemented. These observations indicate that farmers prioritize practicality and reliability, carefully weighing multiple factors before adopting any advisory recommendation.

Practical Implications for Advisory Systems

The observed patterns in farmers' decision-making highlight the importance of making advisory support more responsive to field conditions. One key aspect is the timely delivery of information, as many farm decisions need to be made quickly during critical crop stages. Delays in receiving advice can reduce its usefulness, even when the recommendations are technically sound.

Another important consideration is the need for location-specific recommendations. Farmers tend to respond more positively to advice that reflects their local conditions, including soil type, climate, and available resources. Generalized recommendations may be less effective when they do not align closely with on-ground realities.

Improving interaction between farmers and advisory providers can also enhance the usefulness of advisory services. Regular engagement, simple communication, and opportunities for clarification can help farmers better understand and apply recommendations. These practical aspects can contribute to making advisory support more relevant and usable in everyday farming situations.

Conclusion

Farmers today function as active decision-makers who continuously engage with multiple sources of agricultural advice. Rather than relying on a single channel, they interpret and adapt information based on their own experience, resource conditions, and immediate needs. This reflects an interconnected advisory environment where formal and informal sources collectively influence farm-level decisions.

The effectiveness of advisory support in such systems depends not only on the technical soundness of recommendations but also on their relevance to local conditions and the nature of interaction between farmers and advisory providers. Timely, context-specific, and clearly communicated advice is more likely to be considered and applied in practice. Understanding how farmers navigate multiple sources of advice is essential for making agricultural advisory systems more responsive and effective.

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FISH FOR A HEALTHY HEART: NUTRITIONAL BENEFITS AND ROLE IN PREVENTING CARDIOVASCULAR DISEASES

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Abstract

Cardiovascular diseases are among the leading causes of mortality worldwide. Dietary habits play an important role in maintaining heart health and preventing cardiovascular disorders. Fish is widely recognized as a heart-healthy food due to its rich nutritional composition, particularly its high content of omega-3 fatty acids, high-quality protein, vitamins, and essential minerals. Regular fish consumption has been associated with reduced risk of heart disease, improved blood lipid profile, and better overall cardiovascular health. Omega-3 fatty acids present in fish help reduce inflammation, lower blood pressure, decrease triglyceride levels, and improve heart rhythm. In countries like India, promoting fish consumption can play an important role in improving public health and reducing the burden of cardiovascular diseases. Therefore, increasing awareness about the benefits of fish consumption and encouraging its inclusion in regular diets can contribute significantly to improved heart health and overall well-being.

Keywords

Fish consumption; Heart health; Omega-3 fatty acids; Cardiovascular disease; Healthy diet; Nutritional benefits

Introduction

Cardiovascular diseases (CVDs) are one of the most significant public health challenges globally. Unhealthy diets, lack of physical activity, smoking, and stress contribute to the rising incidence of heart diseases. Adopting healthy dietary practices is essential for preventing cardiovascular disorders and maintaining overall health.

Fish is considered one of the healthiest foods due to its high nutritional value and beneficial effects on heart health. It provides easily digestible protein, essential vitamins, minerals, and heart-protective omega-3 fatty acids.

According to the World Health Organization, cardiovascular diseases account for a large proportion of global deaths each year. Healthy dietary practices, including regular fish consumption, can significantly reduce the risk of heart disease.

Similarly, the Food and Agriculture Organization emphasizes that fish is an important component of healthy diets and contributes significantly to human nutrition. Including fish regularly in meals can therefore improve cardiovascular health and overall well-being.

Nutritional Components of Fish Beneficial for Heart Health

High-Quality Protein

Fish provides high-quality protein that is easily digestible and essential for growth, tissue repair, and metabolic functions. Compared with many other animal protein sources, fish often contains lower levels of saturated fat.

Omega-3 Fatty Acids

Fish is one of the richest natural sources of omega-3 fatty acids such as EPA and DHA. These fatty acids are well known for their cardioprotective effects.

Omega-3 fatty acids help to:

- Reduce triglyceride levels
- Lower blood pressure
- Improve blood vessel function
- Reduce inflammation
- Prevent abnormal heart rhythms

These benefits collectively reduce the risk of heart attacks and strokes.

Vitamins and Minerals

Fish also provides important micronutrients that support cardiovascular health, including:

- Vitamin D
- Vitamin B12
- Selenium
- Potassium
- Iodine

These nutrients support heart function, immune health, and metabolic processes.

Types of Fish Beneficial for Heart Health

Several fish species are particularly beneficial due to their high omega-3 fatty acid content.

Examples include:

- Sardinella longiceps – rich in omega-3 fatty acids
- Rastrelliger kanagurta – contains heart-healthy fats
- Thunnus albacares – good source of protein and omega-3 fatty acids
- Salmo salar – well known for high omega-3 content

The American Heart Association recommends consuming fish at least two times per week to maintain heart health.

Nutritional Composition of Fish (Approximate)

Nutrient	Amount per 100 g fish
Protein	18–22 g
Fat	1–12 g
Omega-3 fatty acids	0.5–2 g
Vitamin D	200–400 IU
Selenium	30–40 µg
Potassium	300–400 mg

These nutrients collectively support healthy heart function and reduce cardiovascular risks.

Comparison of Fish and Red Meat for Heart Health

Feature	Fish	Red Meat
Protein Quality	High-quality, easily digestible	High-quality protein
Fat Type	Rich in omega-3 fatty acids	Higher saturated fat
Cholesterol Effect	Improves HDL and lowers triglycerides	Excess intake increases LDL
Heart Disease Risk	Helps reduce cardiovascular risk	High intake linked to higher risk
Digestibility	Easier to digest	Comparatively heavier

Interpretation:

Fish provides beneficial fats that protect heart health, whereas excessive red meat consumption may increase cardiovascular risk due to higher saturated fat content.

Indian Case Examples Supporting Fish Consumption

Coastal Fish-Eating Communities

Many coastal populations in India consume fish regularly as part of their traditional diets. Studies indicate that these populations often show better cardiovascular health compared to groups consuming diets rich in saturated fats.

Traditional South Indian Diets

Fish is a common component of traditional diets in several coastal regions of South India. These diets are typically balanced and associated with improved heart health outcomes.

Nutrition Awareness Programs

Public health programs in India increasingly promote fish consumption as part of healthy dietary practices to reduce lifestyle diseases such as heart disease.

Conceptual Diagram: Fish and Heart Health

A simple explanation of the protective effect of fish on heart health can be illustrated as:

Fish Consumption → Omega-3 Fatty Acids → Reduced Inflammation & Lower Cholesterol → Improved Blood Circulation → Healthy Heart → Reduced Risk of Cardiovascular Diseases

This relationship highlights the importance of including fish as a regular component of a balanced diet.

Promoting Fish Consumption for Heart Health

Increasing public awareness about the health benefits of fish consumption is important for promoting heart-healthy dietary habits. Nutrition education programs, health campaigns, and government initiatives can encourage people to include fish regularly in their meals.

Development of affordable fish products and improved fish availability can further support increased consumption, particularly in regions where fish intake is low.

Conclusion

Fish consumption plays an important role in maintaining heart health and preventing cardiovascular diseases. Its rich content of omega-3 fatty acids, high-quality protein, vitamins, and minerals makes fish a valuable component of a balanced diet. Regular intake of fish can improve lipid profiles, reduce inflammation, and lower blood pressure, thereby reducing the risk

of heart disease. Promoting fish consumption through nutrition education and public health initiatives can significantly contribute to improved cardiovascular health and overall well-being.

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MICROBIOME ENGINEERING IN SHRIMP AQUACULTURE: PROBIOTIC, BIOFLOC AND DISEASE CONTROL

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Abstract

Shrimp aquaculture industry has been growing exponentially and making a considerable impact on food security globally. Yet, sustainability of the industry is under threat due to diseases, environmental degradation, and misuse of antibiotics. Microbiome engineering has been a new and eco-friendly technology to address problems in shrimp farming by manipulating beneficial microbes associated with shrimp and their culture system. This article discusses the importance of microbiome engineering in shrimp farming, especially in relation to probiotics, biofloc technology, and microbiome engineering in disease management. Probiotics play a crucial role in gut development, immune system development, and suppression of pathogens. Biofloc technology helps in nutrient recycling, water management, and natural feed supplements. A combination of both technologies will be a boon for shrimp farming. Next-generation probiotics, synbiotics, multi-omics technologies, and artificial intelligence technologies are promising technologies in microbiome engineering. Though there are challenges in applying microbiome engineering in shrimp farming due to microbial diversity, it acts as an alternative to antibiotics and helps in developing a robust and high-yielding shrimp farming industry.

Introduction

Shrimp aquaculture is recognized as a rapidly growing sector that contributes significantly to food security and economic development. However, shrimp aquaculture

sustainability is currently faced with many challenges related to disease outbreaks, environmental degradation, and the overuse of antibiotics. Acute hepatopancreatic necrosis disease (AHPND) and white spot syndrome virus (WSSV) are examples of shrimp diseases that have caused significant production losses. Conventional approaches to managing shrimp disease using antibiotics have proven to be unsustainable due to the development of resistance. In this case, microbiome engineering has been recognized as a sustainable approach that aims to manipulate a positive microbial population to improve shrimp health, increase production, and control disease. The concept of shrimp as a "holobiont," where a shrimp host acts as a single unit with its associated microbial populations, has gained recognition in modern aquaculture research (Gutiérrez-Pérez et al., 2022).

Concept of Microbiome in Shrimp Culture

The term "microbiome" refers to a group of microorganisms such as bacteria, archaea, viruses, and fungi, along with their genetic material found within a particular environment such as shrimp guts, rearing water, and pond sediment. The microbiome plays a significant role in maintaining physiological balance in shrimp aquaculture. The role of the shrimp microbiome, particularly the gut microbiome, is crucial in maintaining physiological balance. The balance of microorganisms within a particular environment, also known as "eubiosis," plays a significant role in maintaining optimal shrimp growth. On the other hand, "dysbiosis," or disruption of the balance of microorganisms, often leads to shrimp disease. The microbiome balance is affected by environmental factors, aquaculture practices, as well as shrimp developmental stages. This shows a significant relationship between shrimp and their environment (Zakaria et al., 2025).

Microbiome Engineering: Definition and Principles

The term microbiome engineering involves a deliberate manipulation of the microbes associated with the host and their environment in order to obtain improved health, productivity, and disease resistance in an aquaculture system. In shrimp farming, microbiome engineering involves a deliberate manipulation of gut, water, and sediment microbiota in order to obtain improved levels of beneficial microbes and reduced levels of pathogenic microbes. This concept of microbiome engineering in shrimp farming is based on a number of ecological principles, such as competition between microbes and stability of communities. Unlike other conventional methods of disease management in shrimp farming, which involve antibiotics, microbiome engineering involves a preventive measure of disease management. Recent advances in

microbiome engineering in shrimp farming indicate a shift from a general concept of probiotics to a precision concept of microbial management, which includes using beneficial microbes specific to the host, synthetic microbes, and omics technologies for precision interventions (Tayyab et al., 2025) .

Role of Probiotics in Shrimp Aquaculture

Probiotics are live microorganisms that, when administered in sufficient quantities, have a health benefit to the host. Probiotics are used in shrimp farming to control gut flora, promote digestion, and boost immune systems. Probiotics such as *Bacillus*, *Lactobacillus*, and *Pseudomonas* are used. Probiotics act by mechanisms such as competitive exclusion, production of antimicrobial compounds, and stimulation of innate immunity. Probiotics are used in shrimp farming to restore microbial balance, or eubiosis, when there is a state of dysbiosis. Probiotics have been used in shrimp farming, replacing antibiotics, which has greatly improved survival rates. Probiotics are effective in shrimp farming depending on proper selection of probiotics compatible with the host (Zakaria et al., 2025).

Biofloc Technology (BFT)

Biofloc technology (BFT) is an advanced form of aquaculture technology that uses heterotrophic microorganisms for the degradation of organic wastes into beneficial microbial mass, which improves water quality and provides an alternative source of nutrition for the shrimp. The BFT technology works based on the principle of maintaining an optimal carbon-to-nitrogen ratio, which favors the growth of heterotrophic microorganisms that convert nitrogenous wastes such as ammonia into microbial mass called bioflocs. Bioflocs comprise heterotrophic microorganisms such as bacteria, phytoplankton, fungi, protozoa, and organic matter. In addition to acting as an alternative source of nutrition for the shrimp rich in protein content, bioflocs play an important role in water quality improvement through the recycling of nutrients and reduction of toxic substances in the aquaculture environment. Moreover, biofloc microorganisms produce bioactive compounds that enhance the immunity of the shrimp, thus improving productivity in the aquaculture environment. BFT is an environmentally safe technology for intensive shrimp culture (Kumar et al., 2021).

Integration of Probiotics and Biofloc

The integration of probiotics with biofloc technology is an advanced concept in microbiome engineering. Biofloc technology is known for its rich diversity of microorganisms.

The integration of probiotics with biofloc technology is an advanced concept that not only provides the advantages of selected beneficial microorganisms but also the advantages of microorganisms that have developed naturally. The integration of biofloc technology with probiotics is an advanced concept that not only maintains the stability of microorganisms in the culture system but also improves the balance of microorganisms in the culture system. The integration of biofloc technology with probiotics not only improves nutrient recycling, digestion efficiency, and the immune system of the shrimp but also maintains the dominance of beneficial microorganisms over pathogenic microorganisms. The concept of disease outbreaks is not possible with the integration of biofloc technology with probiotics. New concepts such as synbiotics (probiotics + prebiotics) and aquamimicry also support the integration of probiotics with biofloc technology to enhance the diversity of microorganisms in aquaculture systems.

Microbiome-Based Disease Control

Microbiome engineering plays a crucial role in disease control in shrimp aquaculture by regulating microbial balance and preventing the dominance of pathogenic organisms. Beneficial microbes suppress pathogens through mechanisms such as competitive exclusion, production of antimicrobial compounds, and disruption of quorum sensing, which reduces pathogen virulence. A stable microbial community enhances the immune response of shrimp by stimulating defense mechanisms and maintaining gut integrity. Disease outbreaks are often associated with dysbiosis, where opportunistic pathogens such as *Vibrio* species become dominant. By maintaining eubiosis through probiotics, biofloc systems, and other microbial interventions, it is possible to prevent diseases such as acute hepatopancreatic necrosis disease (AHPND) and other bacterial infections. Thus, microbiome-based strategies offer a sustainable and effective alternative to antibiotics for disease management in shrimp farming (Tayyab et al., 2025).

Advanced Approaches in Microbiome Engineering

Recent developments in microbiome engineering have provided novel approaches that are beyond the scope of traditional probiotics or biofloc technology. These novel approaches include next-generation probiotics (NGPs), synbiotics, a combination of probiotics and prebiotics, or synthetic microbial communities. Other approaches include the use of metagenomics, metabolomics, or other omics approaches for the identification of key microbial groups or functional metabolites associated with shrimp health. In addition, novel technologies such as artificial intelligence (AI) or deep learning have been used for real-time shrimp health

monitoring, disease detection, or prediction of microbial communities in shrimp aquaculture. Other approaches, such as fecal microbiota transplantation (FMT) or CRISPR-based microbial modifications, have been used for disease resistance or for improving microbial stability. These precision-based approaches are a glimpse into the future of sustainable aquaculture, which is beyond the scope of traditional approaches such as biofloc technology or probiotics, i.e., targeted and efficient microbiome manipulation (Tayyab et al., 2025).

Advantages of Microbiome Engineering

Microbiome engineering provides a number of advantages in the aquaculture of shrimp. The advantages include the sustainability and eco-friendly nature of the practice as a replacement for conventional methods of controlling diseases in shrimp aquaculture. The reduction of antibiotics is a significant advantage of the practice. The reduction of antibiotics minimizes the risk of the development of antimicrobial resistance. The practice also improves the growth of the shrimp through the promotion of the growth of beneficial microbes. The practice improves the immune system of the shrimp, which increases the resistance of the shrimp to diseases. The practice also improves the quality of the water through the use of the biofloc system. The system improves the quality of the water through bioremediation, which increases the density of the shrimp culture with minimal water exchange. The practice also improves the stability of the aquaculture system, which increases the sustainability of the practice. The practice is sustainable and eco-friendly and is a significant advantage in the aquaculture of shrimp (Kumar et al., 2021; Tayyab et al., 2025).

Challenges and Limitations

Despite its promising prospects, there are many challenges associated with microbiome engineering in shrimp aquaculture. Some of these challenges include the lack of standardization of microbial interventions owing to the variability of the microbiome in different farms, conditions, and culture practices. The efficacy of probiotics is often inconsistent in the field owing to poor colonization and competition with other microorganisms. Moreover, the maintenance of a balanced microbiome in intensive aquaculture is a complex task that requires proper water quality management, nutrition, and environment. Ecological risks such as the shift in the microbial population and gene flow are also a concern.

Moreover, the high cost of operations and lack of awareness among aquaculture farmers are some of the other challenges that need to be overcome for the successful implementation of microbiome engineering in shrimp aquaculture (Tayyab et al., 2025).

Future Perspectives

The future of shrimp aquaculture is moving towards precision microbiome engineering, where advanced technology and ecological concepts are used to increase the sustainability of aquaculture. New technologies such as multi-omics (omics: genomics, transcriptomics, metabolomics) have been used to increase the understanding of the microbiome-host interface and identify key functional microorganisms for health and disease resistance. New forms of probiotics, host-specific microbial consortia, and engineered microbes using new tools such as CRISPR technology have been used to provide effective disease control measures. Moreover, the application of artificial intelligence (AI) technology has the potential to provide real-time health status for shrimp using deep learning technology. Future technology for shrimp aquaculture is likely to provide a holistic approach to microbiome engineering known as holobiome, where the interactions between gut, water, and sediment microbiomes will be integrated for better biosecurity and eco-efficiency. With the right support for policy-making, farmer awareness, and technological advances, microbiome engineering has the potential to revolutionize shrimp aquaculture for better sustainability in the future (Tayyab et al., 2025; Gutiérrez-Pérez et al., 2022).

Conclusion

Microbiome engineering is a revolutionary concept in shrimp aquaculture that is replacing the traditional practice of using antibiotics for the control of diseases. It is possible to maintain the health of the shrimp and control diseases effectively through the beneficial use of microbes with the help of probiotics and other microbiome technologies. The concept of maintaining a balance between microbes is very important for the prevention of the outbreak of diseases. Even though there are challenges associated with the practical application of microbiome technology in shrimp aquaculture, the recent developments in the field of multi-omics and artificial intelligence have provided a promising solution for the development of eco-friendly, sustainable, and high-yielding shrimp aquaculture systems in the future (Tayyab et al., 2025; Kumar et al., 2021).

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APPLICATION OF RADARS AND REMOTE SENSING IN ENTOMOLOGY

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Introduction

Remote sensing technologies encompassing dedicated entomological radars, repurposed weather radars, LiDAR systems, satellite imagery, and UAV platforms have fundamentally transformed how entomologists study insect flight, migration, population dynamics, and pest outbreaks. Since the pioneering application of radar to entomology in 1968, these tools have enabled observation of insects at spatial and temporal scales completely inaccessible to conventional field methods. Today, the field sits at the convergence of atmospheric science, ecology, agricultural engineering, and artificial intelligence, offering increasingly automated, large-scale, and taxonomically refined insights into the insect world.

1. Historical Development of Radar Entomology

- The origins of radar entomology trace back to the 1940s, when weather radar operators noticed unexplained "angel" echoes in clear air, which were eventually confirmed to originate from birds and insects in the atmosphere.
- The first purpose-built entomological radar was developed in 1968, operating at a frequency of 9.4 GHz (X-band, 32 mm wavelength), which produced strong reflections from larger insects such as grasshoppers, locusts, butterflies, and moths. The foundational demonstration that radar could be systematically used as an entomological tool is largely credited to Schaefer in 1969.
- The early period (1949–2000) was characterized by intensive "observation campaigns," where radar units were transported to field sites and operated for several weeks, often timed to coincide with peak migratory flight activity. These campaigns were supplemented by insect trapping, meteorological measurements, and night-vision observations. Notable early milestones include:
- 1975: First use of airborne entomological radar to study spruce budworm moths over New Brunswick, Canada
- 1975: Simultaneous dual-site scanning and vertical-looking rotating-polarisation radars used to track grasshoppers in Mali
- 1985: Mark-and-recapture radar experiment with African armyworm in Kenya
- From around 2000, continuously operating automated radars replaced campaign-style deployments, enabling routine long-term monitoring with minimal human intervention. This transition ushered in the modern era of quantitative radar entomology.

2. Types of Radar Systems Used in Entomology

2.1 Scanning (X-band) Radar

The earliest entomological radars were horizontally oriented, scanning radars operating predominantly in the X-band (8–12 GHz, wavelength ~3 cm). These radars were effective for detecting large insects (>40 mg), such as acridoid grasshoppers and noctuid moths, and were primarily deployed to study population movements over agricultural landscapes. Scanning radars provided the first quantitative evidence for insect layers in the atmosphere, common heading orientation, and mass migratory events. Their limitation was the inability to monitor continuously at fixed altitudes and their dependency on skilled operators.

2.2 Vertical-Looking Radar (VLR)

The Vertical-Looking Radar (VLR) was developed in the 1970s as a purpose-built system specifically optimized for monitoring high-altitude insect migration. Unlike scanning radars, VLRs point directly upward, enabling them to detect individual insects as they pass through a fixed column of airspace. Modern VLRs detect insects flying at heights ranging from 70 m to 1,810 m above ground, with individual insects as small as 10 mg identifiable in standard systems.

The VLR measures several key parameters from each detected insect:

Parameter	Information Derived
Radar Cross-Section (RCS)	Body mass, overall size estimation
RCS polarization pattern	Body length, width, morphological form
RCS modulation frequency	Wingbeat frequency
Flight speed & direction	Displacement velocity, migration track
Body alignment	Heading direction relative to wind
Altitude	Vertical distribution profile

VLRs operate automatically and almost continuously through day and night, accumulating data over half-month periods to average out weather effects and broaden the geographic sample area. A recent VLR installation in Henan Province, China represents the first high-resolution, long-term automated VLR system in Asia, capable of providing accurate wind velocity estimates from insect tracking data. In the UK, VLRs at Malvern and Harpenden have operated continuously for years, producing systematic data on the vertical distribution and seasonal dynamics of aerial insect populations.

2.3 Harmonic Radar

Harmonic radar operates on an entirely different principle from conventional radar: it transmits at a fundamental frequency (e.g., 9.4 GHz) and detects the return signal at the second harmonic frequency (18.8 GHz), emitted only by a small transponder (a diode and wire antenna) attached to the insect. This eliminates ground clutter, since natural objects do not reflect at the harmonic frequency. The technique enables tracking individual insects at low altitudes with a typical detection range of up to 900 m, making it ideal for studying foraging flight behavior, navigation, and orientation in insects that cannot be monitored by VLRs.

Key applications of harmonic radar in entomology include:

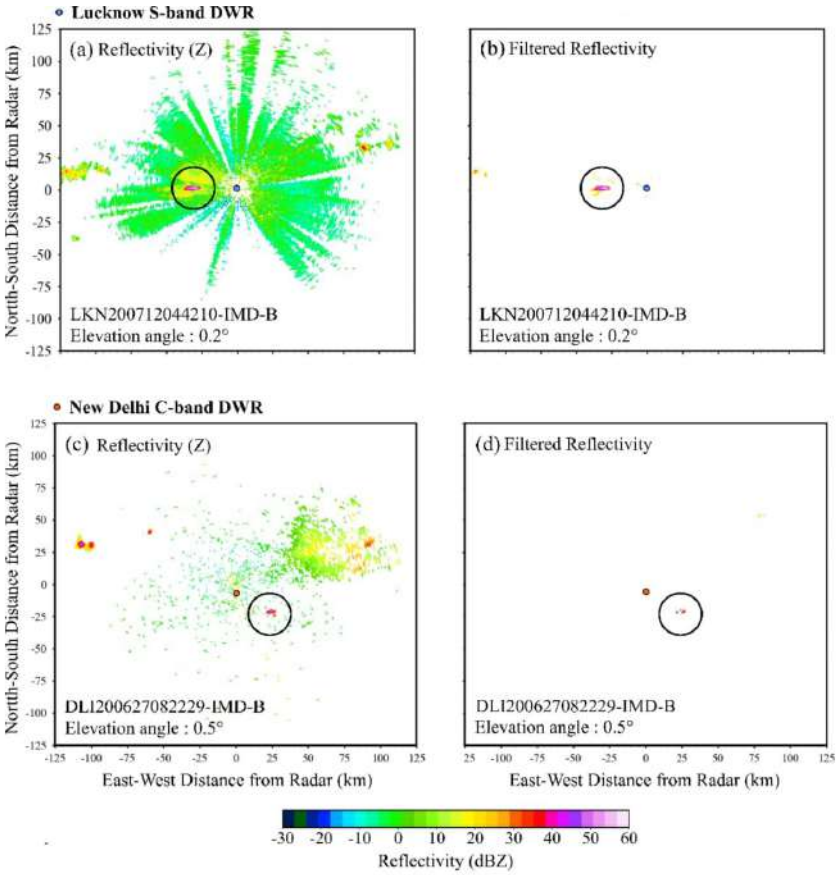
Honeybee orientation flights: Revealed the ontogeny of learning, showing bees progressively expand their familiar area with experience, holding trip duration constant but flying faster with each successive flight

- Honeybee navigation: Demonstrated that displaced bees navigate using a map-like spatial memory, adjusting flight trajectories toward familiar landmarks
- Bumblebee foraging: Among the first insects tracked by harmonic radar, revealing foraging trajectory and directness compared to honeybees
- Invasive wasp (Vespa velutina) tracking: An innovative harmonic radar with a 125 m detection range in hilly, woody terrain was used to track flight trajectories of the invasive Asian yellow-legged hornet toward its nest
- Disease effects on flight: Harmonic radar revealed that honeybees infected with the microsporidian pathogen Nosema ceranae had significantly reduced homing success (65.8% vs. 92.5% in healthy foragers), with prolonged resting times but normal flight characteristics indicating specific impairment of navigational ability rather than general flight performance
- The harmonic radar technique requires tagging individual insects, which limits it to relatively large, robust insects and precludes mass population monitoring.

2.4 Weather/Doppler Surveillance Radar (DWR/WSR)

Routine weather surveillance radars deployed worldwide in national networks primarily for meteorological purposes are increasingly recognized as powerful tools for large-scale entomological monitoring. These radars detect all atmospheric targets including biological ones,

which appear as "clear-air echoes." The US national WSR-88D ("NEXRAD") network, operating at S-band, readily detects birds, bats, and insects in the lower atmosphere.



The critical distinction for entomological use is the ability to discriminate biological echoes from meteorological echoes and from each other. Studies have established that insects are responsible for nearly all daytime clear-air echoes, while birds and insects co-occur at night. Multiple discrimination methods have been developed:

- Radial velocity analysis: Insects typically drift with the wind (low air speed), while birds show self-powered flight against wind
- Spectral width: Differences between populations with different air speeds
- Dual-polarization (dual-pol): Parameters including differential reflectivity (ZDR) and copolar correlation coefficient ($\rho hv\rho v$) enable classification of echoes by target type
- Unsupervised machine learning clustering algorithms applied to dual-pol radar data have demonstrated that the diversity of radar-detected bioscatterers correlates quantitatively with ground-level insect diversity measured by light traps. A major landmark study using UK weather radar data (2014–2021) covering 35,000 km² found that nocturnal

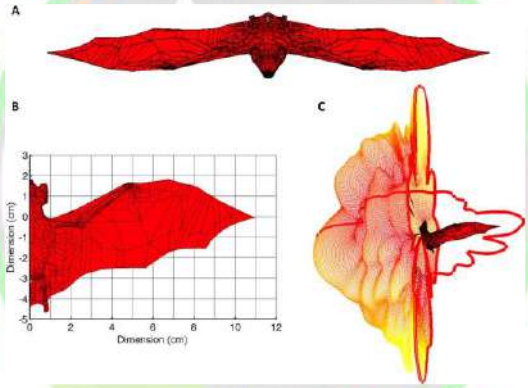
arthropods, especially moths, have significantly declined over time, while daytime flying insects remained relatively stable, with areas of high light pollution showing the most severe declines.

2.5 W-Band (94 GHz) Cloud Radar

A novel approach using W-band (94 GHz, $\lambda = 0.32$ cm) Doppler cloud radars originally designed for cloud microphysics research has demonstrated the ability to estimate aerial insect concentration in a vertical profile from 50 m to 1,000 m above ground. This fills a critical gap between the lower-altitude capabilities of harmonic radar (≤900 m for tagged insects) and VLR systems (typically ≥150 m). The W-band radar's short wavelength makes it particularly sensitive to small insects, complementing X-band systems that are more sensitive to larger targets.

3. Key Radar-Derived Entomological Parameters

3.1 Radar Cross Section (RCS) and Insect Identification



The Radar Cross Section (RCS) is the fundamental quantity measured by radar and relates to how strongly an insect reflects electromagnetic waves. For insects, RCS is a function of body size, morphological shape, orientation relative to the radar beam, and the wavelength used. Research has established quantitative relationships between RCS and key biological parameters:

- Body mass: Estimated from overall RCS magnitude; larger insects have proportionally larger RCS values
- Morphological form: The ratio of body length to width can be inferred from the shape of the RCS polarization pattern
- Wingbeat frequency: The modulation of the RCS signal by wing movement provides a frequency that is species-specific

A Stokes matrix (SM) approach using fully polarimetric radar measurements allows simultaneous extraction of insect orientation, mass, and body length from a single radar observation, resolving the long-standing ambiguity between parallel and perpendicular insect orientations. Machine learning methods, including Decision-Tree Support Vector Machines (DT-SVMs), have been applied to mass, wingbeat frequency, and length-to-width ratio data to classify migrating insects to broad taxonomic groups.

3.2 Insect Layering and Stratification

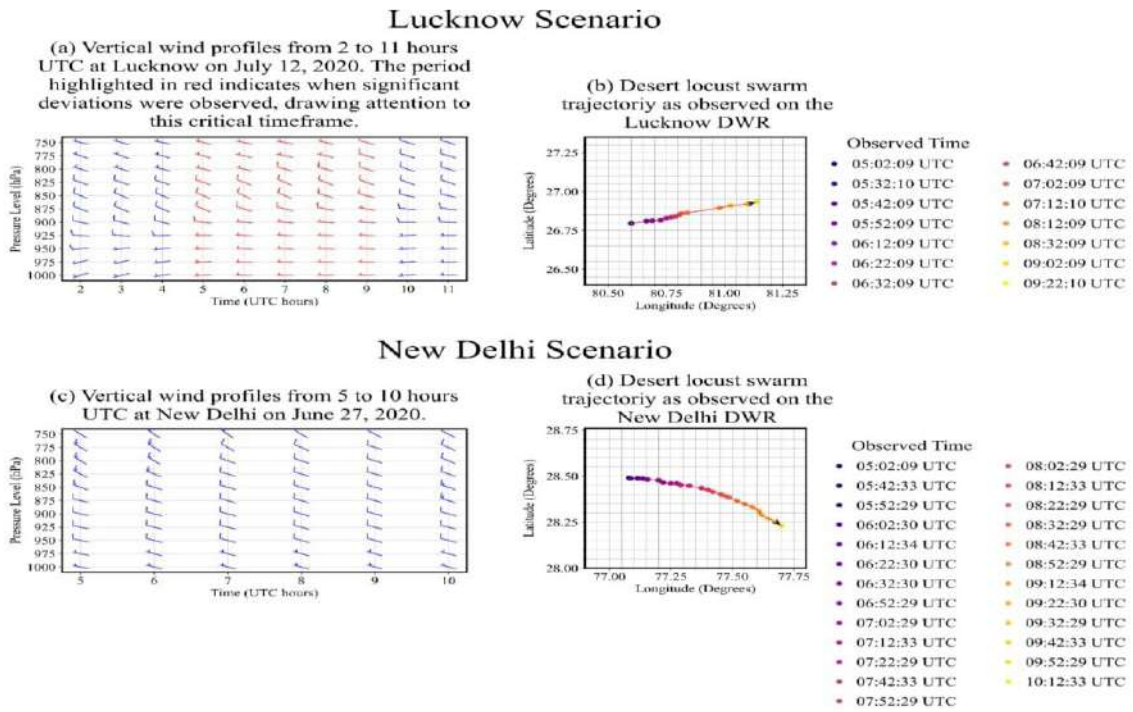
One of the most spectacular phenomena revealed by radar entomology is the formation of insect layers thin bands of high aerial density at specific altitudes. Studies over four decades have shown that insects in these layers frequently display a common orientation (similar headings) rather than random flight directions. Analysis of over 600,000 radar-detected medium-sized migrants (10–70 mg) flying hundreds of meters above southern UK revealed:

Wind-related common orientation was present in 97% of all daytime migration events, 85% at sunset, and 81% at night. Nocturnal migrant headings are systematically offset to the right of the mean wind direction (in the Northern Hemisphere), explained by the use of turbulence cues to detect wind direction consistent with the Ekman spiral effect "Jerks" (time-derivative of accelerations) in flight paths may serve as wind direction indicators at altitude. This common orientation behaviour is highly adaptive: by adding their self-powered flight vector (typically 1–5 m/s) to the wind speed (typically 5–20 m/s at flight heights), insects maximize migration distance per unit energy expenditure.

4. Remote Sensing Applications in Entomological Pest Management

4.1 Desert Locust Monitoring

The desert locust (*Schistocerca gregaria*) threatens over 20% of Earth's landmass and has driven the most intensive application of radar and remote sensing to insect pest management. During the catastrophic 2019–2021 outbreak affecting Africa and Asia, satellite remote sensing played a critical role: the Aerospace Information Research Institute (ARI) of the Chinese Academy of Sciences monitored migration paths and impact assessments across multiple countries documenting damage to approximately one million hectares in India, 940,000 ha in Kenya, and over one million ha in Ethiopia.



Recent research has demonstrated that Doppler Weather Radars (DWRs) can systematically identify and track locust swarm concentrations in near-real-time using both single-polarization (S-band) and dual-polarization (C-band) radar systems, enabling early warning systems with lead times of 5–7 hours and spatial coverage of approximately 100 km. Machine learning research at IIT Bombay (2022–present) is developing near-real-time DWR-based locust detection by training deep learning models on Indian Meteorological Department radar data, addressing the critical need for automated interpretation of biological radar echoes.

4.2 Migratory Moth Pest Surveillance

Noctuid moths including the fall armyworm (*Spodoptera frugiperda*), African armyworm (S. exempta), and cotton bollworm (*Helicoverpa armigera*) are important migratory pests whose high-altitude migrations can be monitored by VLR and weather radars. A landmark project in Kenya (2019–2020) integrated entomological radar, digital pheromone traps, and an image recognition app ("Nondo") to monitor fall armyworm migrations, detecting high-altitude moth targets at up to 800 m altitude with masses consistent with noctuid moths. This demonstrated the viability of real-time, multi-technology pest surveillance networks in Sub-Saharan Africa.

4.3 Satellite Imagery and NDVI for Indirect Pest Detection

Satellite-based remote sensing provides indirect evidence of insect pest damage through changes in vegetation health indices. The Normalized Difference Vegetation Index (NDVI) derived from red and near-infrared reflectance consistently decreases with increasing pest infestation intensity. A study on Hessian fly (Mayetiola destructor) infestation in commercial wheat fields found that NDVI from MODIS satellite data explained pest infestation levels better than high-resolution aircraft imagery, suggesting that low-resolution temporal compositing effectively filters within-field spatial heterogeneity. The strength of the NDVI-infestation relationship increased over time as plant biomass loss accumulated. A systematic review of 103 studies published between 2014 and 2024 confirmed that insect pest monitoring using satellite remote sensing has increased annually, with MODIS, Landsat 7 ETM+, and Landsat 8 OLI/TIRS as the most widely used platforms.

4.4 Hyperspectral and Multispectral Imaging

Hyperspectral imaging acquires data in hundreds of narrow spectral bands, capturing subtle spectral signatures that correspond to specific physiological responses of plants under insect stress or, at close range, the spectral properties of the insects themselves. Key applications include:

- Plant stress detection: Hyperspectral sensors can detect crop stress up to two weeks before it becomes visible to the naked eye, enabling early intervention
- Direct insect identification: Different insect species possess unique spectral signatures driven by differences in coloration, surface structure, and morphometry, enabling automated drone-based monitoring systems capable of differentiating closely related species with >90% accuracy
- Parasitism detection: Proximal hyperspectral remote sensing can non-destructively detect and diagnose physiological responses of host insect larvae to parasitism, enabling timing optimization for biological control
- Vineyard pest monitoring: UAV-based hyperspectral imagery has been validated for detecting grape phylloxera (Daktulosphaira vitifoliae) infestations, increasing the efficiency of existing surveillance compared to human inspectors alone

4.5 GIS and Vector-Borne Disease Mapping

The integration of satellite remote sensing with Geographic Information Systems (GIS) is a cornerstone of mosquito vector surveillance and vector-borne disease management. Indian Remote Sensing (IRS) satellite data processed in spectral bands from visible to thermal infrared (0.45–12.5 µm) at spatial resolutions from 1 to 30 m has been used to map vector breeding habitats for malaria, dengue, chikungunya, Japanese encephalitis, and filariasis across Indian cities and landscapes with 90% spatial accuracy.

Applications of GIS-based vector entomology include:

- Breeding habitat mapping: Land-use/land-cover classification identifies water bodies, paddy fields, and urban drainage systems that serve as mosquito breeding sites
- Abundance and density estimation: Ward-wise cumulative mosquito potential breeding surface maps enable prioritization of control efforts
- Disease risk prediction: Spatial modeling integrating weather parameters, land-use, vegetation indices, and epidemiological data generates predictive maps of outbreak risk
- Buffer zone analysis: 2.5 km buffer zones around identified breeding habitats delineate the area of maximum adult mosquito flight range for targeted control

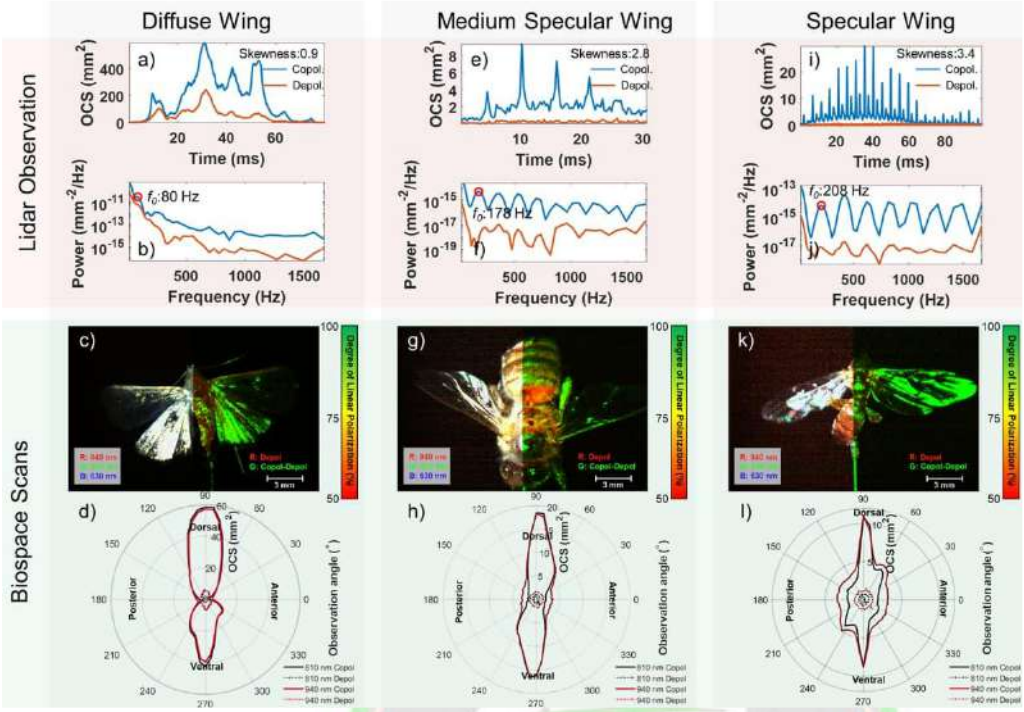
5. LiDAR (Light Detection and Ranging) in Entomology

Entomological LiDAR (light/laser radar) has emerged in the past decade as a transformative complementary technology to microwave radar, particularly for monitoring insects at low altitudes (below 150 m) where conventional VLRs cannot operate effectively.

5.1 Scheimpflug LiDAR Principle

The most widely adopted configuration is the Scheimpflug LiDAR, which orients the detector sensor at an angle relative to the lens (Scheimpflug principle), achieving sharp focus simultaneously at all distances theoretically infinite focal depth with a large optical aperture. A continuous-wave laser beam is directed into the atmosphere, and insects passing through the beam generate backscattered pulses. The system simultaneously captures:

- Wingbeat frequency: Derived from the temporal modulation of backscattered light intensity
- Wing interference patterns (WIPs): Coherent scattering from thin wing membranes creates species-specific fringed spectra arising from the unique optical path difference between front and back wing surfaces



Spatial position: Distance to each insect as it transits the beam

- A hyperspectral Scheimpflug LiDAR (EHSL) developed jointly by NKT Photonics and Lund University can discriminate between free-flying insect species based on the combination of wingbeat frequency and WIPs, with the potential to differentiate hundreds of species in their natural habitat. An infrared (950–1650 nm) EHSL system with 64 spectral bands demonstrated coherent scattering from a damselfly wing at 87 m distance in a 4 ms recording — enabling wing membrane thickness determination to ±4 nm precision, matching laboratory recordings of the same wing.

5.2 Quantitative LiDAR Monitoring

In a landmark field study in Sweden, a high-resolution LiDAR system recorded 22,808 insects during a single summer night, successfully distinguishing three insect clusters based on morphological properties and identifying distinct spatial distributions between field and forest habitats. A subsequent polarimetric LiDAR study recorded 32,533 observations along a 500 m transect, with hierarchical cluster analysis and Gaussian mixture models used to estimate species richness showing that current photonic sensors can differentiate approximately 100 signal types, correlating with Malaise trap diversity estimates. LiDAR has been successfully deployed in challenging environmental conditions, including tropical cloud forests (Ecuador), where a dual-

band (808/980 nm) infrared Scheimpflug LiDAR operated during foggy conditions at a 5 kHz sampling rate, demonstrating robustness for biodiversity monitoring in the Global South.

5.3 LiDAR vs. Radar: Complementary Roles

Feature	Microwave Radar (VLR)	Harmonic Radar	LiDAR
Altitude range	70–2,550 m	<1 km (tagged)	<150 m
Insect tagging required	No	Yes	No
Species resolution	Broad groups (mass, form)	Individual tracking	Potential for hundreds of species
Coverage area	Local–regional	Individual–local	Local
Day/night operation	Both	Both	Both
Minimum insect size	~10 mg	Any (if taggable)	Very small

6. UAVs (Drones) in Entomological Remote Sensing

Unmanned Aerial Vehicles (UAVs) equipped with multispectral, hyperspectral, and thermal imaging sensors represent a rapidly growing platform for insect pest monitoring at the field and landscape scale. Key advantages include the ability to acquire high-resolution spatial data at precisely timed intervals, operate in difficult terrain, and integrate machine learning for automated insect recognition.

UAV sensor payloads relevant to entomology include:

Multispectral cameras: Detect NDVI and other vegetation indices indicating pest-related plant stress

- Hyperspectral cameras: Identify specific pest infestations through unique plant or insect spectral signatures, with >90% accuracy for well-represented species
- Thermal infrared sensors: Detect temperature anomalies associated with pest feeding or colony activity
- LiDAR scanners: Generate high-resolution 3D canopy models to detect defoliation or structural damage caused by borers and beetles
- High-resolution RGB cameras: Enable direct detection of large pest colonies or adult insects visible at canopy level
- The integration of machine learning algorithms with UAV imagery has automated insect recognition pipelines, allowing swift and accurate identification of pest species from aerial platforms. UAVs provide a cost-effective alternative to traditional field monitoring, particularly for large-scale farming operations and remote areas.

7. Aeroecology: Radar at the Continental Scale

Aeroecology the study of biological use of the atmospheric boundary layer and free troposphere has been revolutionized by the repurposing of national weather radar networks for ecological monitoring. At the continental scale, coordinated weather radar networks can provide information on insect migrations, population densities, and biodiversity trends simultaneously across entire regions.

Key developments in continental-scale radar aeroecology include:

- The bioRad R-package was developed to extract biological information from weather radar archives, differentiating animal echoes based on correlation coefficient and radial velocity
- Standard deviation of radial velocity, combinations of differential reflectivity (ZDRZDR) and copolar correlation coefficient (ρhvρ hv), and air speed parameters all contribute to the biological vs. meteorological discrimination workflow

- A UK study using data from 2014 to 2021 over 35,000 km² revealed not only population trends but also the differential effects of land use (woodland vs. farmland) and artificial light at night on day- and night-flying insect assemblages
- This capacity to monitor insect populations over vast areas non-invasively and continuously represents a paradigm shift for insect conservation science, providing quantitative data on declines that were previously based only on fragmented local observations.

8. Machine Learning and AI Integration

- The increasing volume and complexity of radar and remote sensing data from entomological applications has driven rapid integration of machine learning (ML) and artificial intelligence (AI) methods:
- Support Vector Machines (SVMs): Applied to radar-extracted features (mass, wingbeat frequency, length-to-width ratio) for multi-class insect identification
- Unsupervised clustering (hierarchical clustering, Gaussian Mixture Models): Applied to dual-polarization weather radar time series to classify insect communities without ground truth labels
- Deep learning for locust detection: IIT Bombay's ongoing project applies deep neural networks to Indian DWR data to automate the detection of desert locust swarm echoes, reducing the labor-intensive human interpretation currently required
- Convolutional Neural Networks (CNNs): Applied to UAV and satellite imagery for automated detection and enumeration of insect pests in crop canopies
- bioRad package (R): An open-source bioacoustic radar analysis toolkit enabling standardized biological extraction from weather radar archives across institutions
- The trajectory of this integration points toward fully automated, near-real-time insect monitoring networks capable of delivering actionable pest alerts at multiple spatial scales.

9. Challenges and Limitations

Despite tremendous advances, several challenges remain in radar and remote sensing entomology:

- Taxonomic resolution: Radar systems generally cannot achieve species-level identification; at best, broad morphological groups (mass and form classes) can be

distinguished from RCS parameters. LiDAR shows more promise but currently resolves only ~100 signal types

- Radar infrastructure gaps: Desert locust surveillance requires extensive weather radar coverage, but Africa has almost no radar network, and India covers less than 20% of its territory
- Small insect detection: VLRs detect insects >10 mg, missing the vast majority of insect species by number, many of which are small Diptera, Hymenoptera, or Coleoptera
- Weather interference: Precipitation, wind shear, and atmospheric turbulence can mask or mimic biological radar echoes, requiring sophisticated signal processing
- LiDAR range limitations: Current entomological LiDAR systems are effective only at low altitudes and relatively short ranges, limiting coverage to local scales
- Tagging burden in harmonic radar: Attaching transponders to insects is labor-intensive, restricted to robust species, and may affect flight behavior
- Data integration: Combining multi-platform, multi-scale datasets (satellite, weather radar, VLR, LiDAR, UAV) into unified monitoring frameworks remains technically challenging

10. Future Directions

The field is moving rapidly toward a multi-scale, multi-platform monitoring toolkit for insect biodiversity and pest management:

- Global insect biodiversity monitoring networks using radar as a core component are conceptually established and technically feasible, providing Essential Biodiversity Variables (EBVs) including species population, species traits, community composition, and ecosystem function at continental scales
- Integration of VLR + weather radar + LiDAR at complementary altitude ranges (ground to 3 km) would provide seamless vertical coverage of insect flight activity
- Machine learning-enhanced species resolution from multi-parameter radar datasets (frequency, polarization, Doppler velocity) combined with deep learning on concurrent optical sensor data promises improved taxonomic discrimination

- Near-real-time early warning systems for migratory pests combining satellite vegetation monitoring, DWR swarm tracking, and ground-level trap networks are being actively developed in Africa, South Asia, and China
- Nanosatellite constellations (e.g., Planet Labs) providing daily sub-meter imagery could enable fine-resolution satellite entomology at landscape scales currently inaccessible
- Quantum sensing and photon-counting LiDAR may eventually enable single-photon detection of insects at much greater ranges and finer temporal resolution, revolutionizing the precision of low-altitude insect monitoring
- The convergence of increasingly affordable sensors, expanding weather radar networks, open-access satellite data archives, and powerful machine learning frameworks is rapidly lowering the barriers to deploying comprehensive, automated insect monitoring a development with profound implications for food security, vector disease control, biodiversity conservation, and our fundamental understanding of insect ecology.

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BOLTING AND BULB FORMATION IN ONION: CHALLENGES AND SOLUTIONS

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1. Introduction

Onion (*Allium cepa* L.) is a major vegetable crop cultivated globally for its culinary, nutritional and medicinal importance. It is widely used as a flavoring agent and is rich in sulfur-containing compounds, flavonoids and antioxidants that contribute to human health. In India, onion cultivation is an important component of the horticultural sector; however, productivity and market stability are often affected by physiological disorders such as bolting and improper bulb formation. Bolting refers to the premature development of a flowering stalk before adequate bulb formation, which reduces yield and market quality. Bulb formation, on the other hand, is a complex physiological process influenced by environmental factors, genetic characteristics and crop management practices. Understanding the mechanisms governing bolting and bulb development is essential for improving onion productivity and ensuring better storage and

2. Physiology of Bulb Formation

Bulb formation in onion is a photoperiod- and temperature-sensitive process that involves the transition from vegetative growth to bulb enlargement. It is regulated by the interaction of

environmental cues and endogenous plant hormones. Long-day conditions and moderate temperatures promote bulb initiation, while short-day conditions favor vegetative growth. The process involves the accumulation of carbohydrates in the leaf bases, leading to the swelling of bulb scales. Hormones such as gibberellins, auxins and cytokinins play a crucial role in regulating this transition. Proper bulb formation is essential for achieving high yield and good storage quality.

3. Mechanism of Bolting in Onion

Bolting is primarily induced by exposure to low temperatures (vernalization) during the early stages of plant growth. When onion plants experience temperatures between 5°C and 10°C for a prolonged period, they undergo physiological changes that trigger flowering. Once vernalization requirements are met, the plant shifts from vegetative to reproductive phase, resulting in the emergence of a flower stalk. Bolting competes with bulb development for assimilates, leading to reduced bulb size, poor quality and lower market value.

4. Factors Influencing Bolting

Several factors influence bolting in onion, including temperature, photoperiod, variety and planting time. Early sowing or transplanting in regions with low temperatures increases the risk of bolting. Varieties differ in their susceptibility to bolting, with some genotypes being more resistant than others. Large seedlings or sets are more prone to bolting compared to smaller ones. Environmental stress conditions, such as nutrient imbalance and water stress, can also influence bolting behavior.

5. Factors Affecting Bulb Formation

Bulb formation is influenced by a combination of genetic and environmental factors. Photoperiod is a critical factor, as onion varieties are classified into short-day, intermediate-day and long-day types based on their bulb formation requirements. Temperature plays a significant role, with optimal temperatures promoting bulb enlargement. Soil fertility, particularly nitrogen and potassium levels, affects bulb size and quality. Adequate irrigation and proper spacing are also essential for uniform bulb development.

6. Impact of Bolting on Yield and Quality

Bolting has a detrimental effect on onion yield and quality. Plants that bolt prematurely produce smaller bulbs with reduced market value. The formation of flower stalks diverts nutrients away from bulb development, resulting in poor bulb size and shape. Bolted bulbs are

also more prone to storage losses due to increased respiration and reduced dry matter content. Therefore, minimizing bolting is crucial for achieving higher productivity and better storage life.

7. Management Strategies to Prevent Bolting

Effective management practices can significantly reduce the incidence of bolting in onion. Selection of appropriate varieties that are resistant to bolting is the first step. Adjusting sowing and transplanting dates to avoid exposure to low temperatures during early growth stages is essential. Using small-sized seedlings or sets reduces the likelihood of bolting. Proper nutrient management, particularly balanced nitrogen application, helps maintain vegetative growth and delays flowering. In some cases, the use of growth regulators such as maleic hydrazide can suppress bolting.

8. Strategies to Enhance Bulb Formation

Improving bulb formation requires a combination of agronomic and environmental management practices. Selection of suitable varieties based on photoperiod requirements is crucial. Maintaining optimal temperature and light conditions promotes bulb initiation and enlargement. Balanced fertilization, with adequate potassium supply, enhances bulb size and quality. Efficient irrigation management ensures consistent soil moisture, which is essential for uniform bulb development. Proper spacing and weed control reduce competition and improve resource availability.

9. Role of Nutrient and Water Management

Nutrient and water management play a significant role in both bolting prevention and bulb formation. Excess nitrogen can delay bulb formation and increase susceptibility to bolting, while adequate potassium improves bulb quality and storage life. Micronutrients such as sulfur are important for bulb development and flavor. Consistent irrigation is essential to avoid stress

conditions that can affect growth and development. Drip irrigation systems improve water use efficiency and promote uniform bulb formation.

10. Integrated Crop Management Approach

An integrated approach combining improved varieties, optimal planting time, balanced nutrition and efficient water management is essential for managing bolting and enhancing bulb formation. Integrated crop management also includes pest and disease control, which indirectly affects plant health and productivity. Adoption of modern technologies such as precision farming and climate-smart agriculture can further improve onion production.

11. Constraints and Challenges

Despite advancements in production technologies, challenges such as climate variability, lack of awareness and limited access to quality inputs continue to affect onion cultivation. Unpredictable temperature fluctuations increase the risk of bolting, while poor management practices lead to suboptimal bulb formation. Addressing these challenges requires improved extension services and farmer education.

12. Future Prospects

Future research should focus on developing bolting-resistant and climate-resilient onion varieties through advanced breeding techniques. The use of molecular markers and genomic tools can accelerate the development of improved cultivars. Precision agriculture technologies and decision support systems can help optimize crop management and reduce risks associated with environmental variability.

Conclusion

Bolting and bulb formation are critical factors influencing onion productivity and quality. While bolting leads to significant yield losses, proper bulb formation ensures high yield and better storage life. Understanding the physiological and environmental factors governing these processes is essential for effective management. Adoption of improved agronomic practices, integrated crop management and advanced technologies can significantly reduce bolting and enhance bulb formation. With continued research and technological advancements, it is possible to achieve sustainable onion production and improved farmer profitability.

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ENHANCING DAIRY PRODUCTIVITY THROUGH A MULTI-CROP FODDER PRODUCTION SYSTEM

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Abstract

Dairy farming plays an important role in improving the livelihood of rural households in India; however, inadequate availability of quality fodder remains a major constraint affecting livestock productivity. The present article highlights the demonstration of a multi-crop fodder production model aimed at ensuring year-round availability of nutritious green fodder and improving dairy animal productivity. The model integrates high-yielding fodder crops such as hybrid Napier, fodder sorghum, hedge lucerne, and Agathi within a limited land area to provide balanced nutrition for dairy animals. The demonstration was conducted under semi-intensive farming conditions involving ten farmers in two villages. Results indicated that the adoption of the multi-crop fodder system increased average milk yield from 8.1 to 9.4 litres per animal per day, representing an improvement of about 12.2 per cent. Improvements in milk fat and SNF content were also observed. Economic analysis showed higher net returns and benefit–cost ratio compared to the conventional single fodder system, indicating the economic viability of the model.

Keywords: Dairy productivity, multi-crop fodder system, green fodder production, milk yield, nutritional management, dairy cattle, fodder diversification, farm profitability.

Introduction

Livestock farming plays an important role in the rural economy of India by providing food, employment, and income security to millions of small and marginal farmers. Among various livestock enterprises, dairy farming has become one of the most dependable sources of daily income for rural households. India currently ranks first in global milk production and contributes significantly to the world's dairy sector. However, the productivity of dairy animals

in the country remains relatively low compared with many developed nations, mainly due to the shortage of quality feed and fodder. Feed accounts for nearly **60–70 per cent of the total cost of milk production**, making it the most critical component of dairy management (Kumar *et al*., 2022). India faces a significant deficit in fodder resources, with shortages of about **30–35 per cent green fodder, 10–12 per cent dry fodder, and nearly 35 per cent concentrate feed ingredients** (Singh *et al*., 2023). These shortages directly affect the productivity, health, and reproductive performance of dairy animals. Small and marginal farmers often have limited landholdings and cannot allocate large areas exclusively for fodder cultivation. As a result, they depend largely on crop residues and purchased feed, which may not provide balanced nutrition.

Concept of the Multi-Crop Fodder Model

The **10-cent fodder model**, equivalent to approximately **0.04 hectares**, is a compact and efficient fodder production system designed primarily for smallholder dairy farmers. The model integrates several fodder crops in a planned layout so that different crops mature at different times, thereby ensuring continuous availability of fodder.

In the demonstration, the following fodder crops were included:

- Hybrid Napier grass (*Pennisetum purpureum x Pennisetum glaucum*)
- Fodder sorghum (*Sorghum bicolor*)
- Hedge lucerne (*Desmanthus virgatus*)
- Agathi (*Sesbania grandiflora*)

These crops were selected because of their high biomass production, nutritional value, adaptability to tropical climatic conditions, and complementary growth patterns. Hybrid Napier grass is widely recognized as one of the most productive perennial fodder grasses in tropical regions. It is capable of producing **high green biomass yields ranging from 250 to 350 tonnes per hectare annually under proper management** (Reddy *et al*., 2022). The grass is highly palatable, rich in nutrients, and suitable for multiple harvests throughout the year.

Fodder sorghum is another important fodder crop due to its rapid growth, high biomass production, and tolerance to drought conditions. Multi-cut sorghum varieties allow several harvests within a growing season, providing consistent fodder supply (Kumar and Suresh, 2021). Leguminous fodder crops such as hedge lucerne and Agathi are valuable components of the model because they contain high levels of protein and improve soil fertility through biological

nitrogen fixation. These legumes enhance the overall nutritive value of the fodder system and support better milk production in dairy animals (Sharma *et al*., 2023).

Demonstration Details

The demonstration of the **multi-crop fodder model** was conducted under semi-intensive dairy farming conditions during the year 2025. The programme aimed to evaluate the effectiveness of diversified fodder production in improving dairy productivity and farmer income.

The key details of the demonstration are as follows:

Enterprise: Large animals (dairy cattle)

Thematic area: Nutritional management

Number of villages: 2

Number of farmers involved: 10

To ensure successful adoption of the technology, several extension activities were conducted. These included:

- One farmer training programme on fodder production and feeding management
- Five field visits for monitoring crop growth and providing technical guidance

Farmers were trained on land preparation, planting techniques, crop management, harvesting intervals, and proper feeding of fodder to dairy animals.

Impact on Milk Production and Milk Quality

The performance of the multi-crop fodder model was evaluated by comparing milk production and milk quality parameters before and after adoption of the technology. The results demonstrated significant improvement in dairy productivity.

The average milk yield of dairy animals increased from **8.1 litres per day to 9.4 litres per day** after adopting the multi-crop fodder system. In contrast, animals fed with fodder from a conventional single-crop system showed only a marginal increase from **8.0 litres to 8.2 litres per day**. Overall, the multi-crop fodder model resulted in approximately **12.2 per cent increase in milk yield**. This improvement can be attributed to the availability of balanced and nutritious fodder throughout the year.

In addition to increased milk yield, improvements were also observed in milk quality parameters such as fat and solids-not-fat (SNF) content. The fat percentage increased from **4.1 per cent to 4.6 per cent**, while the SNF content improved from **7.2 per cent to 7.9 per cent**.

These improvements in milk composition indicate better nutritional intake and digestive efficiency in dairy animals. Previous studies have also reported that diversified fodder systems enhance feed intake, nutrient utilization, and milk production in dairy cattle (Patel *et al*., 2024).

Economic Benefits of the Technology

Apart from improving milk production, the multi-crop fodder model also generated higher economic returns for farmers. Economic analysis revealed that the cost of fodder cultivation under the multi-crop system was slightly higher than that of the conventional system due to the inclusion of multiple crops.

However, the increase in milk yield significantly improved overall income.

The economic results are summarized below:

System	Gross Cost (₹)	Gross Income (₹)	Net Return (₹)	B:C Ratio
Multi-crop fodder model	4,300	16,920	12,620	2.93
Single fodder system	3,400	12,177	8,777	2.58

The **benefit-cost ratio of 2.93** obtained from the multi-crop fodder model clearly indicates that the system is economically viable and profitable for dairy farmers. Similar findings have been reported by several researchers who observed that integrated fodder production systems significantly enhance economic returns and reduce feed costs in dairy enterprises (Singh *et al*., 2023).

Advantages of the Multi-Crop Fodder Model

The 10-cent multi-crop fodder model offers numerous advantages, particularly for smallholder farmers with limited land resources.

1. Year-Round Availability of Green Fodder

By integrating different fodder crops with varied harvesting intervals, the model ensures continuous supply of fresh fodder throughout the year.

2. Improved Milk Yield and Quality

Balanced nutrition from diversified fodder crops improves milk production and enhances milk composition.

3. Efficient Use of Small Land Areas

The model enables farmers to produce sufficient fodder within a small land area of only 10 cents.

4. Reduced Feed Cost

Availability of home-grown fodder reduces dependence on purchased feed and concentrates.

5. Improved Soil Fertility

Leguminous fodder crops enrich the soil with nitrogen, improving soil health and sustainability.

6. Climate Resilience

Diversification of fodder crops reduces the risk of crop failure and ensures stable fodder supply even under variable climatic conditions. Such integrated fodder production systems have been recommended as an effective strategy for enhancing livestock productivity in smallholder farming systems (Sharma *et al*., 2023).

Farmers' Feedback

Farmers who participated in the demonstration expressed positive feedback regarding the technology. According to the participating farmers, the multi-crop fodder model ensured consistent availability of green fodder throughout the year. This reduced their dependence on purchased fodder and improved feeding practices. Many farmers also reported improvements in animal health, body condition, and milk production. The observed **12.2 per cent increase in milk yield** encouraged farmers to adopt the technology on a larger scale. The technology was found particularly beneficial for **small and marginal farmers**, as it required only a small land area and minimal additional investment.

Conclusion

The demonstration of the **10-cent multi-crop fodder model** clearly demonstrated its potential to improve dairy productivity and farmer income. By integrating high-yielding fodder crops such as hybrid Napier, fodder sorghum, hedge lucerne, and Agathi, the system ensures continuous supply of nutritious fodder throughout the year. The adoption of this model resulted in **increased milk yield, improved milk quality, and higher economic returns**, making it a sustainable and practical solution for smallholder dairy farmers. Promotion of this technology through farmer training programmes, demonstrations, and extension activities can significantly improve fodder availability and strengthen dairy farming systems in rural areas. Widespread adoption of such innovative fodder production models will contribute to enhancing livestock productivity and improving the livelihoods of farming communities.

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CARBON SEQUESTRATION POTENTIAL OF RAINFED COTTON IN TAMIL NADU

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Abstract

Cotton is one of the important commercial crops and plays and important role in Indian economy. In India, cotton cultivation area was 112.94 lakh hectares (2024-25) and the total production was 294.25 lakh bales (170 kg/bale) with a yield of 448kg/ha. Cotton occupies a prominent position in the textile industry as an important component of textile fibers. Cotton raw material extraction stage is an important source of greenhouse gas (GHG), contributing between 0.3% and 1% to the global warming potential, including material and energy inputs such as fertilizers, herbicides, insecticides, agricultural films, diesel, electricity, packaging materials. Cotton sequesters 2.2 kg of carbon and emits 1.7 kg of green house gas per one kg of fibre. With an extent of 12.5 million hectares cultivation across three cotton-growing regions in India hold significant potential for soil carbon sequestration.

Key words: Carbon sequestration, cotton stalk, rainfed, soil fertility

Introduction

All agricultural crop residues and agro industrial wastes are lingo-cellulosic material but their individual characteristics vary over a wide range. In the present scenario, for conversion of crop residues to useful energy products, selection of crop residue suitable for a specific use or application is extremely important. The biomass left in the field after picking seed cotton is called cotton stalks. On an average about 3 tonnes of stalks per hectare is available through hybrid yield, little more than from *desi* cotton. Cotton stalks are major source of energy and can be used directly through combustion or can be converted to gaseous, liquid, solid fuels which are more convenient to use and efficient through thermo-chemical and biochemical conversion

process in addition to soil incorporation.

Analysis results indicate that land-based carbon removals can be a cost-effective approach to achieve climate mitigation for cotton corporations. The amount of removed carbon can be greatly improved by avoiding emissions from land use change, adopting a higher level of conservation tillage to improve mineral soil carbon sequestration and increasing carbon storage time in products to enlarge the climate benefit of cotton products carbon removals. Based on case study results, the carbon removals potential of global cotton production is estimated to be 5.4 Mt CO2-eq in 2019 and projected to reach 6.2 Mt CO2-eq in 2029, which can mitigate over 0.01% of the GWP caused by the total worldwide anthropogenic emissions. Though this climate mitigation is relatively small, it breaks out the general cognition of agriculture carbon removals and provides us preliminary insight into cotton carbon sequestration capability and it's potential. As a cost-effective approach to achieve climate mitigation, carbon removals from carbon pools of the land, plants and products can promote both environmental and economic development of corporations. The amount of sequestrated carbon by cotton can be greatly improved by the responsible production and consumption of cotton through three main aspects:

i) avoiding the emissions from land use change of forest, grassland and wetland for cotton cropland expansion, especially the forest conversion,
ii) adopting more appropriate land management including reducing tillage intensity and increasing residue inputs to improve the cropland soil carbon stock
iii) increasing carbon storage time in products to enlarge the climate benefit of cotton product carbon removals.

There are multiple measures of achieving carbon removals and they can be generally distinguished into seven categories, including five approaches capturing CO2 by photosynthesis: afforestation and reforestation (AR), soil carbon sequestration (SCS), ocean fertilisation (OF), biochar (BC) and bioenergy with carbon capture and storage (BECCS) and two by chemical processes: enhanced weathering (EW) and direct air capture with carbon capture and storage (DACCS). Among them, storing carbon in land, plants and products is the one contributing to the carbon removals and therefore is the focus of this study. During the growth process, plants capture the CO2 in the air via photosynthesis, releasing oxygen back and storing carbon in the live biomass, dead organic matter and soil through the biogenic carbon cycle (Pérez-Moreno & Read *et al.*, 2001). After harvesting, the carbon is still stored in the products made of harvested

plants until the products decompose or be incinerated (Aalde et al., 2006). Cotton stock has high level of carbon.

The typical cotton stalk production level (yield of biomass residue) is approximately 2 to 3 tonnes per hectare. This amount can vary depending on the cotton species, cultivation practices (such as high-density planting systems) and regional conditions. The quantity of stalks actually collected and available for industrial use is often estimated to be around 2 tonnes per hectare after initial field cleaning (removing leaves, boll rinds, and small branches).A residue-to-crop (stalk-to-fiber) ratio of approximately 5:1 is typical, with specific studies using ratios around 3.96 depending on the harvesting method (e.g., stripper vs. picker machines). In India, an average of 3 tonnes of stalks are generated per hectare of land, leading to an estimated 23 million tonnes generated annually across the country.

Cotton area and productivity in Tamil Nadu

Cotton is cultivated under both rainfed and irrigated condition with the area of 1.73 lakh ha with the production3.02 lakh bales and productivity of 313 kg /ha. Rainfed cotton cultivation is the major practice in Southern Agro climatic zone of Tamil Nadu (Majority in Virudhunagar, Ramanathapuram, Tirunelveli and Tuticorin).

Carbon sequestration potential of cotton

According to a preliminary research conducted by Cotton Incorporated (2009), more carbon is stored in soil and cotton product than the equivalent carbon contained in the GHG emissions during material production, showing promising carbon sequestration potential of cotton.

Carbon sequestration level

During growth, cotton synthesizes water and CO_2 into biomass through photosynthesis and immobilizes them within the plant. Excluding the biomass consumed by the respiration process of cotton itself, the remaining biomass will be allocated to the main product seed cotton and by-product cotton stalk during the cotton cultivation-harvesting stage, representing carbon sequestration by seed cotton and carbon sequestration by cotton stalk (Chen *et al.,* 2024). The carbon stored in cotton stalk exhibits varying carbon sequestration effects and carbon footprint values with the application of different treatment methods to cotton stalk.

A study by (Hedayati *et al.,* 2019) focuses on the farm-level analysis and calculates the GHG emissions of 1 ton of cotton lint to develop emission reduction strategies. The results

indicated that replacing conventional cotton with organic cotton can reduce GHG emissions by 58% during the planting stage. Researchers pointed out two carbon sequestration methods during the cotton planting stage: soil carbon sequestration and cotton plant carbon sequestration. Li (2020) conducted a CF accounting study on cotton lint, which found that during the raw material extraction stage, cotton plants sequester more carbon than they emit, indicating a carbon sequestration effect.

Soil Carbon Sequestration

Carbon sequestration encompasses soil organic carbon (SOC) and inorganic carbon sequestrations (SIC), both plays pivotal role in mitigating climate change and determining agro-ecosystem functions. SOC and SIC involve the storage of carbon in various forms through distinct processes. In cotton-growing areas, the annual availability of stalks ranging from 3-5 Mg/ha contributes to 4-6 g/kg of soil organic carbon concentration upon incorporation. While organic carbon (OC) is essential (0.3 m soil depth), there is also an inorganic carbon (IC) component in soils (0.3-1.0 m soil depth), especially relevant to rainfed cotton growing areas. IC is considered as a potential carbon sink for rainfed cotton growing areas (>63%).

SIC significantly influences the soil fertility, water retention, crop production and provides contributions in ecosystem services like provisioning, regulating, cultural and supporting categories. However, irrigation in conjunction with inputs of nitrogen and sulfur fertilizers can destabilize inorganic C, releasing CO2 through carbonate precipitation but not happened under rainfed condition. Cotton stalks have a carbon content of approximately 40-47% by dry weight. When managed correctly, they have significant potential for carbon sequestration, particularly when incorporated into the soil. The residue to product ratio of cotton is from 1.4 to 3.4, which means that around 1.4–3.4 kg cotton stalks and branches are generated per kg seed cotton production (Lal, 2005; FAO, 2013; Venkatramanan *et al.*, 2021).

Carbon Sequestration Potential

- **Direct soil incorporation:** Incorporating cotton stalks into the soil can contribute to soil organic carbon (SOC) retention and enrichment, with studies showing an increase in SOC content in the range of 4-6 g/kg.
- **Biochar production:** Converting cotton stalks into biochar is highly effective for long-term carbon sequestration due to biochar's stable carbon structure. This process can store

roughly 53% of the initial carbon in a stable form and can amount to direct negative emissions of around 2.42 tons 2CO2 per hectare per year.

- **Porous carbon material:** Cotton stalks can be processed into porous carbon materials that exhibit excellent CO2 adsorption capacities, which can be used for industrial carbon capture application

Among three methods, direct soil incorporation can be practiced by the farmers with minimum technical support.

Calculation of carbon level

The general formula to calculate the amount of CO2 sequestered in cotton stalks involves determining the total biomass and its carbon content.

- **Total Biomass Calculation**: First, calculate the total dry weight of the cotton stalks per unit area (e.g., kg/ha). This typically involves field measurements and the use of allometric equations or harvest index data.
- **Carbon Content Estimation**: Assume that approximately **50% of the dry biomass weight is organic carbon** (C).
    - Total Carbon (TC) = Total Dry Weight (TDW) * 0.5.

  CO2 Equivalent Conversion: Convert the mass of carbon to the mass of carbon dioxide (CO2) equivalent using the ratio of the molecular weights of $CO2$ (44) to C (12), which is approximately **3.67**.
    - Total CO_2 Sequestered = TC * 44/12 or TC * 3.67.

Final Formula:

CO_2 Sequestered (kg) = Total Dry Weight of Cotton Stalks (kg) * 0.5 * 3.67

The carbon is considered sequestered when the biomass is returned to the soil by the process of incorporation, increasing soil organic carbon content. Land management activities play an important role in influencing the steady-state soil carbon stock. Tillage and residue inputs are the two practices considered in the quantification equation of soil carbon stock change (Aalde *et al.*, 2014). Based on IPCC classifications, there are three levels of tillage: full-tills, reduced-till and no-till and three levels of residue input: low, medium and high.

Cultivation of cotton under conventional method, the full-till level tillage system is applied, and most of the cotton residue is burnt or removed from the field for avoiding leaving pests like bollworm.

Carbon sequestration at Global potential

Estimation results show that there is 5.4 million tonnes (Mt) CO2-eq reduced GWP in 2019 and projected to increase by 5% and reach 5.7 Mt CO2-eq in 2024 and increase by 14% and reach 6.2 Mt CO2-eq in 2029. In addition, as shown in the scenario analysis results, the cotton carbon sequestration capability can be doubled if applying no-tillage and high residue with manure land management practices and higher increase can be achieved by extending the material lifetime of cotton. Thus, global cotton production has the capability to mitigate more than 0.01% of the GWP caused by total anthropogenic emissions. Though the offset is relatively small, any action towards climate mitigation is valuable.

Interventions needed under rainfed farming

1. Awareness on cultivation and cotton stalk incorporations
2. Promotion of HDPS under rainfed condition
3. Promotion of Organic cotton
4. Promotion of rice follow cotton under no tillage method of cultivation
5. Promotion of residue incorporation and practising mineralization of cotton stalk
5. Estimation of SOC at every season
6. Documentation of carbon level in soil and atmosphere
7. Making partnership with farmers on benefit.

Convergence and support needed

1 Technical knowhow on cultivation and residue incorporation by the SAU

2 Provides machinery supports for the cultivation and residue incorporation by the department of agricultural engineering and department of agriculture and farmers welfare.

3 Supports for the enrichment, estimation of SOC and atmospheric CO2 level by the SAU

4 Involving agencies on carbon trading with public private partnership.

Conclusion

Rainfed cotton cultivation tends to deplete soil organic carbon and reduce soil fertility due to the crop's exhaustive nature. Promoting practices that conserve and retain crop residues can enhance soil organic carbon levels, thereby sustaining soil fertility and long-term productivity. Adopting such carbon sequestration practices through a public–private partnership approach can further support sustainability and the successful implementation of climate-resilient agricultural systems

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EDIBLE OIL ECONOMY OF INDIA – NATIONAL MISSION ON EDIBLE OIL AND OIL PALM (NMOOP) –FERTURES - SIGNIFICANCE

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Abstract

The main occupation of rural Indians is agriculture. About 30per cent of the national income originates from the agriculture sector. In 1970, to meet out the domestic consumption of the edible oil in that period the government has started cooperative industries like amul. They started a operation golden play under the amul. To meet out the demand and promote domestic production custom duty is increased from 5.5 – 27.5 %. NMOOP has been launched with the aim to enhance the edible oilseeds production and oils availability in the country by harnessing Oil Palm area expansion, increasing crop production and to reduce import burden on edible oils. Andhra Pradesh, Telangana and Kerala are the major Oil palm growing States . To increase in Crude Palm Oil production from 28 lakh tonnes by 2028-29. It is a Centrally Sponsored Scheme . Mini Mission being implemented in the state level. The State Government would involve the officials of various line Department /Ministry and stake holders. Financial assistance are being provided to the farmers @ 85% cost of the planting material and 50% cost of the other components like maintenance cost of new plantations for four years. Inputs for inter-cropping in oil palm during gestation period one of the mainly focused on the financial assistance among the all some. Here some of the crop financial assistance. FFBs of oil palm is a perishable item and Harvesting of FFBs need special tools machinery and skilled labour. The modern tools available are costly. NMOOP aims to make India a leader in the global edible oil market. Through this measure import will decrease and to promote the farmers for cultivation. With a focused approach on research, technology, and sustainability, this mission has the potential to transform

India's edible oil landscape, ensuring food security, economic growth, and a healthier future for generations to come.

key words: Oil palm, Edible oils, NMOOP, Tools , Funds, FFB.

Introduction

The main occupation of rural Indians is agriculture. About 30per cent of the national income originates from the agriculture sector. About 75 per cent of its population and 66.67 per cent of the labour force directly or indirectly is dependent on agriculture for livelihood. A large number of important industries like jute, textiles, edible oils, tobacco, sugar, etc. receive the raw materials produced by agriculture sectors. Country needs 25 million tons of edible oils to meet its requirement at current consumption level of 19 kg per person per year. Out of the total requirement, 10.50 million tones is produced domestically from primary (Soybean, Rape, Mustard, Groundnut, Sunflower, Safflower and Niger) and secondary sources (Oil palm, Coconut, Rice Bran, Cotton seeds & Tree Borne Oilseeds) and remaining 60 per cent, is met through import. The oilseed production of the country has been growing impressively. The major challenges in oilseed production is largely rain-fed conditions (70% area), high seed cost (Groundnut and Soybean), small holding with limited resources, low seed replacement rate and low productivity.

Edible oil economy of India

The diverse agro-ecological conditions in the country are favourable for growing 9 annual oilseed crops, which include 7 edible oilseeds (groundnut, rapeseed & mustard, soybean, sunflower, sesame, safflower and niger) and two non-edible oilseeds (castor and linseed). Oilseeds cultivation is undertaken across the country in about 27 million hectares mainly on marginal lands, of which 72% is confined to rainfed farming. During the last few years, the domestic consumption of edible oils has increased substantially and has touched the level of 18.90 million tonnes in 2011-12 and is likely to increase further. With per capita consumption of vegetable oils at the rate of 16 kg/year/person for a projected population of 1276 million, the total vegetable oils demand is likely to touch 20.4 million tonnes by 2017. A substantial portion of our requirement of edible oil is met through import of palm oil from Indonesia and Malaysia. At present private companies are importing edible oil in large quantity.. Oil Palm is comparatively a new crop in India and is the highest vegetable oil yielding perennial crop. With

quality planting materials, irrigation and proper management, there is potential of achieving 20-30 MT Fresh Fruit Bunches (FFBs) per ha after attaining the age of 5 years.

Current status

In 1970, to meet out the domestic consumption of the edible in that period the government has started cooperative industries like amul. They started a operation golden play under the amul . To meet out the demand and promote domestic production custom duty is increased from 5.5 – 27.5 %. This result in the reducing in the import of the edible oil. It is, therefore, necessary to exploit domestic resources to maximize production to ensure edible oil security for the country. India is dependent on imports to meet its edible oil requirements and is the largest importer of edible oils in the world. During 2020-21, India imported around 133.52 lakh tonnes of edible oils costing around ₹ 80,000 crore. Out of all the imported edible oils, the share of palm oil is about 56%, followed by soybean oil at 27%, and sunflower at 16%. Domestic edible oil production has not been able to keep pace with the growth in consumption which is above 25 million tonnes. The per capita consumption which was 15.8 kg per person per annum in 2012-13 has increased to around 19.00 kg at present. During 2020-21, the domestic production of edible oils was 122.89 lakh tonnes.

Year	Domestic availability	Imports of edible oils	Total availability/ consumption	%self sufficiency	%share of import	Per captia availability of edibile oil (kg/yr)
2015-16	86.30	148.50	234.80	36.8	63.2	19.10
2016-17	100.99	153.17	254.16	60.3	60.3	18.75
2017-18	103.80	154.00	249.72	58.4	58.4	19.30
2018-19	103.52	144.56	259.22	60.0	60.0	18.26
2019-20	106.00	133.52	250.56	57.7	57.7	18.76
2020-21	122.89	150.00	256.41	52.07	52.07	18.25

Area and oil palm growing states

A total area of around 28 lakh hectares fit for oil palm cultivation in India. Out of the total 27.99 lakh ha potential area, an area of 18.37 lakh is in the general states, and 9.62 lakh in the NE States. Presently in the North East the coverage is around 38,992 hectares against the potential of 9.62 lakh hectares, leaving much scope for expansion.

Andhra Pradesh	240016 Mt
Telangana	39347 Mt
Kerala	4281 Mt

During 2020-21, the production of CPO was around 2.72 lakh tonnes, obtained from 1.87 lakh hectares of fruiting area. Andhra Pradesh, Telangana and Kerala are the major Oil palm growing States and account for 98% of the total production. Karnataka , Tamil Nadu, Odisha, Gujarat and Mizoram also have a sizable area under Oil palm cultivation. Recently Arunachal Pradesh, Assam, Manipur and Nagaland have also initiated Oil palm plantation programmes. Oil palm cultivation takes place in the States based on a catchment area allocated by the State Government to the Oil palm processors/industry

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leading area	Andhra Pradesh [1.62 lakh ha]
leading production	Andhra Pradesh [300,0000 lakh ha]
leading productivity	Andhra Pradesh [19.81 lakh ha]

The prices for FFBs are either governed through the Oil Palm Acts of the State Governments, or through Regulations and Orders. The reasons behind the slow pace of development of oil palm in India are manifold, the most significant being the lack of assured price for the FFBs for the oil palm farmers and the uncertainty in the payment of price of FFBs since it is linked to the landed CPO price which is prone to major fluctuations in the payment. Further, there was no support from the Government of India for the FFB price to the farmer.

National mission on edible oils- oil palm (NMOOP)

Considering the growing domestic demand for edible oils, the staggering deficiency and the cost to the exchequer on account of imports, the urgency of scaling up the oil palm area is of national interest and does not need any over emphasis. Therefore, to fulfil the national interest, National Mission on Edible Oils - Oil Palm (NMOOP) has been launched with the aim to enhance the edible oilseeds production and oils availability in the country by harnessing Oil Palm area expansion, increasing CPO production and to reduce import burden on edible oils. The State Department of Agriculture, State Department of Horticulture, Central University, ICAR Institutions, CDDs, SAUs, KVKs, Central Agencies/Cooperatives, Oil palm processors/ Associations, DD Kisan etc will be the implementing stake holders of the NMEO-Oil palm.

Area of operation

NMEOOP will be implemented in the various States as per recommendation of IIOPR Report or State recommendation. NMOOP headed by Hon'ble Agriculture Minister would be empowered for inclusion of additional potential States/districts with consultation of ICAR/ IIOPR in addition to t h e identified areas as per t h e Report of IIOPR, 2020.Potential states and districts are of Andhra Pradesh, Chhattisgarh, Goa, Gujarat, Maharashtra, Madhya Pradesh, Mizoram, Karnataka, Kerala, Odisha, Tamil Nadu, Telangana, Arunachal Pradesh, Assam, Bihar, Manipur, Meghalaya, Nagaland, Tripura, Uttar Pradesh, West Bengal and Andaman & Nicobar islands.

Target of NMOOP

Around 9 million tonnes of palm oil is imported every year which is around 56 % of the total imports of edible oil. To increase area of oil palm to 10 lakh hectares from 3.5 lakh ha during 2019-20 by 2025-26 (additional 6.50 lakh ha). The target for general states is 3.22 lakh hectares and 3.28 lakh ha for North Eastern states, with targeted FFB production of 66.00 lakh tonnes. To increase in Crude Palm Oil production from 0.27 lakh tonnes during 2019-20 to 11.20lakh tonnes by 2025-26 and 28 lakh tonnes by 2028-29. Increase consumer awareness to maintain consumption level of 19.00 kg/person/annum till 2025-26. The state wise area expansion target for General and NE states.

Mini mission

Mini Mission being implemented in the state level. The State Government would involve the officials of various line Department /Ministry and stake holders. This comprising of three (03) Mini Missions (MM), Oilseeds (MM-I), Oil palm (MM-II) and Tree Borne Oilseeds (MM-III) was launched in April, 2014. Mini Mission I (Oilseeds): The goal of this mission is to increase the production of oilseeds to 35.51 million tones. Mini Mission II (Oil Palm): This mission aims to increase the area under oil palm cultivation and increase the production of Fresh Fruit Bunches (FFBs).Mini Mission III (Tree-borne Oilseeds):The goal of this mission is to increase the collection of seeds from tree-borne oilseeds to 14 lakh tones.

Factors

The difficulties raising labour productivity in the sector, largely the result of the difficulties in mechanising harvesting operations. Functional obstacles to use in cooler climate climates. India imported 16.5 million tones (MT) of edible oils, with domestic production

fulfilling only 40-45% of the country's requirements. The country's goal of achieving self-sufficiency in edible oils. India is dependent on imports to meet its edible oil requirements and is the largest importer of edible oils in the world. The oil palm is a water-guzzling, monoculture crop with a long gestation period unsuitable for small farmers and the land productivity for palm oil is higher than for oilseeds, which create apprehension for more land to be given for oil palm cultivation. In southeast Asia, the plantation of palm oil trees has replaced massive tracts of rainforests. The palm is an invasive species that is not a natural forest product of north eastern India and its impact on the biodiversity. This spread and interfere in a new ecosystem by posing a serious threat to the native biodiversity. They don't allow local species to grow and wildlife to move through. Focus areas are biodiversity hotspots and ecologically fragile and oil palm plantations would denude forest cover and destroy the habitat of endangered wildlife.

Funding pattern

NMEO-OP is a Centrally Sponsored Scheme and the cost will be shared as 60:40 between the Central and the State Government for General states and 90:10 for NE states and 100% for UTs and for central agencies. As per ICAR-IIOPR Report 2020, oil palm can be cultivated in 20 states covering 284 districts. All the potential states and districts identified by ICAR- IIOPR will be under NMEO-OP including NE states and Andaman and Nicobar Islands. Further, if States identify other districts suitable for cultivation, they will also be considered.

Financial assistance

Financial assistance are being provided to the farmers @ 85% cost of the planting material (Rs. 12000/-per ha) and @ 50% cost of the other components like maintenance cost of new plantations for four years (Rs. 20000/- per ha). Installation of drip - irrigation systems, diesel/electric pump-sets, bore-well (Rs. 50000/- per unit). water harvesting structures/ponds, construction of vermicompost units and purchasing of machinery & tools etc. Inputs for inter-cropping in oil palm during gestation period one of the mainly focused on the financial assistance among the all some.

CROP	ASSISTANCE (Rs./ha)
GROUNDNUT	7500
SOYBEAN	4500
SUNFLOWER	4000
SESAME/SAFLOWER/ CASTOR	3000

Machinery/ harvesting tools

FFBs of oil palm is a perishable item and Harvesting of FFBs need special tools , machinery and skilled labour. The modern tools available are costly. Therefore, the assistance for harvesting tools like cutter, wire mesh, motorized chisel, portable ladder/poles, chaff cutter, tractor & trolley etc have been revised. Items included in SMAM are also eligible for assistance. The States may also support Farmer's Association / NGOs/Self Help Groups/Farmers Groups/ Women Groups/Cooperative Societies/FPOs for this component under AAP. Support will be provided for equipments /tools up to 50% of the cost and/or up to the amount, for equipments /tools:

(i) Manually handled/high reach oil palm cutter – ₹25,000 per unit.

(ii) Oil Palm protective wire mesh- ₹20,000 per unit.

(iii) Motorized Chisel – ₹15,000 per unit.

(iv) Aluminium Portable ladder – ₹5,000 per unit.

(v) Chaff cutter for chaffing of oil palm leaves– ₹50,000 per unit.

(vi) Tractor up to 20 HP with trolley as per SMAM guidelines and other machinery recommended by ICAR/SAUs, which is useful to the oil palm growers could be included under local initiatives covered under flexi fund.

(vii) Import of machinery: mechanical sprayer for young oil palm fields, mechanical oil palm harvesting machine, compact FFBs transporter/sprayers etc.

Oil palm processing mills in India

FFBs are highly perishable in nature and therefore, require crushing within 24 hrs of harvesting. Therefore, creation of processing units is a pre-requisite for under taking area expansion of oil palm. In order to provide a complete package for oil palm development, new mills will be setup in NE states @ 50% of the cost limited to Rs. 500.00 lakhs for a FFB processing unit of 5 MT/hr for newly planted oil palm area. The assistance will be given to processors, Cooperatives, Federations, Government recognised farmer associations, state Government Agencies through State Government. The assistance on sett up of FFBs processing unit will increase, proportionately for additional capacity of processing/hours. The land for mills will be provided by the State Government to the processor on lease/rent/purchase basis. Provision of assistance for Oil palm Processing Mills is confined to NE States/UTs only.

Case study

National Mission on Oilseed and Oil palm (NMOOP) for oilseeds & oil palm development program in India was started in July 2014. The present study was conducted in the Bikane district of Rajasthan. Bikaner district has been selected purposely because of Bikaner district has highest production of oilseeds (472026 tones) among all districts of the state. Further, two panchayat samities namely Lunkaransar and Khajuwala were selected based on highest area and production of these crops and NMOOP scheme was also operated in these panchayat samities. Two villages from each selected panchayat samities were selected randomly where NMOOP activities have been in operations in the year 2014-15. From each village 20 beneficiaries and the equal number of non-beneficiary farmers were selected randomly. The findings revealed that majority of beneficiary and non-beneficiary farmers belonged to medium adoption category. It was found that there was a significant difference in level of adoption between beneficiary and non-beneficiary farmers about recommended interventions of mustard crop.

Conclusion

To promote the domestic oil production and to avoid the import of the edibile oil .The National Mission on Edible Oils is a vital initiative towards achieving self-sufficiency in edible oil production, reducing dependence on imports, and enhancing the livelihoods of farmers. By promoting oilseed cultivation, improving productivity, encouraging domestic processing, NMOOP aims to make India a leader in the global edible oil market. With a focused approach on research, technology, and sustainability, this mission has the potential to transform India's edible oil landscape, ensuring food security, economic growth, and a healthier future for generations to come. Let us pledge to support and contribute to the success of this mission and increase the country edible oil economy.

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BETTER BIOSTIMULANTS: NEW WAYS TO PROTECT GOOD SOIL MICROBES

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Abstract

Soil health is fundamentally driven by the activity of beneficial microorganisms that regulate nutrient cycling, organic matter decomposition, and plant growth. However, modern agricultural practices have increasingly threatened these vital microbial communities. Biostimulants have emerged as a sustainable and innovative approach to restore and protect soil microbial life while enhancing crop productivity. This article explores the role of next-generation biostimulants including microbial consortia, seaweed extracts, and humic substances in supporting beneficial soil microbes.

Introduction: The Invisible Workforce Beneath Our Feet

Soil is not just a medium for plant growth it is a living ecosystem teeming with billions of microorganisms. These beneficial microbes, including bacteria, fungi, and actinomycetes, play a crucial role in nutrient cycling, organic matter decomposition, and plant health. However, modern agricultural practices such as excessive chemical fertilizer use, pesticide application, and intensive tillage have significantly disrupted this delicate microbial balance.

Figure. 1 Healthy soil concept

In recent years, biostimulants have emerged as a sustainable solution to enhance soil health while protecting beneficial microbial communities. Unlike fertilizers, biostimulants do not directly supply nutrients but stimulate natural processes that improve nutrient uptake, plant growth, and microbial activity.

2. What Are Biostimulants?

Biostimulants are natural or derived substances that enhance plant growth and soil biological activity. They work by stimulating physiological and biochemical processes in plants and soil microbes.

Common Types of Biostimulants:

- ✓ Seaweed extracts (e.g., Ascophyllum nodosum)
- ✓ Humic and fulvic acids
- ✓ Protein hydrolysates and amino acids
- ✓ Microbial inoculants (e.g., PGPR, mycorrhizae)
- ✓ Compost and vermicompost extracts

These substances improve root development, nutrient efficiency, stress tolerance, and microbial diversity in soils.

3. Importance of Protecting Beneficial Soil Microbes

Beneficial microbes are essential for maintaining soil fertility and ecosystem stability.

Key Functions:

- Nutrient Solubilization: Convert unavailable nutrients (Zn, P, Fe) into plant-available forms
- Organic Matter Decomposition: Break down residues into humus
- Disease Suppression: Compete with harmful pathogens
- Soil Structure Formation: Improve aggregation and porosity
- When these microbes are harmed, soil productivity declines, and dependence
- on chemical inputs increases.

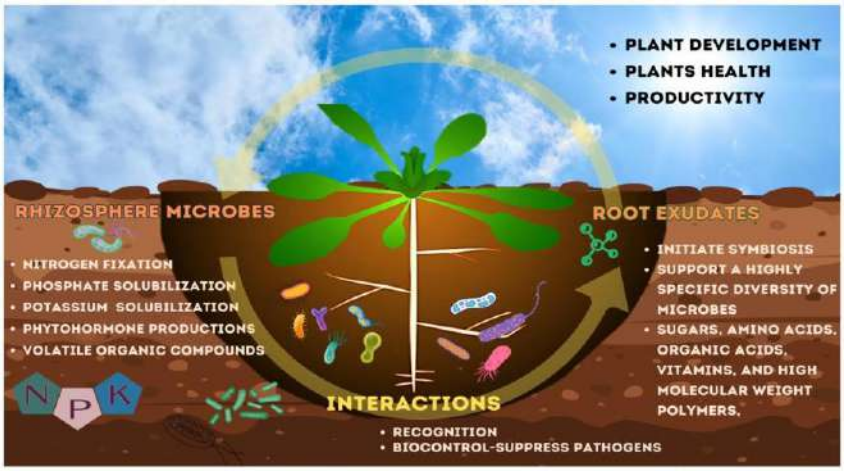


Figure. 2 Bio-stimulants and Microbial Interaction

4. Threats to Soil Microbial Health

Several agricultural practices negatively affect microbial populations:

- Overuse of chemical fertilizers
- Excessive pesticide application
- Soil compaction and erosion
- Monocropping and lack of crop diversity
- Climate change and drought stress

These factors reduce microbial diversity and disrupt ecological balance in soil systems.

5. New-Generation Biostimulants: Protecting Microbial Life

Recent advances in agricultural science have led to the development of next-generation biostimulants that not only promote plant growth but also actively protect and enhance beneficial microbes.

a) Microbial Consortia-Based Biostimulants

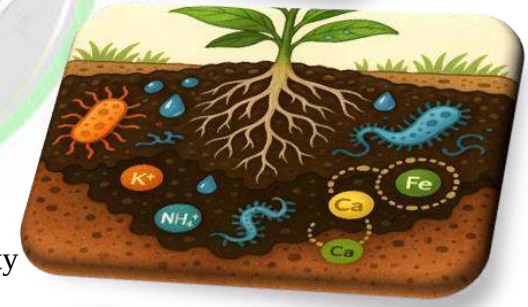
Instead of single strains, modern formulations use multi-strain consortia (e.g., ZSB + PSB + PGPR). These provide:

- Synergistic nutrient solubilization
- Better survival and adaptability
- Enhanced soil resilience

b) Seaweed-Based Biostimulants

- Seaweed extracts are rich in:
- Natural hormones (auxins, cytokinins)
- Polysaccharides and antioxidants
- They improve microbial activity by:
- Acting as carbon sources
- Enhancing microbial enzyme production

c) Humic Substances as Natural Chelators



- Humic and fulvic acids:
- Protect microbes by buffering soil conditions
- Form chelates with micronutrients
- Improve microbial habitat and nutrient availability

d) Nano-Biostimulants (Emerging Technology)

- Nano-formulations:
- Deliver nutrients efficiently
- Reduce toxicity
- Enhance microbial compatibility
- Though still under research, they show promise for future agriculture.

6. Mechanisms: How Biostimulants Protect Microbes

Biostimulants support microbial communities through several mechanisms:

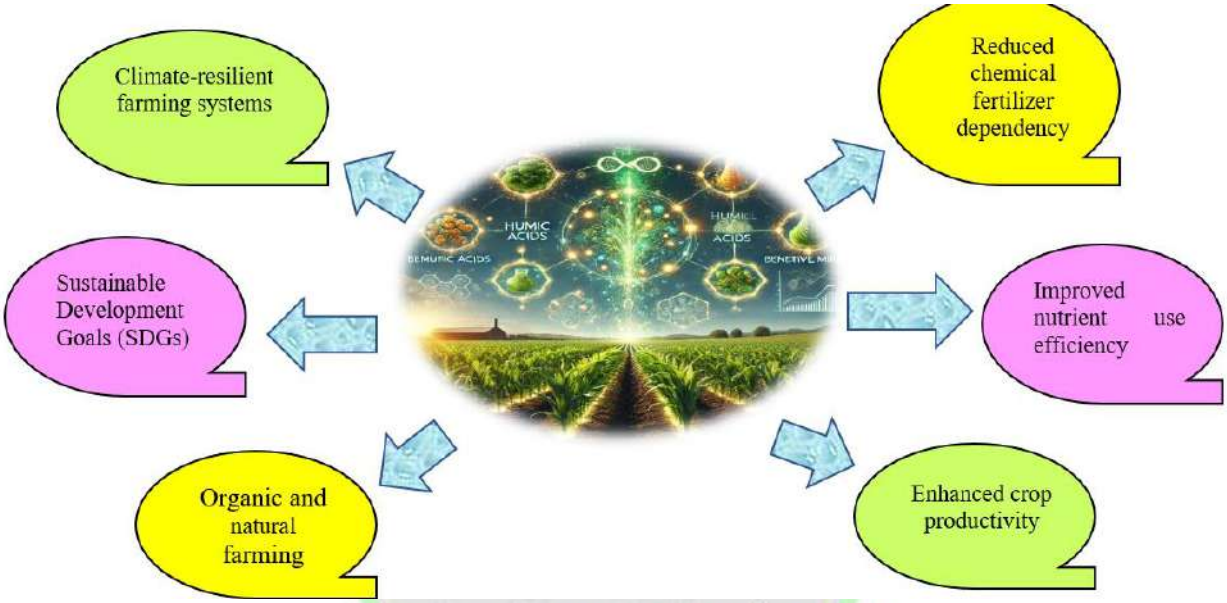
- ✓ Providing carbon substrates for microbial growth

- ✓ Improving soil structure and aeration
- ✓ Reducing chemical stress by lowering toxicity
- ✓ Enhancing root exudation, which feeds microbes
- ✓ Stimulating enzyme activities involved in nutrient cycling

These interactions create a positive feedback loop between plants, microbes, and soil.

7. Role in Sustainable Agriculture

Biostimulants are key to achieving



8. Practical Applications for Farmers

- ➢ Recommended Practices:
- ➢ Use integrated biostimulant approaches (organic + microbial)
- ➢ Apply vermicompost extracts or seaweed sprays
- ➢ Introduce bioinoculants like ZSB, PSB
- ➢ Avoid excessive chemical inputs
- ➢ Maintain soil moisture and organic matter

Benefits:

- ➢ Better crop growth and yield
- ➢ Improved soil fertility
- ➢ Reduced input costs
- ➢ Long-term sustainability

9. Future Perspectives

- The future of biostimulants lies in:
- Precision agriculture integration
- AI-based soil health monitoring
- Customized microbial formulations
- Climate-resilient biostimulant products

Research is focusing on understanding soil microbiomes and designing targeted solutions for different agroecosystems.

Conclusion

Biostimulants represent a transformative approach in modern agriculture by bridging the gap between productivity and sustainability. Protecting beneficial soil microbes is essential for maintaining soil health, and next-generation biostimulants provide an effective tool to achieve this goal. By adopting these innovative solutions, farmers can ensure long-term soil fertility, improved crop performance, and environmental sustainability.

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PERIWINKLE to PROFIT: THE FARMER'S GUIDE TO SUCCESS

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Introduction

The Vellore district comes under Semi-arid tropical condition with hot summers where most of the farmers grow crops like Paddy, Groundnut, Millets (sorghum, pearl millet, ragi, maize), pulses, sugarcane, and some fruits and vegetable crops which requires more water. This entire farming relies on either monsoon rain, which often leads to scarcity when the monsoon fails to occur or Groundwater for irrigation even though it is not fit for irrigation and the availability of groundwater is reducing day by day. The soil is also poor in nature where it contains less (fertile) organic carbon and nitrogen. Under this existing condition the productivity of the farms in and around Vellore is also very less

So, the best alternative is the farmers can switch to medicinal plant cultivation which doesn't require much care, water, fertilizers, and other cultural operations like other cereals and pulse crops that are grown. Medicinal plants are the plants which contains chemical components and secondary metabolites like phenol, flavonoids, alkaloids, which are uses to cure illness. Plant parts such as leaves, roots, bark, seeds, flowers, fruits and some other parts of the plant can be used. These Medicinal plants can be grown in medium to poor soil with less water requirement. The need for these medicinal plants increases day by day because most of them were switching to this homeopathy over allopathic medicine.

Recently WHO estimated that 80% of world population rely on herbal medicines for their primary health care. The treatments through these natural herbs are considered to be safer than these drugs because there is no side effect. Since The India has richest source of traditional system of medicine and is a larges producer and exporter of medicinal plants, plant drugs, and value-added products, these medicinal plants have more export value in the global trades. So, there is a huge demand for these medicinal plants in India and other countries. Value addition and little processing by the farmers can increases its value.

This increases the revenue of the farm and profit of the farmer. The plants such as Aloe vera, Asparagus, Periwinkle, Ashwagandha, Ginger, Tulsi etc., So, farmers can utilize these resources and make a profit out of it.

One such plant is Periwinkle (*Catharanthus roseus*), Cutukattumalli or Nityakalyani - vernacular name, Apocynaceae family which can be grown, processed, and can be exported. It has a great demand in the global trades because it contains the alkaloids such as **Vinblastine** and **Vincristine** which has Anti-cancer property. Root, stem, and leaves of these plants are used for the alkaloid extraction.

This is used to treat leukaemia, Hodgkin's lymphoma, breast cancer, high blood pressure, diabetes, and other microbial infection. These plants are hardy as they are grown in poor conditions because it has high drought-tolerant capacity, well grown in wide range of climate condition. It is less susceptible to pest and disease due to presence of these alkaloids.

CULTIVATION ASPECTS OF PERIWINKLE

There are three types of plants: Nirmal (white flowered plant released by CIMAP), Purple flowering (Fig 1), and White flowering plant (Fig 2).

Fig 1: *Catharanthus roseus* var. *roseus* (Purple flowering plant)

Fig 2: *Catharanthus roseus* var. *alba* (White flowering plant)

- **Varieties:** Nirmal and Dhawal are the varieties of white flower plant released by CIMAP. Arka Pahit and Arka Nidhi developed by IIHR.
- **Soil and Climate:** It is suitable for all type of soils except alkaline and water logging. Soil should be well drained and the pH ranges from 6 - 7.5. Deep sandy soil or loam soil with medium fertility is enough for large scale production. It can be grown under rainfed condition or annual rainfall more than or equal to 100cm.
- **Propagation:** It can be propagated either by seeds or by stem cuttings. Now a days it is also propagated through micropropagation but seeds are widely used.
- **Seed Rate:** Direct Sowing - 2.5 tO 5 Kg/ha and Transplanting – 0.5 Kg/ha. For direct seeding seeds has to be mixed with the sand for even distribution.
- **Time Of Sowing:** It is usually done at June - July or September – October.
- **Land Preparation:** land is deeply ploughed to attain fine tilth; this ensures good water infiltration and aeration in the root zone. The FYM is added at the last plough which improves the physical structure and water holding capacity of the soil.
- **Sowing:** Seed are sown in the nursery bed and are transplanted after 4 – 6 weeks with 4 – 6 leaves.
- **Stem Cuttings:** Cuttings of 15 – 20 cm is used with nodes; this ensures the parental character.
- **Spacing:** 60 x 45 for transplanting and 45 x 20 cm is ideal for direct planting.
- **Manures And Fertilizers:** Apply 20 t FYM per hectare during last plough, basal dose of N, P and K at 25:50:75 Kg/ha is added and the top dressing is done with 50 kg of N at 60

DAT. More application of artificial fertilizers will reduce the quality of alkaloid present in the plant.

- **Irrigation:** As it is a hardy crop, it doesn't require much water. Optimum moisture has to be maintained. This can be planned based on the soil type and other climatic parameters. Water stagnation has to be avoided because it affects the plant growth, attract diseases and reduce the alkaloid content. Frequent light irrigation is sufficient.
- **Weeding:** Done 2 times,1st 90 DAS or DAT followed by 60 days after 1st weeding.
- **Pest and Disease:** Less pest and disease incident because of presence of these alkaloids. Some common issues are root rot, root-knot nematode, leaf minor and leaf spot. This can be eliminated through IPM (Integrated pest management).
- **Topping:** Topping of 2cm at 50% flowering will improve the root volume and the alkaloid content of the plant.
- **Harvest:** Leaves and Roots are harvested. Roots, leaves and flowers are harvested at different stages. The critical time for harvesting is at flowering stage. Leaves can be harvested at two times 1st at 6 months and 2nd at 9 months after planting (only mature leaves). Roots are harvested after one year. The roots are taken and the stem portion is replanted. Once the harvesting is done, these materials are shade dried to bring down its moisture content to 10%. Should be handled properly because to maintain its alkaloid content. Proper drying is essential to avoid fungal growth. Grading is done based on the colour, aroma, and size. It is packed in the Airtight containers.

➢ **Yield:**

YIELD	IRRIGATED (Kg/ha)	RAINFED Kg/ha)
Root	1500	750
Stem	1500	1000
Leaves	3000	20000

The alkaloid content in leaf is 0.15 to 1.34%, vinblastine is 0.002% and vincristine 0.005%.

PROCESSING AND VALUE ADDITION

As the plants contains various Alkaloids such as vinblastine, vincristine, vindesine, vinorelbine and cathachunine which has anti-cancer properties. Ajmalicine, serpentine, vindoline, vindolicine and vincamine are also present in this plants which are known for its Anti-

hypertensive properties. These plant act as a best alternative for the modern drugs and have a great demand in pharmaceutical industries. This also plays a major role in the homeopathic medicines. Using organic solvents, the alkaloids are separated from the plant materials.

Essential oils are also extracted from these plants by various distillation process. Among which steam distillation is the effective method. These are used for skin care, oral health, wound healing properties.

- Catharanthus roseus Dhawal essential oil contains Tricosane - 37.9% and Heneicosane - 20.8%.
- Catharanthus roseus Nirmal essential oil contains Tricosane – 38.0% and Heneicosane - 21.0%.

This can be value added by converting it into a dried power and consume it as an herbal tea, drinks, some innovative food products and other cosmetic purposes. Farmers should adopt effective marketing strategies such as branding, proper packing and exporting can improve the farm revenue.

Conclusion

In Vellore condition, the best alternative for this conventional cultivation is medicinal plant cultivation. Proper cultural practices and the post- harvest cares of periwinkle improve the productivity of the land and generates good revenue to the farmers. If processing and value additon are done it enhance the efficiency of the farm and boost ups the profit to the farmer. So, this will be the best alternative for the farmers who how faces lose in conventional farming and the farmers who holds less hectares or acres of land.

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MICROENCAPSULATION IN FOOD NUTRIENTS PRESERVATION

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Abstract

In the Food Industry, microencapsulation is an effective process for creating a functional barrier that protects highly sensitive bioactive compounds within microcapsules, thereby increasing their bioavailability. Spray drying is a common method used to protect active ingredients such as vitamins, oils, fragrances, and probiotics. The microencapsulation process provides many benefits and functionalities, such as handling of sensitive bioactive compounds, solubility enhancement, thermal stability, protection against environmental degradation, controlled-release behavior, and prevention of unpalatable tastes and odors.

Introduction

Microencapsulation is a technique in which encapsulating agents trap very small quantities of functional or bioactive compounds within protective capsules. The materials used for this encapsulation, termed encapsulants or wall materials, create a shielding layer around the core substance. This methodology facilitates controlled release and protects sensitive bioactive components from adverse environmental conditions, including oxidation, humidity, and photodegradation. The application of microencapsulation technology across food technology, pharmaceutical sciences, and agricultural sectors, where it improves the preservation, absorption efficiency, and precise delivery of functional components. The main objective is to protect bioactive compounds from a range of physical and chemical stresses, including temperature fluctuations, pH changes (acidic or alkaline conditions), moisture, and exposure to damaging agents. The encapsulating agent, also termed the matrix material, coating substance, or capsule shell, can be formulated from a single component or a blend of multiple constituents, including

polysaccharides, proteinaceous materials, fatty substances, waxy compounds, and similar biomolecules. The protective layer formed through microencapsulation serves as a mechanical barrier, effectively shielding the entrapped material from environmental influences. The microencapsulation process is generally characterized by four distinct phases: incorporation of the core material, solidification of the encapsulating agents, development of the core structure, and selection of matrix materials. The dimensions of microencapsulated particles are determined by the specific application requirements and typically range from 1 to 1000 µm. The effectiveness of microencapsulation is influenced by multiple critical parameters: the inherent characteristics of the bioactive compound being encapsulated, the physicochemical attributes of the wall material, the interfacial dynamics among the core substance, matrix material, and surrounding conditions, the proportional relationship between the entrapped component and encapsulating agent, the preservation capacity of the bioactive material within both the microcapsule structure and food system, and the mechanism governing the discharge of the core substance. The encapsulation of bioactive substances within microcapsules provides protection against thermal stress, oxidative damage, moisture exposure, photodegradation, and additional environmental stressors. Furthermore, the microencapsulation technique functions as a regulatory mechanism that controls the discharge pattern, dissolution characteristics, delivery efficiency, and biological accessibility of phytochemical extracts and functional compounds.

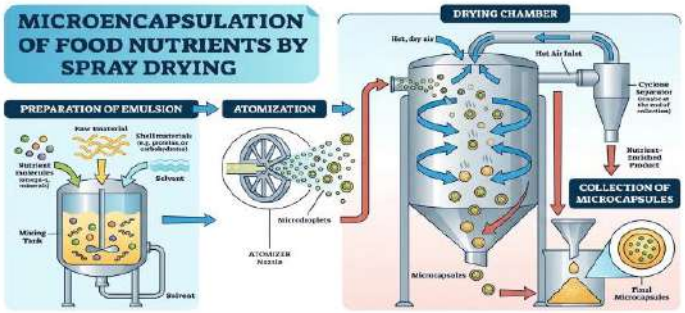
Common microencapsulation techniques

Microencapsulation techniques are classified according to the principle governing microparticle development. These methodologies are grouped into three principal categories: chemical approaches, physical processes (encompassing extrusion technology, atomization drying, fluid-bed encapsulation, and lyophilization), and physicochemical strategies (comprising phase separation in organic systems, complex coacervation, emulsification techniques, and vesicular lipid assembly).

Spray drying method

Spray drying is frequently applied for the microencapsulation of valuable ingredients. Owing to its adaptability and cost-effectiveness, this method is considered suitable for industrial use. High encapsulation efficiencies are typically achieved, and continuous processing at a large scale can be readily implemented. The spray drying technique involves preparing a suspension in which bioactive compounds are mixed with encapsulating agents. This prepared suspension is

subsequently atomized through a spray nozzle into a heated drying chamber maintained at 150-300°C. The atomized droplets are rapidly dehydrated, resulting in dry particulate powder. A notable advantage of the spray-drying methodology is the production of encapsulated particles with diameters ranging from 10 to 185 µm. However, this technique is associated with certain limitations, including substantial capital investment, constraints on suspension viscosity, challenges in maintaining consistent particle dimensions, and the need for elevated processing temperatures that may affect heat-sensitive bioactive materials.



Challenges

The primary goal of encapsulation technology is to protect bioactive components, including functional compounds, prebiotic substances, and probiotic microorganisms, against adverse conditions in the surrounding environment or within the food matrix. Moreover, intrinsic constraints and challenges are inherent to every encapsulation technique, necessitating careful evaluation during both method selection and practical implementation. Among these limitations, the primary obstacle is the complexity of translating microencapsulation protocols from laboratory-scale operations to commercial-scale production. The scale-up procedure is characterized by its complexity and technical demands, requiring considerable financial investment and, consequently, elevating the end-product costs. Temperature management presents a critical challenge in spray drying operations, as excessive thermal exposure can adversely affect sensitive bioactive substances and viable probiotic cultures.

Functional components, including bioactive substances, prebiotic fibers, and probiotic microorganisms, play a crucial role in extending shelf life and enhancing the nutritional profile of food products. These bioactive elements are also recognized for their potential contributions to human health promotion. Through microencapsulation technology, the integrity of the food matrix is maintained, functional ingredients are shielded from the adverse acidic environment of

the gastric system, and the targeted release of these compounds at specific sites within the gastrointestinal tract is facilitated.

Conclusion

Presently, microencapsulation technology is widely employed as a novel strategy for developing functional foods by incorporating bioactive components in encapsulated or microparticulate forms. This encapsulation methodology serves as an effective tool for improving the preservation stability, biological absorption efficiency, and extended viability of such functional constituents within food systems. Furthermore, significant improvements in organoleptic characteristics and sensory attributes can be achieved with this technology. The use of novel encapsulating matrices derived from natural materials or valorized food-processing by-products can enhance the functional efficiency and performance of microencapsulated systems.

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GOAT FARMING IN BIHAR: CHALLENGES AND LIVELIHOOD POTENTIAL FOR SMALLHOLDERS

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Abstract

Goat farming has emerged as one of the most promising livestock-based livelihood activities for small and marginal farmers across India, particularly in the state of Bihar. The state is home to millions of goats, largely maintained by landless and resource-poor households who rear them under traditional extensive or semi-intensive systems. Goats are considered "poor man's cow" due to their low investment requirements, quick returns, and resilience to climatic fluctuations. The growing domestic demand for chevon (goat meat), coupled with the socio-cultural preference for goats in religious festivals, ensures a vibrant market for small ruminants. However, the potential of goat farming in Bihar remains underutilized due to several challenges such as high disease prevalence, scarcity of quality feed and fodder, poor genetic base, lack of organized markets, and weak extension services. Farmers often rear goats as a subsistence activity rather than a structured enterprise. These limitations prevent goat rearing from achieving its full potential as a poverty alleviation tool. This article examines the status of goat farming in Bihar with special focus on small and marginal farmers. It highlights the economic and social opportunities goat farming provides, identifies key constraints that limit productivity and profitability, and proposes practical strategies for strengthening goat-based livelihoods. The suggested interventions include community-based breeding programs, improved animal health and veterinary service delivery, fodder development initiatives, creation of farmer producer

organizations, improved access to finance and insurance, and stronger women-centric goat value chains. A convergence of policy support, institutional innovations, and local participation can transform goat farming from a coping mechanism into a sustainable and profitable rural enterprise.

Keywords: Goat farming, Bihar, smallholder livestock, value chain, breed improvement, fodder security, veterinary services, livelihood diversification.

Introduction

Livestock plays a vital role in the rural economy of Bihar. Among different livestock species, goats occupy a special place due to their unique adaptability, multiple utility, and importance for resource-poor farmers. According to the 20th Livestock Census (2019), India possesses around 148.88 million goats, making it the largest goat population in the world. Bihar contributes significantly to this population, and goats are the second most important livestock species in the state after cattle. For millions of small and marginal farmers, goat rearing is not just an economic activity but also a cultural and social practice. Goats are reared in almost every village, primarily by households with little or no land. They require comparatively low inputs, thrive on crop residues, and multiply quickly, making them a reliable source of supplementary income. For many families, goats act as “living banks” — animals can be sold at short notice to meet urgent household needs such as medical expenses, school fees, or social ceremonies.

The demand for goat meat is steadily rising in both rural and urban markets. Unlike beef or pork, goat meat enjoys near-universal acceptability across communities in India. It is also priced higher than chicken, ensuring good returns for producers. In Bihar, seasonal peaks in demand occur during festivals such as Eid and Holi, when goats are sold in large numbers in local markets. This strong consumer preference ensures that goat farming will remain a viable livelihood option in the future. Despite these advantages, goat farming in Bihar continues to face major obstacles. Farmers often lack access to veterinary services, quality breeding stock, scientific housing, or balanced nutrition. Mortality rates in young kids remain high due to diseases like PPR (Peste des Petits Ruminants) and parasitic infestations. Market systems are poorly organized, forcing farmers to sell animals individually to traders at low prices. Limited credit and insurance services further constrain farmers’ ability to expand.

Thus, while goat farming presents immense opportunities for small and marginal farmers, a number of structural, technical, and institutional barriers need to be overcome. This article

explores these opportunities and challenges, and proposes strategies for transforming goat farming in Bihar into a robust driver of inclusive rural development.

Overview of Goat Farming in Bihar

- The **Bihar Livestock Master Plan (2018–19 to 2022–23)** highlights that livestock, particularly goats, play a crucial role in achieving the state's rural development and livelihood goals. Most goats in Bihar are owned by **scheduled castes and marginalized women**, who traditionally rear them on a subsistence basis. For these disadvantaged groups, including landless laborers, goats are more manageable and economically viable compared to larger livestock.
- Goats provide **multi-faceted utility** including; meat, milk, skin, wool, hair, and manure and contribute approximately **9% of India's livestock GDP**. In India, over 90% of goats are reared under **extensive management systems**, grazing on community rangelands with low inputs and outputs. The national goat population is **148.88 million**, the second largest in the world, and has been growing at an average rate of **3.5% per year** between 2007 and 2019 (20th Livestock Census, 2019).
- **Bihar ranks fourth** among Indian states in goat population, with **12.82 million goats**, accounting for **8.00% of the country's total goat population**. Goat farming is not restricted to low-income households; it is increasingly recognized as a **sustainable and profitable enterprise** for diverse rural households. The state's thriving demand for goat meat has made goat farming one of the most popular commercial livestock businesses in Bihar.
- With around **40% of Bihar's population living below the poverty line**, goat farming presents a significant opportunity to **bridge the gap between meat demand and supply**. Annually, about **600,000 goats are slaughtered in the state's registered slaughterhouses**, representing roughly **32% of Bihar's total goat meat production**.
- Traditionally, goat rearing in Bihar was confined to **landless and economically disadvantaged communities**. Today, however, the scenario has shifted: goat farming is increasingly recognized as a **viable industry**, attracting unemployed individuals and aspiring entrepreneurs who are establishing goat farms across the state. Bihar also **supplies goats to neighboring states**, enhancing inter-state trade and income opportunities.
- Many individuals are achieving profits through **small-scale goat farming enterprises**. The state offers **excellent grazing areas**, making extensive (free-range) goat rearing feasible.

However, **commercial goat farming is most profitable under intensive, stall-fed systems**, which allow for better growth rates and disease management.

- Goat farming in Bihar has proven to be a **successful and sustainable business**, though it requires patience. Unlike sheep, goats take longer to reach marketable size; a period of **3–4 years is generally needed to establish a profitable enterprise**.
- The **investment required for goat farming** varies depending on flock size. Operations can start with as few as **two goats**, gradually expanding sheds and herd size as farmers gain experience and confidence. It is strongly recommended to **attend goat farming training programs** before initiating an enterprise to learn essential management practices.
- The **principal source of income** for goat-rearing families is live goats, with **chevon (goat meat) being the main revenue-generating product**. While goat skin and other edible and non-edible by-products hold high market value, they often do not directly benefit smallholder farmers due to lack of processing facilities and market access.

Role of Bihar Rural Livelihoods Promotion Society (BRLPS / JEEViKA) in Goat Sector Development in Bihar

The **Bihar Rural Livelihoods Promotion Society (BRLPS)**, popularly known as **JEEViKA**, has been a transformative force in strengthening the goat sector in Bihar. Through large-scale, community-based interventions, JEEViKA has empowered small and marginal farmersparticularly women and landless households by providing; training, organizing producer groups, facilitating market linkages, and developing micro-enterprises focused on goat health and productivity. These initiatives have collectively contributed to **enhanced incomes, improved nutrition, and greater socio-economic empowerment** among rural households. The important roles of JEEViKA in Bihar are;

1. Capacity Building and Training

JEEViKA has conducted extensive training programs aimed at improving the knowledge and skills of goat rearers. These programs cover **animal health management, nutrition, breeding practices, productivity enhancement, and market access strategies**. By equipping farmers with practical skills and technical know-how, JEEViKA ensures that goat farming becomes a more efficient, productive, and profitable enterprise.

2. Formation of Goat Producer Groups (PGs): One of JEEViKA's key strategies has been to mobilize **women self-help groups (SHGs) into specialized Goat Producer Groups (PGs)**.

These PGs serve as platforms for collective learning, input procurement, and collective marketing. By organizing goat rearers into formal groups, JEEViKA strengthens community participation, fosters peer-to-peer knowledge sharing, and increases bargaining power for smallholder farmers in local and regional markets.

3. Community-Based Marketing: Bakri Bikray Kendra: To improve market access for smallholder goat farmers, JEEViKA introduced the **Bakri Bikray Kendra**, a community-based marketing system. These centers act as **aggregation and sales points** where goat producers can bring their animals, and traders are invited to participate in organized weekly markets. This system reduces dependence on intermediaries, enhances price transparency, and ensures better income realization for producers.

4. Development of Pashu Sakhis: JEEViKA has also pioneered the concept of **Pashu Sakhis**, women micro-entrepreneurs trained to provide basic animal health services within their communities. Pashu Sakhis offer **vaccination, deworming, disease diagnosis, and advisory services** to goat rearers, improving herd health and productivity while simultaneously generating income for the service providers themselves. This initiative has enhanced access to veterinary services in remote areas where formal animal health infrastructure is limited.

5. Formation of Goat Producer Societies: At the **panchayat level**, JEEViKA has facilitated the creation of **Goat Producer Societies (GPS)**. These societies organize **weekly markets and collective sale events**, connecting producers with traders and other stakeholders in the value chain. The GPS model enables farmers to **negotiate better prices, reduce transaction costs, and ensure consistent market access** for their livestock.

6. Value Chain Development and Enterprise Support: Through initiatives like the **Seemanchal Jeevika Goat Producer Company** in Araria, JEEViKA has created **value-chain support services** for goat rearers in the districts of Purnea, Araria, and Katihar. This company provides technical assistance, input supply, marketing linkages, and coordination of producer groups, enhancing the overall efficiency and profitability of goat farming. To date, **over 17,000 SHG members** have been mobilized into goat producer groups under this program, highlighting its scale and impact.

7. Outcomes and Impact: JEEViKA's interventions in goat rearing have led to measurable **improvements in household income, nutrition, and empowerment**, particularly for women and marginalized communities. By integrating **livelihood support, skill development,**

veterinary services, and market access, the program demonstrates a **holistic approach** to livestock-based rural development. The success of goat farming initiatives under JEEViKA serves as a model for scaling livestock enterprises in other parts of India.

Challenges of the Goat Farming Sector in Bihar

Goat farming in Bihar holds immense potential for small and marginal farmers, yet it faces a multitude of challenges that constrain productivity, profitability, and sustainability. One of the primary challenges is **extreme climatic conditions and natural calamities**, such as floods, droughts, and erratic rainfall, which adversely affect pasture availability, fodder production, and overall herd health. Coupled with this is the **depletion of natural resources**, particularly communal grazing lands, which are shrinking due to population pressure, urbanization, and land conversion for agriculture or infrastructure development. Important challenges are;

- **Feed and fodder scarcity** is a persistent problem. The increasing goat population intensifies pressure on already limited grazing areas, and low-quality crop residues often fail to meet nutritional requirements, leading to stunted growth and poor reproductive performance. Government census data indicate that while goat populations are rising, **declining grazing land** poses a major threat to the sustainability of traditional extensive systems.
- **Regulatory constraints**, including tax regulations on marketing and livestock transactions, add complexity and reduce profitability for smallholders. Another major limitation is the **unavailability of high genetic potential breeds**, and the absence of productive exotic breeds for crossbreeding hampers growth, carcass quality, and market competitiveness.
- Farmers often lack **scientific feeding practices**, relying on seasonal fodder and crop residues that are nutritionally inadequate. This is compounded by **health-related challenges**, including frequent disease outbreaks, high kid mortality, endemic and trans-boundary diseases, and inadequate veterinary infrastructure. **Limited availability of drugs, vaccines, high-quality semen doses, and doorstep veterinary services** further restricts productivity and herd improvement.
- The **market system remains largely unorganized**, with farmers dependent on local traders, resulting in poor price realization. There is also intense **competition for resources** such as land and water, and emerging challenges related to **climate change** threaten both feed availability and animal health. Socio-cultural factors and **ethical concerns**, including caste-

based practices, traditional norms, and societal perceptions, influence adoption of improved farming practices and access to markets.

- **Financial and insurance constraints** are also critical. Smallholders often lack collateral for loans, have limited access to formal credit, and underutilize livestock insurance, leaving them vulnerable to risks. Finally, **limited knowledge and inadequate extension services** hinder adoption of best practices in breeding, feeding, health management, and marketing, leaving farmers dependent on traditional and less productive methods.

Collectively, these challenges underscore the urgent need for a **holistic approach** that addresses environmental, biological, institutional, financial, and socio-cultural dimensions to make goat farming a viable, resilient, and profitable enterprise in Bihar.

Livelihood potential for small holders (small and marginal farmers) in Goat Sector in Bihar

Goat farming offers significant opportunities for small and marginal farmers in Bihar due to its **low investment requirements, high reproductive rate, and quick returns**. Goats provide **meat, milk, manure, and other by-products**, contributing to both household nutrition and income generation. The sector is particularly **women-friendly**, empowering rural women through management of flocks and participation in producer groups. Government programs, subsidies, and training initiatives, such as those under **JEEViKA and the National Livestock Mission**, support farmers in improving productivity and accessing markets. Strong local and inter-state **demand for goat meat** and potential for **value addition** further enhance profitability and livelihood security. Additionally, goats act as **"living banks"**, providing financial resilience during crop failures or emergencies. Some of the important opportunities are;

- **High Demand for Goat Meat (Chevon):** Goat meat is culturally and religiously preferred across India, including Bihar. Festivals, weddings, and other social occasions drive strong market demand, providing farmers with **consistent income opportunities**.
- **Rapid Reproduction and Quick Returns:** Goats have high reproductive efficiency, with most breeds capable of **two kiddings per year**. This allows farmers to quickly expand their herds and generate income in a relatively short time.
- **Low Investment Requirement:** Goat farming requires **minimal land, infrastructure, and capital** compared to large ruminants. Small farmers can start with 2–5 goats, making it accessible for landless and resource-poor households.

- **Integration with Crop Farming:** Goats can feed on **crop residues, weeds, and by-products**, converting otherwise unused biomass into high-value meat and manure. This integration enhances **farm productivity and sustainability**.
- **Employment Generation:** Goat farming provides **self-employment opportunities** for smallholders and landless farmers, including women and youth, in activities such as rearing, health care, marketing, and processing.
- **Nutritional Security:** Goats provide **meat and milk**, which are rich in protein and essential nutrients. Households can improve their nutritional intake while simultaneously generating income from surplus production.
- **Women Empowerment:** Goat farming is **labor-intensive but manageable** by women, allowing them to actively participate in decision-making, manage flocks, and generate income, enhancing **social and economic empowerment**.
- **Potential for Value Addition:** By-products like **skins, manure, and hair** can be processed into leather, organic fertilizers, and handicrafts, providing additional income streams and promoting entrepreneurship.
- **Market Expansion Opportunities:** Bihar has growing **domestic and inter-state markets**, with cities demanding quality goat meat. Farmers can access **urban markets and institutional buyers**, such as restaurants and hotels.
- **Government Support and Subsidies:** Programs under the **National Livestock Mission, JEEViKA, and RKVY** offer **training, input support, and financial assistance**, reducing the initial burden on small farmers and promoting structured goat farming.
- **Climate Resilience:** Goats are **hardy animals** capable of thriving in harsh and marginal environments, including drought-prone areas, making them suitable for small farmers facing climate variability.
- **Livestock as Financial Security:** Goats act as **"living banks"**, providing farmers with an emergency source of cash during financial stress, crop failure, or household needs, reducing dependence on informal credit.
- **Community-Based Enterprise Models:** Formation of **Goat Producer Groups (PGs) and Farmer Producer Organizations (FPOs)** under programs like JEEViKA helps small farmers **pool resources, access better markets, and reduce transaction costs**.

- **Export Potential:** Certain indigenous breeds of goats, particularly **Black Bengal**, are highly prized for their meat and skin quality. This presents opportunities for **domestic and international trade**, boosting income for farmers.
- **Integration with Rural Development Programs:** Goat farming can be linked with **self-help groups, skill development programs, and livelihood missions**, providing technical assistance, credit, marketing support, and insurance coverage, making smallholder farming more **profitable and sustainable**.

Strategies to Overcome Challenges Faced by Small and Marginal Farmers in Bihar

Strategies to overcome the challenges faced by small and marginal farmers in Bihar, an integrated approach is essential. Regular vaccination and community-based animal health services can reduce disease-related losses, while improved housing, hygiene, and fodder management ensure better growth and productivity. Promotion of high-yielding fodder crops, silage, and balanced feeding practices can address seasonal feed shortages. Genetic improvement through community buck programs, controlled breeding, and adoption of superior breeds enhances herd quality. Formation of farmer producer groups and community marketing centers strengthens market access, ensures fair prices, and facilitates value addition. Access to microfinance, livestock insurance, and government subsidies reduces financial vulnerability, while training, capacity building, and women-led enterprises empower farmers and improve management skills. Convergence of state programs, monitoring systems, and exposure to best practices completes a holistic strategy to make goat farming a profitable and sustainable livelihood for smallholders in Bihar. Some of the important strategies are;

A. Production & Animal Health

- **Regular Vaccination Programs:** Organize scheduled vaccination drives against PPR, FMD, enterotoxemia, and other prevalent diseases to reduce mortality rates in goat herds. Community-based health camps can increase coverage.
- **Community Animal Health Workers (Pashu Sakhis):** Train local youth and women as para-veterinarians to provide first-line services like vaccinations, deworming, and basic treatments, ensuring timely interventions in remote villages.
- **Disease Surveillance and Early Warning Systems:** Establish block-level monitoring for disease outbreaks, including reporting mechanisms and rapid response teams to prevent epidemics.

- **Improved Housing and Biosecurity Measures:** Promote cost-effective housing (raised platforms, ventilated sheds) and implement quarantine measures for new animals to minimize disease spread.
- **Hygienic Handling Practices:**Train farmers in proper milking, manure management, and general hygiene to prevent infections and improve overall herd health.

B. Feed & Fodder Management

- **Fodder Cultivation and Management:**Encourage planting of high-yielding, fast-growing fodder crops (Napier grass, berseem, maize fodder) on small plots or community lands to ensure year-round feed availability.
- **Fodder Preservation Techniques:** Introduce silage, hay-making, and feed block preparation to overcome seasonal feed shortages, particularly in lean periods.
- **Balanced Feeding Practices**

  Train farmers to formulate rations combining crop residues, agro-industrial by-products, and mineral supplements to improve growth rates and reproductive performance.
- **Community Fodder Banks:** Establish village-level fodder banks where surplus fodder is stored and made available during scarcity, ensuring sustainable feed supply for small flocks.
- **Promotion of Dual-Purpose Crops;** Encourage intercropping and crop rotation with fodder-friendly crops that provide both grain for humans and leaves/stalks for goats, integrating goats into the cropping system.

C. Breeding & Genetic Improvement

- **Community Breeding Programs:** Set up community buck stations with high-quality, locally adapted bucks to improve the genetic potential of flocks and increase productivity.
- **Controlled Breeding and Record-Keeping:** Introduce systematic mating schedules and simple record books for births, deaths, and weights to select superior animals over generations.
- **Promotion of Improved and Indigenous Breeds:** Encourage crossbreeding with superior breeds while conserving high-value indigenous breeds like Black Bengal to optimize meat quality and growth rates.
- **Artificial Insemination (AI) Services:** Where feasible, pilot AI programs to ensure genetic improvement in smallholder herds and reduce dependency on random mating.

D. Market Access & Value Chain Development

- **Formation of Farmer Producer Groups (FPOs/SHGs):** Organize smallholders into collective groups for input purchase, collective sales, and access to formal markets, increasing bargaining power and income.
- **Community-Based Marketing Centers (Bakri Bikray Kendra):** Establish regular village-level markets where farmers can sell goats directly to traders or consumers, ensuring fair prices and reducing intermediaries.
- **Value Addition and Processing:** Promote small-scale processing units for meat, skin, and manure products. Packaging, branding, and hygienic processing can increase revenue and market appeal.
- **Market Information Systems:** Disseminate price, demand, and buyer information through mobile SMS or apps to help farmers make informed marketing decisions and plan sales strategically.

E. Finance, Credit & Insurance

Tailored Microfinance and Credit Support: Provide easy access to low-interest loans, input financing, and revolving credit schemes suitable for small-scale goat farming, reducing dependency on moneylenders.

Livestock Insurance Awareness and Coverage: Promote adoption of insurance schemes covering mortality and disease risks. Simplified claim procedures and group-based policies can make insurance feasible for marginal farmers.

F. Cross-Cutting & Institutional Strategies (Integrated Approach)

- Encourage **women-led initiatives**, ensuring women manage groups, micro-enterprises, and community veterinary services.
- Promote **training and capacity building** through demonstrations, farmer field schools, and exposure visits to successful goat farms.
- Foster **convergence with government programs** (National Livestock Mission, RKVY, JEEViKA, NABARD area development schemes) to provide subsidies, technical assistance, and policy support.
- Develop **monitoring and evaluation systems** at block and panchayat levels to track productivity, market access, and adoption of best practices.

Way Forward:

- Goat farming in Bihar presents a unique opportunity to improve rural livelihoods, particularly for small and marginal farmers, but realizing its full potential requires a **multi-pronged and integrated approach**. Strengthening **animal health services** through vaccination drives, community-based veterinary workers, and better availability of medicines will reduce mortality and improve productivity. **Feed and fodder management** should be enhanced through cultivation of high-yielding fodder crops, silage preparation, and establishment of community fodder banks to overcome seasonal scarcity.
- **Genetic improvement** through community breeding programs, selective mating, and introduction of superior indigenous and crossbred goats can enhance growth rates, meat quality, and reproductive efficiency. **Capacity building and training** for farmers especially women on; scientific feeding, housing, and health management will improve herd performance and income.
- On the market side, formation of **farmer producer groups, panchayat-level goat societies, and community-based marketing centers** can provide better price realization and reduce dependency on intermediaries. **Value addition** through meat processing, skin and manure products, and branding can further enhance profitability.
- Access to **financial services, microcredit, and livestock insurance** will protect smallholders against risks and allow expansion of their operations. Policies and programs must focus on **convergence**, integrating initiatives from JEEViKA, the National Livestock Mission, and other rural development schemes to provide technical, financial, and institutional support.
- Finally, promoting **women-led enterprises**, fostering entrepreneurship, and leveraging technology for market information, herd management, and traceability will ensure goat farming becomes a **sustainable, resilient, and profitable livelihood option** in Bihar. With coordinated efforts from government, NGOs, and local communities, goat farming can evolve from a subsistence activity to a **strategic driver of rural economic growth and empowerment**.

Conclusion

Goat farming in Bihar has immense potential to improve rural livelihoods, generate employment, and contribute to nutritional security. For small and marginal farmers, goats act as

a lifeline by providing quick and reliable income. However, the sector is constrained by disease prevalence, feed scarcity, poor breeds, and weak markets. By adopting a holistic approach that combines improved animal health, fodder development, genetic improvement, market linkages, financial support, and capacity building, goat farming can be transformed from a traditional subsistence activity into a profitable and sustainable enterprise. Special emphasis on women-led goat farming groups and farmer collectives can further enhance inclusiveness. If effectively supported through state policies, extension services, and community participation, goat farming can become a cornerstone of rural development in Bihar, helping millions of small and marginal farmers escape poverty and achieve sustainable livelihoods.

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GENETIC IMPROVEMENT IN SESAME (*SESAMUM INDICUM* L.) FOR YIELD & QUALITY TRAITS

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Abstract

Sesame (*Sesamum indicum* L.) is an important oilseed crop valued for its high-quality edible oil and significant global economic importance. However, its productivity remains relatively low due to a narrow genetic base, indeterminate growth habit, and limited breeding efforts. Genetic improvement through the assessment and utilization of genetic variability, heritability, combining ability, and heterosis provides an effective approach to enhance yield and seed quality traits such as oil and protein content. Several studies have reported substantial genetic variation among sesame genotypes for yield and its components, which can be efficiently exploited through breeding programmes. Traits such as seed yield per plant, number of capsules per plant, capsule length, and oil content often exhibit high heritability coupled with high genetic advance, indicating the predominance of additive gene action and suggesting that direct phenotypic selection can lead to significant improvement.

1. Introduction

Sesame (*Sesamum indicum* L.), commonly referred to as the **"Queen of Oilseeds,"** is one of the oldest cultivated oilseed crops, known for its superior oil quality and rich nutritional composition (Sharma *et al*., 2020). Sesame oil is highly valued due to its high oxidative stability, presence of natural antioxidants (such as sesamin and sesamol), and health benefits (Bakamal *et*

al., 2025). Despite its importance, sesame productivity is relatively low compared to other major oilseed crops. This is mainly attributed to its narrow genetic base, indeterminate growth habit, and limited progress in systematic breeding programmes (Singh *et al*., 2025). Therefore, the adoption of modern breeding strategies focusing on genetic variability, selection, hybridization, and molecular approaches is essential for improving yield potential and seed quality traits (Rahaman *et al*., 2026).

2. Genetic Variability in Sesame

2.1 Importance of Variability

Genetic variability is the foundation of any crop improvement programme, as the efficiency of selection depends on the presence of sufficient genetic diversity (Sonaniya *et al*., 2025). In the absence of variability, genetic improvement through selection becomes ineffective. Numerous studies have reported significant genetic variation among sesame genotypes for key agronomic and quality traits, including:

- Seed yield per plant
- Number of capsules per plant
- Test weight (seed weight)
- Oil content
- Protein content

These traits exhibit considerable genotypic and phenotypic variation, making them ideal targets for selection in breeding programmes.

2.2 Heritability and Genetic Advance

Heritability measures the proportion of total phenotypic variation that is attributable to genetic factors, while genetic advance estimates the expected improvement in a trait under selection.

In sesame, several yield and quality-related traits have been reported to exhibit high heritability along with high genetic advance, indicating the predominance of additive gene action (Naqi *et al*., 2025). This suggests that simple phenotypic selection would be highly effective in improving these traits.

3. Breeding Strategies for Yield and Quality

3.1 Combining Ability & Heterosis

Combining ability analysis and heterosis studies play a crucial role in identifying superior

parental lines and promising hybrid combinations (Dhall *et al*., 2025). Techniques such as diallel mating design (full and half diallel) and line × tester analysis are commonly used.

These approaches help in:

- Identifying good general combiners (GCA)
- Detecting specific hybrid combinations with high performance (SCA)
- Exploiting heterosis for yield and oil content

Such strategies are essential for developing high-yielding and quality-improved sesame hybrids.

3.2 Stability Across Environments

Multi-environment testing is important for identifying genotypes with stable performance across diverse agro-climatic conditions (Takele *et al*., 2025). Stable genotypes ensure consistent yield and quality under varying environmental conditions, making them suitable for wide adaptation.

4. Molecular Tools and Genetic Diversity

In addition to conventional breeding, molecular tools have significantly improved the efficiency of sesame improvement programmes. Molecular markers such as **Simple Sequence Repeats (SSR)** are widely used to assess genetic diversity at the DNA level (Gaddam *et al*., 2025). These tools help in:

- Estimating genetic distance among genotypes
- Grouping genotypes into clusters
- Selecting genetically diverse parents for hybridization

This enhances the precision and effectiveness of breeding programmes.

5. Challenges and Future Prospects

Despite advancements, sesame breeding faces several challenges:

- Limited genomic and molecular resources compared to major crops like rice and wheat
- Indeterminate flowering and asynchronous maturity
- Complex inheritance of quality traits

Future breeding strategies should focus on:

- Marker-assisted selection (MAS)
- Genomic selection
- Genome editing technologies (e.g., CRISPR-based approaches)

These advanced tools can significantly accelerate the development of improved sesame varieties.

Conclusion

Genetic improvement of sesame is both essential and achievable. The presence of substantial genetic variability, high heritability of key traits, and the identification of superior hybrid combinations provide a strong foundation for crop improvement. Integration of conventional breeding methods with modern molecular approaches will facilitate the development of high-yielding, high-quality sesame varieties adaptable to diverse agro-ecological conditions.

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KID MANAGEMENT IN GOATS: THE KEY TO HIGHER PRODUCTION AND PROFITABILITY

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Introduction

Goat farming plays a vital role in the rural economy of India, particularly among small and marginal farmers. Goats are highly adaptable animals that can thrive under diverse agro-climatic conditions and require relatively low investment compared to other livestock species. They provide multiple benefits including meat, milk, manure, and serve as a reliable source of income and livelihood security. However, the success and profitability of goat farming largely depend on the survival and proper growth of kids, which form the future productive stock of the herd. High kid mortality, especially during the early stages of life, remains a major constraint in goat production systems. Most of these losses are preventable and occur due to poor management practices, lack of awareness, inadequate nutrition, and disease conditions. Therefore, scientific kid management is essential to ensure higher survival, better growth, and improved economic returns in goat farming.

IMPORTANCE OF KID MANAGEMENT

Kid management forms the foundation of a successful goat farming enterprise, as healthy kids develop into productive adults contributing to both meat and milk production. Proper care during the early stages of life enhances immunity, promotes faster growth, and reduces the risk of diseases. Even a small improvement in kid survival rate can significantly increase the overall productivity and profitability of the farm. On the other hand, neglecting kid management results in poor growth performance, increased disease incidence, and higher mortality, ultimately leading to economic losses.

Hence, adoption of scientific kid management practices is crucial for sustainable goat farming.

CARE OF NEWBORN KIDS

The care of newborn kids begins immediately after birth and plays a crucial role in ensuring their survival. Clearing mucus from the nose and mouth is essential to facilitate proper breathing, and the kid should be thoroughly dried using a clean cloth or straw to prevent chilling. The umbilical cord must be cut and disinfected with iodine solution to avoid infections. Providing a clean, dry, and warm environment is vital, as newborn kids are highly sensitive to environmental stress, particularly cold and damp conditions which can lead to hypothermia and death. Ensuring that the kid starts suckling from the mother as early as possible is equally important for its survival and health.

COLOSTRUM FEEDING

Colostrum feeding is the most critical aspect of kid management, as it directly determines the immunity and survival of the newborn. Goat kids are born without sufficient immunity and depend entirely on colostrum for protection against diseases. It is essential that colostrum is fed within the first hour of birth, as the absorption of antibodies is highest during this period. Adequate quantity of colostrum should be provided for at least the first three days of life. Apart from immunity, colostrum also supplies essential nutrients and energy, and supports the development of the digestive system. Failure to provide timely colostrum feeding can result in weak immunity, increased susceptibility to diseases, and higher mortality rates.

FEEDING AND NUTRITION MANAGEMENT

Proper feeding and nutrition are vital for the growth and development of kids. After the initial colostrum feeding period, kids should be allowed to suckle their mothers regularly or be provided with milk feeding at appropriate intervals. Early introduction of solid feed, known as creep feeding, should be practiced from two to three weeks of age to promote rumen development. A balanced creep feed containing energy, protein, vitamins, and minerals supports rapid growth and improves feed efficiency. Providing clean and fresh drinking water at all times is equally important for maintaining digestion and overall health. Adequate nutrition during early life ensures better weight gain, early maturity, and improved production performance in adulthood.

HOUSING AND ENVIRONMENTAL MANAGEMENT

Proper housing is essential for maintaining the health and well-being of goat kids. The housing system should be clean, dry, well-ventilated, and protected from extreme weather conditions. Overcrowding should be avoided as it increases stress and facilitates the spread of diseases. Providing separate housing for kids allows better monitoring and management. Environmental factors such as temperature and humidity play a significant role in kid survival, and maintaining an optimal temperature range of 20 to 30°C is recommended. During colder periods, adequate bedding such as straw should be provided, while in hot weather, proper ventilation and shade are necessary to prevent heat stress. Effective housing management reduces stress, enhances growth, and minimizes disease incidence.

HEALTH CARE AND DISEASE PREVENTION

Preventive health care is a key component of successful kid management. Regular vaccination and deworming should be carried out as per veterinary recommendations to protect kids from common diseases such as diarrhea, pneumonia, enterotoxemia, and parasitic infections. Deworming should begin at one month of age and continue at regular intervals, while vaccination schedules must be strictly followed. Farmers should closely observe kids for early signs of illness such as dullness, reduced feeding, coughing, or diarrhea, and immediate veterinary intervention should be sought when necessary. Maintaining hygiene, proper feeding, and stress-free conditions significantly reduce the incidence of diseases and improve survival rates.

WEANING AND GROWTH MANAGEMENT

Weaning is an important stage in the life of a kid and is generally carried out at two to three months of age. A gradual weaning process helps reduce stress and allows the kid to adapt smoothly from milk feeding to solid feed. Ensuring that kids are consuming sufficient solid feed before weaning is essential for maintaining growth rate. After weaning, providing a balanced diet and monitoring body weight regularly are important for evaluating growth performance and making necessary adjustments in feeding practices.

RECORD KEEPING AND SCIENTIFIC MANAGEMENT

Maintaining proper records is an essential aspect of scientific goat farming. Information such as birth weight, growth rate, vaccination, and deworming schedules should be systematically recorded. These records help farmers identify high-performing animals, make

informed breeding decisions, and improve overall herd productivity. Record keeping also assists in monitoring the effectiveness of management practices and ensuring better farm planning.

ROLE OF WOMEN AND ETHNOVETERINARY PRACTICES

Women play a significant role in goat farming, particularly in rural households, where they are actively involved in feeding, cleaning, and caring for kids. Training and empowering women farmers can greatly improve kid management practices and farm productivity. In addition, traditional ethnoveterinary practices such as the use of neem leaves for parasite control and turmeric for wound management can support kid health. However, these practices should be used in combination with scientific veterinary care for effective disease management.

ROLE OF KVKs AND FIELD IMPACT

Krishi Vigyan Kendras play a crucial role in disseminating scientific knowledge and improving goat farming practices among farmers. At KVK Kundrakudi in Sivagangai district, several training programmes, demonstrations, and field visits have been conducted focusing on kid management practices. Field observations indicated that poor management practices, delayed colostrum feeding, and lack of hygiene were major causes of kid mortality. Following KVK interventions, farmers adopted improved practices such as timely colostrum feeding, proper housing, and balanced nutrition. This resulted in healthier kids, improved growth rates, reduced mortality, and enhanced income, demonstrating the effectiveness of scientific interventions in goat farming.

ECONOMIC IMPORTANCE AND COMMON MISTAKES

Kid survival has a direct impact on farm profitability, as even a small increase in survival rate can significantly enhance income. Improved kid management leads to faster growth, early market readiness, and reduced veterinary costs. However, common mistakes such as delayed colostrum feeding, poor hygiene, inadequate nutrition, overcrowding, and neglect of vaccination continue to affect productivity. Avoiding these mistakes and adopting scientific practices are essential for maximizing returns from goat farming.

Conclusion

Kid management is the backbone of successful goat farming and plays a decisive role in determining productivity and profitability. Proper care during the early stages of life ensures better survival, faster growth, and improved health of the animals. Field experiences from KVK Kundrakudi clearly demonstrate that simple, low-cost scientific practices can significantly

improve kid survival and farmer income. By adopting improved kid management practices, farmers can transform goat farming into a sustainable and profitable enterprise. Investing in kid management is ultimately an investment in the future of the herd and the livelihood of the farmer.

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MARKER ASSISTED INTROGRESSION OF BLAST RESISTANCE IN RICE

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Introduction

Rice (Oryza sativa L.) is the staple food and primary source of food for more than half of the world's population and provide more than 20% of calories consumed by the world population.The rice production system makes a vital contribution to the reduction of hunger and poverty. Rice production has widely increased after the green revolution. It is predicated that the world population will meet the global food demands to production of grain yields. Some of the superior varieties is not increasing due to the influence of stress factors. However, a rigorous yield loss that has affected the rice cultivation is accounted to biotic and abiotic stresses. Sometimes, the climate changes are the major problems that address the requirement for sustainable crop development and resistance to biotic stresses. Nowadays different methods are used to improve the stress tolerance plants. Some of the DNA marker technology has immensely contributed to genetic improvement through the selection of desirable traits.

Rice blast is the most important fungal disease, which is caused by the fungus Magnaporthe oryza .The fungus colonizes can infect rice plant right from seedling to adult plant stages from leaves (leaf blast), panicles (panicle blast) and other parts of the rice plants. It most infections occur on the leaves and first symptoms of the disease appear as small brown or greyish dots on the leaves. Blast disease affects rice production in all rice growing regions. The yield losses are most serious in temperate regions and upland conditions. The blast resistance in rice plants has been one of the most important traits being in breeding programs over several decades. Different breeding strategies have been adopted. The development and deployment of rice

varieties introgressed with major resistance genes is the most cost-effective and environment-friendly approach to control of blast disease. And introduction of resistance genes into susceptible cultivar objective (kushibuchi,1997).As a result, several blast resistance rice varieties were introduced, but within a short period of time, they have become seriously blast susceptible because of the emergence of new pathogens of blast fungus. This breakdown of blast resistance clearly indicates that the resistance cannot be widely achieved until true resistance genes are identified (Hittalmani et al.,).The use of different resistant rice varieties in the cultivation of rice , could be the most active, and cost effective way to reduce the adverse effect of the blast disease. This is one of the important objectives breeding rice plan. Marker-assisted backcrossing has enormous potential to introduce the blast resistance genes into diverse rice cultivars (Collard and Mackill, 2008; Collard et al., 2008). Introgression of blast resistant genes into advanced improved rice lines is a cost-effective and environmentally friendly approach to combat yield losses (Wen and Gao, 2012). Themain advantage of marker- assisted selection is the accuracy of selection of the true plant within the short breeding cycle to produce blast resistant rice varieties. Currently, the blast resistant breeding program has achieved greater success with the advent of marker-assisted selection (Ragimekulaetal.,2013).

BLAST DISEASE IMPROVEMENT DUE TO MOLECULAR MARKERS TECHNIQUES

Molecular markers have played an increasing role in rice breeding for cultivar improvement, screening, selection and germplasm collections (Wang et al., 2007). The new sequencing tools provide valuable information for the discovery, validation and assessment of genetic markers in populations (Sahebi et al., 2015). For instance, the analysis of next generation sequencing (NGS) data by means of bioinformatics developments allows discovering new genes and regulatory sequences and their positions, and makes available large collections of molecular markers (Perez- de-Castro et al., 2012). The whole genome sequence data substantially enhanced the efficiency of polymorphic marker development for QTL fine mapping and the identification of possible candidate genes (Wan et al., 2006). These performances can be useful as genetic resources for breeding of rice cultivars. The use of molecular markers for rice has been recently reviewed (Temnykhetal.,2001;Xu, 2002; Semagnetal.,2006; Langetal.,2008; Kumar etal.,2009; Benalietal.,2011). In the case of rice blast(M. oryzae) a large number of the major genes had

been identified and was targeted for mapping investigations using a variety of marker systems and approaches (Ashkanietal.,2014).

DNA markers including are simple sequence repeats(SSRs),Single-nucleotide polymorphisms(SNPs),Amplified fragment length polymorphisms(AFLPs),Random amplified polymorphic DNAs (RAPDs),cleaved amplified polymorphic sequences(CAPS), and Restriction fragment length polymorphisms(RFLPs)have been identified to be linked with blast resistance genes in rice (Ashkanietal.,2014; Tanweeretal.,2015). In recent year, scientists have used these markers for genetic mapping to identify candidate genes and QTLs in many plant species

Microsatellites are SSR markers, and have been used extensively to identify genes and QTLs associated blast resistance in rice. Microsatellites are abundant in plants (McCouch et al., 2001), causing more polymorphism and better repetition over other marker systems. The genetic map covering all 12 rice chromosomes with at least one microsatellite at the distance of 0.5 cM has been developed by International Rice Microsatellite Initiative (IRMI; McCouch et al., 2002). Currently, breeders are focusing on MAS instead of using conventional breeding. Application of MAS reduces the time for phenotypic selection and saves the costs to select a desired trait (Koide et al., 2009). This method is helpful tool, and more accurate approach in introducing novel cultivars and it also help breeders to expedite breeding research in crops by enabling selection based on the genotype rather than on the phenotype. After the discovery of molecular markers linked with gene of interest, selection of specified traits to develop new cultivar could be made at an early level (Zhu et al., 2012).

Marker-assisted backcross breeding (MABC) as another technique recently has been given attention in rice breeding for the introgression of blast resistance genes (one or a few genes) into the susceptible or in an adapted or elite varieties. MABC is the process of using markers to select for target loci, minimize the length of the donor segment containing a target locus and accelerate the recovery of the recurrent parent (RP) genome during backcrossing (Charcosset, 1997; Hospital, 2001; Hasan et al., 2015). The main purpose of MABC is to transfer the desired character/or targeted gene along with recovering the recurrent parent characters/or genes. MABC is now playing an important role for the development of blast- resistant cultivars (Sundaram et al., 2009) and is superior to conventional backcrossing in precision and efficiency and time saving. Molecular markers which are tightly linked with important traits are used in MABC. Therefore, molecular markers are the tools that can be used to detect the presence of desire

character in backcrossing and greatly increases the efficiency of selection. Recently through application of MABC many blast resistance genes have been successfully introgressed into the genetic background and improved the blast resistance.

RESISTANT GENES AND QTLs FOR BLAST DISEASE

Resistance to blast was classified into complete and partial resistance (Wang etal.,1994). Complete resistance is a qualitative character and race specific controlled by a major gene(R genes). Meanwhile, partial resistance is a quantitative character and non-race specific, which is controlled by many genes known as quantitative resistance loci(QRL; Young, 1996). However, if the resistance is highly partial, it can also be controlled by a major gene and is race specific. Qualitative and quantitative blast resistances have been reported in rice germplasm (Ou, 1985). Many qualitative resistance major genes for blast resistance have been identified and mapped in the rice genome (Sharmaetal.,2012; Ashkanietal.,2014). About 22 R-genes have been successfully cloned and molecularly characterized. In the practice of resistance breeding, using a single R gene which has a broad resistance spectrum is more effective. There have been many reports on introgression of Pi genes related to blast disease into commercial and elite varieties. For example, the Pi-9 gene that exists in the indica rice line 75-1-127 (Liuetal.,2002a), was introgressed from the wild species O. minuta (Amante-Bordeosetal.,1992). The Pi-ta allele was identified in O. rufipogon and O. nivara, or in their hybrids with O. sativa (Jena andKhush,2000). These R genes function in a gene-for-gene fashion, so the pathogen can adapt by mutating or deleting the corresponding a-virulence gene.

Therefore varieties those carrying R genes which confer high levels of resistance typically lose their resistance after a few years (Chen et al., 2003). Quantitative resistance donated by quantitative trait loci (QTL) are long-lasting disease resistance against a wide-range of pathogens, promising for sustainable rice production in the future (Song and Goodman, 2001). QTL mapping is a modern type of study to locate genes controlling a quantitative trait. Since the first publication of a QTL analysis of rice resistant to blast (Wang et al., 1994), several QTLs related to blast resistance have been detected using different type of markers. Identification of QTLs, associated with blast resistance has been delivered the effective genetics evidences for the molecular marker assisted breeding and cloning of the major genes. In the other word, QTL mapping is useful in identifying multiple loci controlling complete resistance in a highly resistant cultivar as well as in estimating the number, location and effect of genomic region involved in

partial blast resistance (Sallaud et al., 2003). Many rice improvement programs now aim to incorporate quantitative or polygenic resistance into rice varieties. Previous studies have verified that genetic linkage maps constructed with various DNA markers are very useful for the analysis and detection of qualitative trait loci (Bao et al., 2000; Price et al., 2000). Molecular linkage maps have helped resolve the effects of minor and major QTLs and estimate the amount phenotypic variation explained at each locus.

DEVELOPING BLAST RESISTANT LINES

The crossing was performed between the parental lines of PongsuSeribu2 and MR219 and the F1 hybrid was produced. After confirming the hybridity of the plants, true hybrid heterozygous plants were back crossed with recurrent parent MR219 and BC1F1 generation seeds were produced. Foreground selection for the desired alleles and background selection for the recovery of the recurrent parent were performed. The plants with the desired allele and maximum recovery of recurrent parents were again back crossed, and subsequently the BC2F1 generation was produced. The same steps were followed for the BC2F1 generation, and the best plants were selfed to produce the BC2F2 generation seed. The complete genome genotyping with SSR markers was performed, distributed overall 12rice chromosomes. The true plants on the basis of genotype with the desired alleles were back crossed in each generation. In every generation, the plant showing the heterozygous allele for PongsuSeribu2 was selected. At the final stage, 15 homozygous plants carrying target alleles along with a similar genome of MR219 in each chromosome were selected in the BC2F2 generation and blast resistant lines were produced.

ALLELE MINING AND BLAST RESISTANCE GENES

Allele mining is the commonly used approach to identify novel alleles or allelic variants of a gene/or candidate genes of interest, based on the available information about the genes, from a wide range of germplasm. This technique possesses good potential to be used in molecular plant breeding of crop improvement programs. The success of allele mining mainly depends on the type of genetic materials used for screening and should be as diverse as possible and availability of genome and gene sequence information of a particular crop species. For efficient allele mining, wild relatives and local landraces are used because they are reservoirs of useful alleles hidden in their phenotype (Tanksley et al., 1996). The current availability of complete rice genome sequences in addition to several bioinformatic tools have made it possible to mine allelic

diversity throughout rice germplasm. EcoTilling and sequence based allele mining are the two widely used approaches in allele mining.

FOREGROUND SELECTION

The robust tightly linked marker RM208F 5-tctgcaagccttgtctgatg-3, RM208R 5-taagtcgatcattgtgtggacc-3 on chromosome 2 linked to the Pi-b gene (Wangetal., 1999) andRM206 5-cccatgcgtttaactattct-3, RM206R 5- cgttccatcgatccgtatgg-3on chromosome 11l inked to the Pi-kh gene (Sharmaetal.,2005) were used for selecting target genes.

BACKGROUND SELECTION

A total of 72 polymorphic markers were identified from 300 SSR markers with known chromosomal position covering all 12 rice chromosomes .SSR markers unlinked to the target gene covering the entire chromosome, including carrier chromosomes 2 and 11 that were polymorphic between the recurrent and donor parent ,were used for the background selection to recover the recurrent parent genome. Atleast five polymorphic markers per chromosome were used to generate the data. The assessment of the recovery of the recurrent parent genome was based on the selection of SSR marker data that was carried out by using the software program Graphical Geno Types (GGTs) version2.0.

MARKER-ASSISTED SELECTION

Marker assisted selection (MAS) is of enormous use in gene pyramiding where the presence of more than one gene has to be confirmed. With the use of molecular techniques, it would now be possible to hasten the transfer of desirable genes among varieties. Availability of tightly linked genetic markers for resistance genes will help in identifying plants carrying these genes. Simultaneously without subjecting them to pathogen or insect attack in early generations. Thus with MAS it is now possible for the breeder to conduct many rounds of selection in a year without depending on the natural occurrence of the pest or pathogen and theoretically without the pest or pathogen as well.

MARKER-TRAIT ASSOCIATION

Marker-trait association was analyzed by using SAS9.3software to identify the association among the resistance component, i.e.,It has tightly linked polymorphic markers of corresponding blast resistance genes. Data of genotypic segregation of linked SSR markers obtained from the BC2F2 population were combined with phenotypic segregation data of the BC2F2 population for blast resistance traits. The data were interrogated to determine the

significance level and linear model regression analysis for association between the marker genotypes and resistance component traits.

MANAGEMENT FOR BLAST

In developing countries, poor farmers cannot afford to control blast disease by the application of chemicals and pesticides. Chemical control of plant pathogens is most effective and yet the use of chemicals is not generally desired due to the serious environmental threat it poses. Besides, their continuous use leads to the resurgence of resistant races of the pathogen under selection pressure. Although biocontrol agents for blast have been successfully deployed to combat the disease in the laboratory, greenhouse and field tests, the feasibility of such strategies on a commercial scale still remains to be tested. Use of resistant cultivars is the best alternative to overcome yield losses. The variability of the pathogen and the history of resistance breakdown have led to the development of a number of different plant breeding approaches to achieve durable blast resistance.

Disease management extremely needed to sustain the world for food consumption. Rice blast caused by M. oryzae is the most severe fungal disease, which limits the rice production and causing the yield loss of 157 million tons of rice per annum in the worldwide (Kaundaletal.,2006). Development of resistant varieties with durable resistance by incorporating new genes into the improved germplasm has been proved to be economical, environmentally friendly and effective to control the rice blast disease (SkamniotiandGurr,2009). The availability of different molecular tools allows characterization of genes of interest and identification of plants carrying the target genes and might well serves to improve the efficiency of conventional breeding. Due to molecular dissection it is now possible to identify blast resistance genes and QTLs or combined effects of multiple loci with major and minor effects. The marker developed from these genes or QTLs can be used in marker assisted selection for selection of resistance without confounding the effects of environmental factors.

Conclusion

Molecular markers associated with genes or QTLs have been reported for numerous economically-important traits in rice. Theoretically, such marker information should be useful for improving qualitative or quantitative traits in rice via marker assisted breeding. In practice, while markers have been used rather extensively for improving complex traits. This has been due to various reasons, including population specific marker (e.g., lack of correspondence between

QTLs identified in interspecific populations and those existing in breeding populations), lack of marker validation by repeating experiments, lack of polymorphism in breeding populations, and linkage drag. For simple inherited characteristics, in particular blast disease resistance traits, however, markers have been used for rice breeding to great extent in both public and private-sector breeding programs. MAS is not only faster than phenotypic selection but it is also cheaper and more efficient. The present study suggests that DNA markers for blast resistance (putative Pi-b and Pi-kh) genes are reliable for marker-assisted selection of blast resistance in rice breeding. The recovery of the recurrent parent along with the intogression of blast resistance genes with MABC breeding was much faster than that with conventional breeding. To our knowledge, this is the first report on the successful introgression of blast resistant genes(Pi-b and Pi-kh) into the elite high yielding rice cultivar MR219 in Malaysia.

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CRISPR-CAS9 AND TRADITIONAL RECOMBINANT DNA METHODS: A COMPARATIVE ANALYSIS

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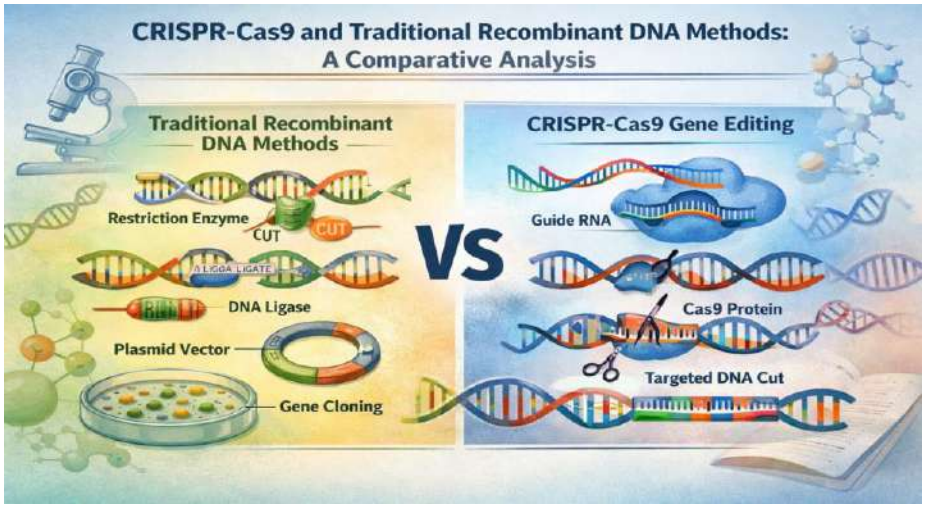
Introduction

Genetic engineering has come a long way—from the early days of carefully cutting and joining DNA fragments in the lab to the modern ability to edit genes with remarkable accuracy. Traditional recombinant DNA techniques were the stepping stones that first allowed scientists to modify genetic material. Using tools like restriction enzymes, ligases, and cloning vectors, researchers learned how to insert, remove, or rearrange genes, opening the door to breakthroughs in medicine, agriculture, and biotechnology. However, these methods could be slow, technically demanding, and not always precise in where changes occurred. The arrival of CRISPR-Cas9 changed that landscape in a dramatic way. Inspired by a natural defense mechanism found in bacteria, CRISPR-Cas9 acts like a programmable pair of molecular scissors. With the guidance of a short RNA sequence, it can target almost any gene and make edits quickly and with far more accuracy than older techniques. This innovation has shifted gene editing from a complex challenge to a powerful tool accessible to more scientists across the world. Comparing CRISPR-



Cas9 with traditional recombinant DNA methods helps us understand not just how the technology has evolved, but also why it matters. By looking at their differences in precision, speed, and application, we can better appreciate how far genetic engineering has advanced—and where it may take us in the future.

Mechanisms of Action

The fundamental difference between these two technologies lies in how they "navigate" to the target DNA sequence.

Recombinant DNA (Restriction Enzymes)

Traditional rDNA relies on **Restriction Endonucleases**. These are proteins that recognize specific, often short, palindromic sequences of DNA (typically 4–8 base pairs long). The key analogy is that a restriction enzyme is like a physical key that only fits one specific lock. To change your target, you must find an entirely different "key" (a different protein). Scientists use these enzymes to cut DNA at specific sites, then use **DNA Ligase** to "paste" the desired gene into a plasmid or vector.

CRISPR-Cas9

CRISPR-Cas9 is a bipartite system consisting of a **Cas9 protein** (the "scissors") and a **Guide RNA** (the "GPS"). The programming analogy include instead of finding a new key, you simply reprogram the GPS. By changing the sequence of the 20-nucleotide Guide RNA (gRNA), you can direct the Cas9 protein to virtually any location in the genome. The gRNA binds to the target DNA via base-pairing. Cas9 then creates a double-strand break (DSB), triggering the cell's natural repair mechanisms (NHEJ or HDR) to either delete or insert genetic material.

Key Comparative Features

The following table summarizes the practical differences between the two methodologies:

Feature	Recombinant DNA (Traditional)	CRISPR-Cas9
Targeting	Limited by available restriction sites.	Nearly universal (requires only a PAM site).
Precision	Often involves random integration (transgenics).	Highly precise, site-specific editing.
Ease of Use	Labor-intensive; requires protein engineering.	Simple; requires only RNA synthesis.

Feature	Recombinant DNA (Traditional)	CRISPR-Cas9
Multiplexing	Extremely difficult to edit multiple genes.	Can target multiple genes simultaneously.
Timeframe	Months to years for complex organisms.	Weeks to months.
Regulatory Status	Heavily regulated as "GMOs."	Often "Gray area" (may not be labeled GMO).

Advantages and Limitations

The Persistence of Traditional Methods

Despite CRISPR's dominance, traditional rDNA remains relevant in specific niches:

Large Cargo: Traditional vectors are often better at carrying very large gene sequences (over 100kb).

Off-Target Effects: CRISPR can sometimes cut DNA at unintended sites that resemble the target sequence.Traditional restriction enzymes, while less flexible, are often more predictable within their specific recognition sites.

Standardized Production: For the mass production of proteins like insulin, traditional plasmid-based rDNA is still the industry standard.

The "CRISPR Revolution"

The primary advantage of CRISPR is its **democratization** of gene editing. Because it is inexpensive and requires minimal specialized equipment, even smaller laboratories can perform advanced genomic research. Additionally, its ability to perform **multiplexing** allows researchers to study complex polygenic traits—something that was nearly impossible with traditional cloning.

1. Efficiency and Success Rates

The most striking difference between the two technologies is the probability of a successful genetic edit.

Traditional rDNA (Homologous Recombination): In eukaryotic cells, the efficiency of traditional gene targeting (without a nuclease) is notoriously low, often cited at **in to cells**. This required massive screening of colonies to find a single successful event.

CRISPR-Cas9: In contrast, CRISPR-mediated editing typically achieves efficiencies ranging from **20% to over 60%** in many plant and animal models. For example, a 2021 study on rice showed an average mutation frequency of **59.4%** across multiple target genes.

2. Market Dominance and Economic Impact

As of **2025**, the global genome editing market is estimated to be worth approximately **$10.98 billion**, with a projected compound annual growth rate (CAGR) of **16.95%** through 2034.

Market Share: By 2023, CRISPR-Cas9 already accounted for more than **44%** of the total revenue in the gene-editing sector, effectively sidelining older methods like ZFNs (Zinc Finger Nucleases) and TALENs in academic research.

Cost Reduction: Customizing a guide RNA (gRNA) for CRISPR costs roughly **$10–$50** and takes 2–3 days. In comparison, engineering specific proteins for traditional methods or older nucleases could cost **thousands of dollars** and take weeks of specialized labor.

The Flaws of First-Generation rDNA

While traditional recombinant DNA (rDNA) methods (often referred to as "first-generation" genetic engineering) were revolutionary in the 1970s and 80s, they possess several inherent flaws that CRISPR-Cas9 was specifically designed to overcome. The primary disadvantages of traditional methods can be categorized into lack of precision, inefficiency, and regulatory complexity.

1. Random Integration and Insertional Mutagenesis

A major limitation of traditional recombinant DNA methods is the lack of control over where new genes integrate into the genome. When viral vectors such as lentiviruses or retroviruses are used for gene delivery, the inserted DNA is integrated randomly into the host genome. This creates a risk known as insertional mutagenesis, where the introduced gene may disrupt essential regions like tumor-suppressor genes, potentially leading to cancer. A notable example occurred during early gene therapy trials for Severe Combined Immunodeficiency (SCID) in the 1990s, when several patients developed leukemia after therapeutic genes integrated near the oncogene LMO2, triggering uncontrolled cell division.

2. Low Targeting Efficiency

Traditional gene targeting methods that operate without modern nucleases like Cas9 depend on a naturally rare process called Homologous Recombination (HR). In mammalian cells, successful HR events occur at a rate of roughly 1 in 1,000,000 cells, making precise edits

extremely inefficient. To identify the few successful modifications, researchers were often required to rely on selection markers and screen thousands of cell colonies—a process that could take 6 to 12 months just to create a single knockout mouse line. By comparison, CRISPR dramatically improves this efficiency, often achieving 20–60% success rates because the targeted DNA break forces the cell to repair the correct site.

3. The Restriction Site Bottleneck

Traditional cloning also faces physical and sequence-based limitations due to reliance on restriction enzymes, which cut DNA only at specific palindromic sequences, such as GAATTC for EcoRI. This means that if the target gene contains these sequences internally, the enzyme may unintentionally cut it apart. In many cases, scientists had to introduce silent mutations just to make the gene compatible with available enzymes. Editing was limited to where these restriction sites existed, making researchers "slaves" to the DNA's natural sequence. CRISPR bypasses this obstacle, requiring only a short PAM sequence (like NGG), which is present across roughly 90% of the human genome, vastly expanding targetability.

4. Scalability and Multiplexing Limitations

Another major drawback of traditional methods is their lack of scalability. Edits must be performed one gene at a time, which becomes a major challenge when studying complex disorders that involve multiple genetic factors. For instance, modifying three different genes might require three full cycles of cloning, selection, and breeding—potentially stretching the project over several years. CRISPR introduces a more efficient alternative with multiplexing, allowing multiple guide RNAs to target several genes at once, enabling simultaneous edits within a single step.

5. High Cost and Time Requirements

Finally, traditional recombinant DNA approaches come with high financial and time investments. Custom protein engineering for older editing tools like ZFNs or TALENs, or extensive colony screening for rDNA workflows, often costs between $5,000 and $25,000 per project. The timeline is equally demanding: producing a transgenic plant or animal through conventional methods can take 1 to 2 years. In contrast, CRISPR can achieve comparable outcomes in as little as 2 to 4 months, dramatically lowering barriers to entry for research laboratories worldwide.

Precision vs. Predictability: Navigating the Downsides of Modern Genetic Tools

While CRISPR-Cas9 is a transformative tool, it is not a "magic wand." By 2025, as therapies move from the lab to the clinic, several critical technical, biological, and ethical limitations have become the primary focus of researchers.

The limitations of CRISPR-Cas9 can be divided into four main categories:

1. Technical & Biological Limitations

1.1 Off-Target Effects

Even with its "GPS" (Guide RNA), CRISPR can occasionally cut at unintended sites that are similar to the target sequence.The risk is that Off-target cuts can lead to chromosomal translocations, unintended gene knockouts, or the activation of oncogenes (cancer-causing genes). While AI-driven algorithms have improved prediction, completely eliminating off-target risk remains a hurdle for *in vivo* human therapies.

1.2 Mosaicism

When CRISPR is used in embryos or early-stage organisms, it doesn't always edit every cell. Some cells may be edited while others remain "wild-type" or contain different mutations. This creates a "patchwork" organism (a mosaic), which can lead to unpredictable health outcomes or failure to cure the disease.

1.3 Low Efficiency of Precise Repair

One of the key limitations of CRISPR-Cas9 lies in the challenge of achieving precise DNA repair. Although CRISPR creates a targeted break in the DNA, the cell ultimately decides how that break is repaired, and most cells default to a faster but less accurate pathway known as Non-Homologous End Joining (NHEJ). This “quick and dirty” repair method often introduces random insertions or deletions at the cut site. In contrast, the pathway required for precise gene insertion—Homology-Directed Repair (HDR)—is far less efficient, especially in non-dividing cells such as neurons or cardiac muscle cells. As a result, while CRISPR easily enables gene disruption, its ability to perform highly accurate edits remains limited by the cell’s own repair preferences.

2. Delivery and Logistics

The Cas9 protein is physically large.Common delivery vehicles like **Adeno-associated viruses (AAVs)** have a limited "payload" capacity. Fitting both the large Cas9 gene and the Guide RNA into a single viral shell is a tight squeeze, often requiring scientists to use smaller,

less-studied Cas variants (like *SaCas9*).Getting CRISPR components specifically to the lungs, brain, or pancreas without affecting the rest of the body is difficult. As of 2025, **Lipid Nanoparticles (LNPs)** are the gold standard for liver delivery, but reaching other organs still faces high rates of "clearance" by the immune system or the kidneys.

3. Immunogenicity (Immune Response)

Since the Cas9 protein is derived from bacteria (*Streptococcus pyogenes*), the human immune system may recognize it as an invader. **Pre-existing Immunity:** Studies have shown that up to **79% of humans** already have antibodies or T-cells against Cas9 because they have been exposed to these bacteria in common infections (like strep throat). The Consequence is that the immune system might destroy the edited cells or cause a dangerous inflammatory "cytokine storm" upon treatment.

4. Ethical and Regulatory Barriers

Limitation	Description
Germline Editing	Editing sperm, eggs, or embryos means the changes are inherited by future generations. This is currently banned or strictly limited in most countries due to the "unknown unknowns" of long-term evolution.
Equity & Access	With therapies like Casgevy costing **$2.2 million per patient**, CRISPR risks becoming a tool available only to the extremely wealthy, widening the global health gap.
"Designer Babies"	The thin line between *therapeutic* editing (curing a disease) and *enhancement* (increasing height, intelligence, or athletic ability) remains a major philosophical and regulatory challenge.

Conclusion: The Future of Genomic Architecture

As of 2025, the discussion surrounding traditional recombinant DNA methods and CRISPR-Cas9 is no longer about competition, but about how the two complement each other. Recombinant DNA still acts as the dependable “workhorse” of biotechnology, powering large-scale production of insulin, growth hormones, and industrial enzymes—technologies that keep healthcare and biomanufacturing running. Meanwhile, CRISPR-Cas9 has taken the lead in areas where precision truly matters, such as personalized medicine, gene therapy, and functional genomics. This year feels like a turning point: the early limitations of CRISPR—like off-target

edits and the bulky Cas9 protein—are being tackled by next-generation tools. Prime Editing now makes it possible to "search and replace" DNA without breaking the helix, Base Editing can change a single nucleotide with striking efficiency, and AI tools can predict the best guide RNAs before experiments even begin. These innovations are making gene editing more accessible than ever, no longer restricted to top-tier labs. Yet, a new challenge has emerged. With therapies like Casgevy carrying multi-million-dollar price tags, the bottleneck is no longer scientific—it's economic. The world now faces the question of how to make these life-changing treatments affordable to everyone who needs them. In many ways, the story of biotechnology has shifted: we are moving from the age of genetic transfer through recombinant DNA to the age of genetic surgery powered by CRISPR.

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NON-APIS POLLINATORS ROLE IN PULSE PRODUCTIVITY

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Abstract

Pulses are the cornerstone of India's nutritional security and sustainable agriculture. Though widely regarded as self-pollinated crops, increasing scientific evidence demonstrates that non-apis pollinators includes wild bees such as carpenter bees, leafcutter bees, sweat bees, mining bees, and bumble bees, significantly enhance pod set, seed quality, and yield stability in pulses. Studies from pigeonpea, soybean, and alfalfa indicate measurable yield gains due to insect visitation. In Indian rainfed and semi-arid agro-ecosystems, conservation and management of non-apis pollinators present a low-cost and climate-resilient strategy to boost pulses' productivity while safeguarding biodiversity.

Keywords: Pulses, non-apis bees, Pollination, Yield enhancement, Sustainable agriculture

Introduction

India is the world's largest producer and consumer of pulses, cultivating crops such as chickpea, pigeonpea, lentil, greengram, blackgram, field pea, and soybean across diverse agro-ecological zones. Pulses provide 20–25% dietary protein and improve soil fertility through biological nitrogen fixation.

Globally, 87 of the 115 major food crops depend on animal pollination (Klein *et al*., 2007). The economic value of insect pollination is estimated at €153 billion annually (Gallai *et al*., 2009). Pulses are recognized as crops that benefit from bee-mediated pollination, and

strengthening plant–pollinator interactions enhances productivity. Although pulses are considered self-pollinated, research clearly shows that even self-compatible crops experience improved yield when visited by insects (Esquivel *et al*., 2021). Non-Apis bees such as carpenter bees (*Xylocopa* spp.), leafcutter bees (*Megachile* spp.), and sweat bees (*Halictus* spp.) are important pollinators of pigeonpea, facilitating natural outcrossing in this partially cross-pollinated crop. Studies have shown that insect-mediated pollination, particularly by wild bees, can increase pigeonpea yield by about 15–30%, and hybrid pigeonpea developed through insect-assisted cross-pollination has demonstrated **yield advantages of up to 47% over conventional varieties** (Saxena, 2006; Suso *et al*., 2016). This paradigm shift highlights the importance of non-apis pollinators in pulse cultivation.

Diversity of Non-apis Pollinators in India

India hosts more than 760 species of bees across six families (Ghosh *et al*., 2024). Except for honey bees (*Apis* spp.), the rest are collectively termed non-apis or wild bees.

Important non-apis pollinators associated with pulse ecosystems (Fig. 1) include:

Fig. 1. Major non-Apis pollinators in the pulse ecosystem

(Image credit: Wikimedia Commons, Creative Commons licenses)

- Carpenter bees (*Xylocopa* spp.)
- Leafcutter bees (*Megachile* spp.)

- Sweat bees (*Halictus*, *Nomia*, *Lasioglossum*)
- Mining bees (*Andrena* spp.)
- Bumble bees (*Bombus* spp.) (Himalayan regions)
- Stingless bees (Meliponini)

These bees vary in size, foraging behavior, and nesting biology, often making them highly efficient pollinators under field conditions. Garibaldi et al. (2013) demonstrated that non-Apis bees enhance fruit sets twice as effectively as honey bees, and their contributions are complementary rather than substitutive.

Floral Biology of Pulses and Pollination Efficiency

Pulse flowers are papilionaceous, with reproductive organs enclosed inside keel petals. Effective pollination requires mechanical pressure for pollen release.

Large-bodied bees like carpenter bees and leafcutter bees:

- Depress the keel petals.
- Expose stamens and stigma.
- Facilitate efficient pollen transfer.

This results in:

- Higher pod set.
- Increased seeds per pod.
- Better seed filling.
- Improved 100-seed weight

Enhancing insect-mediated outcrossing in pulses has been identified as a promising approach for yield improvement.

Case Studies

1. Pigeonpea – Natural Outcrossing and Hybrid Success

Pigeonpea is a partially cross-pollinated crop with natural outcrossing ranging from **20–70%**. In India's semi-arid tropics, non-Apis bees such as carpenter bees (*Xylocopa* spp.) and leafcutter bees (*Megachile* spp.) play a major role in facilitating natural outcrossing by effectively triggering the papilionaceous flowers. Bumble bees (*Bombus* spp.), though mainly distributed in temperate and Himalayan regions, are also efficient pollinators of pulses due to their large body size and strong foraging activity, which enable effective pollen transfer between flowers. The development of hybrid pigeonpea exploiting insect-mediated cross-pollination has

shown yield superiority of up to 47% over traditional cultivars, demonstrating the significant contribution of wild pollinators in improving productivity and genetic diversity (Suso *et al*., 2016; Potts *et al*., 2016).

2. Chickpea – Improved Pod Formation

Though predominantly self-pollinated, chickpea fields in Punjab, Haryana, and Madhya Pradesh show improved pod setting in the presence of wild bee activity. Under fluctuating temperatures in rainfed systems, insect visitation improves fertilization efficiency and seed filling.

3. Greengram and Blackgram – Bund Vegetation Effect

In southern and eastern India, maintenance of flowering weeds along bunds increases the abundance of sweat bees and mining bees. Such ecological management enhances pod number and seed weight, aligning with conservation strategies.

4. Soybean – Evidence from Mass-Flowering Legumes

Soybean produces abundant florets and attracts diverse bee species. Studies report:

- 6–20% yield increase with bee visitation
- Increased yield when nesting habitats for native bees are preserved.

These findings reinforce the importance of non-apis pollinators in pulse ecosystems.

5. Alfalfa – Demonstration of Pollinator Impact

The introduction of the leafcutter bee (*Megachile rotundata*) increased alfalfa seed yield from 50 kg/ha to 350 kg/ha and up to 1000 kg/ha with improved management. This example illustrates the transformative impact of non-apis pollinators in leguminous crops.

Ecological Compatibility with Indian Pulse Systems

Adaptation to Semi-Arid Conditions

Many pulses are cultivated in rainfed conditions. Several non-apis bees are ground nesters, preferring sandy soils (Abrol *et al*., 2013), making them naturally suited to pulse agroecosystems.

Climate Resilience

Non-apis bees often forage at higher temperatures and under variable climatic conditions, ensuring pollination stability.

Complementary Pollination

Wild bees supplement honey bee activity, ensuring resilience and reducing dependency

on a single pollinator group.

Threats to Non-Apis Pollinators

Pollinator decline is attributed to:

- Indiscriminate pesticide use.
- Habitat destruction.
- Monocropping systems.
- Climate change.
- Parasites and disease.

Strategies to Enhance Pollination in Pulses

1. Habitat Conservation

- Maintain flowering bund vegetation.
- Preserve undisturbed soil patches.
- Plant border crops like mustard and coriander.

2. Integrated Pest Management

- Avoid spraying during flowering.
- Prefer biopesticides.
- Spray during evening hours.

3. Nesting Enhancement

- Provide wooden blocks for carpenter bees.
- Install trap nests for mason bees.
- Reduce deep ploughing during nesting periods.

Conclusion

Non-apis pollinators are silent yet powerful contributors to pulses productivity in India. Scientific evidence clearly demonstrates that even self-pollinated legumes benefit significantly from insect visitation. Given India's dominance in pulses cultivation and the prevalence of smallholder farming, promoting pollinator-friendly practices can enhance yield, stabilize production under climate stress, and conserve biodiversity. Strengthening non-Apis pollinator populations is not merely an ecological concern; it is a strategic necessity for India's food and nutritional security.

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ASSOCIATION OF CONSTANS LIKE PROTEINS IN PLANT FLOWERING AND ABIOTIC STRESS RESPONSE

Article ID: AG-VO6-I04-34

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Introduction

Flowering is a critical developmental transition in plants that directly influences reproductive success and crop productivity. The proper timing of flowering ensures successful pollination, seed formation, and maturation under favorable environmental conditions. Plants integrate environmental signals such as photoperiod, temperature, and abiotic stresses to precisely regulate floral transition (Zhang *et al*., 2023).

The CONSTANS (CO) gene and its homologous CONSTANS-Like (COL) gene family are key regulators of photoperiodic flowering. COL proteins are zinc-finger transcription factors characterized by conserved B-box domains and a CCT (CONSTANS, CONSTANS-Like, and TOC1) domain. These proteins act as molecular links between the circadian clock and downstream flowering genes. In the well-established CO–FT pathway, CO activates the expression of *FLOWERING LOCUS T (FT)*, which functions as a mobile floral signal inducing flowering at the shoot apical meristem (Steinbach, 2019).

Based on conserved domain organization, COL proteins are classified into three subfamilies. Although the core CO–FT module is evolutionarily conserved across plant species, functional divergence exists between long-day and short-day plants. For example, in *Arabidopsis thaliana*, CO promotes flowering under long-day conditions, whereas in *Oryza sativa* (rice), the CO homolog Hd1 exhibits dual functions depending on day length.Recent studies suggest that COL proteins function beyond photoperiod regulation and serve as integration hubs connecting flowering pathways with abiotic stress responses. Evidence indicates their involvement in drought, salt, and cold stress through interactions with hormonal signaling pathways, particularly abscisic

acid (ABA). This dual functionality highlights the role of COL genes in balancing growth, reproduction, and stress adaptation.

In major cereal crops such as wheat (*Triticum aestivum*), which possesses a complex hexaploid genome (AABBDD), the COL gene family remains less characterized compared to model plants. Given the increasing challenges posed by climate change and environmental stresses, understanding the structural, evolutionary, and functional aspects of COL genes is essential for developing early-maturing and stress-resilient crop varieties.

Proper regulation of flowering time is essential for reproductive success and crop productivity. In *Arabidopsis thaliana*, the florigen gene *FLOWERING LOCUS T (FT)* is positively regulated by CONSTANS (CO), a BBX transcription factor. Steinbach (2019) investigated the function of CONSTANS-LIKE 4 (COL4), whose role in flowering was previously unclear. The study demonstrated that COL4 acts as a flowering repressor under both long-day and short-day conditions by regulating *FT*, *FT-like genes*, and *SOC1*. Reduced COL4 expression resulted in increased *FT* and *AP1* expression and accelerated flowering, whereas overexpression delayed flowering. Co-localization of COL4 and CO in nuclear speckles suggests an antagonistic interaction that fine-tunes flowering time control.

Farokhpouri*et al*. (2025) reported that 51 CONSTANS-like (TaCOL) genes were identified in wheat and grouped into nine phylogenetic clades, showing an uneven distribution across chromosomes. Promoter analysis revealed the presence of light-responsive and ABA-responsive cis-elements, indicating that these genes may participate in photoperiod regulation and stress responses. Expression analysis demonstrated that many TaCOL genes are expressed in different tissues, especially in leaves, and several members respond to drought stress. Under drought conditions, different TaCOL genes showed distinct expression patterns. The drought-tolerant synthetic wheat line R16P1 exhibited higher antioxidant enzyme activity and better chlorophyll retention compared to its parental cultivar Pishgam. Furthermore, qPCR validation showed stronger drought-induced expression of selected TaCOL genes in R16P1, suggesting their important role in heading date regulation and drought tolerance.

CONSTANS-like (COL) proteins are central regulators of photoperiodic flowering, linking the circadian clock with activation of the FT pathway. Structural analysis shows that COL proteins contain conserved B-box and CCT domains and are classified into three subfamilies. Functional studies in Arabidopsis demonstrate that COL members such as COL4 act as flowering repressors

and fine-tune CO activity. COL proteins function as integration hubs coordinating light signaling, transcriptional regulation, and post-translational control mechanisms. Emerging evidence indicates that COL genes also interact with abiotic stress pathways, particularly drought and ABA signaling. Overall, COL proteins play a crucial role in balancing flowering time regulation and environmental adaptation in plants.

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OZONE AS A GREEN ALTERNATIVE IN FOOD PROCESSING

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Abstract

Ozone processing is a green, economical technology of industrial interest for ensuring food safety. Ozone is a non-thermal, powerful oxidizing and antimicrobial agent that has been widely used for decontamination in many industries, including food, water treatment, pharmaceuticals, textiles, healthcare, and medical sectors. O_3 is an alternative preservation method that is most suitable for decontamination, guaranteeing the microbiological hygiene and safety of food products. It has been demonstrated as a potential way for reducing pollutants in dairy industry effluents. Ozone is a strong oxidizing agent that is mainly used in water treatment, sanitizing, removal of undesired odors, and the fruit, vegetable, meat, and poultry processing industries.

Introduction

Food quality and safety are being improved through expanding initiatives within the food processing industry worldwide. Recently, the preference of consumers is changing towards the organic foods which are tastier, free from any additives and having a longer shelf life. In food preservation techniques ozone based technology is advantage for the producers and the consumers. O3 is considered a promising alternative processing technique for enhance the food safety due to its very rapid action and its strong oxidative characteristics. Ozone is an effective and promising non thermal food processing technique used as an alternative to conventional heating treatment because of its economical and environmentally beneficial. Ozone (O3) has recently been recognized as an innovative preservation method, driven by consumer preference for fresh and safe foods in which sensory characteristics and nutritional quality are preserved and no detectable chemical residues remain after treatment. Ozone was classified as Generally

Recognized as Safe (GRAS) in 1997, and in 2001 it was officially authorized by the Food and Drug Administration (FDA) for use in the food industry, including applications involving direct contact with food products.

What exactly is ozone?

Ozone is widely regarded as a strong oxidizing agent with broad-spectrum antimicrobial activity against bacteria, molds, protozoa, and viruses. Its antimicrobial action occurs through oxidative reactions with essential cellular constituents, including proteins, enzymes, unsaturated fatty acids, and nucleic acids, resulting in damage to the cell wall and membrane and subsequent cell destruction. Ozone (O_3) is an allotrope of oxygen that is synthetically generated by the dissociation of molecular oxygen (O_2) followed by recombination into a triatomic form. Ozone is commonly produced by two methods at the commercial level, namely corona discharge and ultraviolet-based photochemical generation. In the corona discharge method, ozone is produced by applying a high voltage across a dielectric barrier, creating a strong electric field that facilitates the conversion of oxygen into ozone. The diatomic molecules are split into single reactive oxygen atoms, which are subsequently combined with oxygen molecules to produce triatomic ozone.

The effectiveness of the ozone generation process is mainly influenced by several parameters, including the magnitude of the applied voltage, the characteristics of the dielectric material, the width of the discharge gap, and operational factors such as temperature and pressure.

Application of ozone in Food Processing

Ozone is widely used to disinfect processing environments, including production areas, equipment, and contact surfaces, as well as for fumigation and sterilization. In addition to its role in sanitizing equipment and surfaces, ozone is also employed for the preservation of foods and the extension of their shelf life

Grain Storage

Ozone has been widely recognized as an effective fumigant for managing insect infestations in stored agricultural commodities and as a strong antimicrobial agent with minimal adverse effects on grain quality. When ozone gas is applied in storage silos, it rapidly interacts with insect pests and contaminating microorganisms, damaging cellular structures or interfering with essential metabolic activities. Several investigations have demonstrated the effectiveness of

ozone in controlling key storage insects, including the rice weevil, red flour beetle, and lesser grain borer. Moreover, ozone treatment has been reported to inhibit mold growth and facilitate the breakdown of existing mycotoxins, thereby improving the safety and quality of stored food products.

Fruits and Vegetables

Due to their high moisture content and metabolic activity, fruits and vegetables are highly perishable and susceptible to microbial spoilage. Ozone-based treatment has been applied as an alternative preservation method for various food products, including processed items such as jams, jellies, pickled products, and fermented foods. In fruit and vegetable processing, ozonation is employed to suppress pathogenic and spoilage microorganisms, minimize mycotoxin contamination, and promote the breakdown of pesticide and other chemical residues. Beyond food applications, ozone is also used for wastewater treatment, drinking water sanitation, and surface decontamination of fresh produce, thereby improving safety and hygiene.

Meat and Poultry processing

Ozone is widely used for surface decontamination of carcasses, meat cuts, and poultry parts due to its strong antimicrobial and oxidizing properties. It also effectively destroys microorganisms such as *Salmonella, Listeria, and E. coli without affecting* product quality. In a meat and poultry processing plant, ozonated water and gas are used to sanitize equipment, conveyor belts, and knives, and to reduce cross-contamination. Furthermore, ozone gas played an important role in wastewater and odor treatment, oxidizing volatile compounds and organic matter. Aqueous ozonation was used to wash fish to reduce the microbial flora. The ozone treatment had no adverse effect on product quality.

Water treatment

In the food processing industry, ozonated water is widely used for washing raw materials, cleaning equipment, and ensuring a hygienic water supply without leaving chemical residues. Ozone also helps in oxidizing organic and inorganic contaminants, such as iron, manganese, and sulfur compounds. Ozone will not release any harmful residues in water. In the food processing industry, water is considered a vital component, as it is extensively used across numerous processing operations. It is commonly employed in unit processes such as blanching, chilling, cooling, heating, pasteurization, rinsing, soaking, and washing, as well as for generating steam, making it an indispensable resource in food manufacturing.

Conclusion

Ozone has been recognized as a promising non-thermal technology in food processing, as its application does not require elevated temperatures and is considered energy efficient. Concerns have been raised about its use in food systems because ozone can act as an irritant and a toxic gas at high concentrations. However, when used under controlled conditions, ozone is regarded as a safe and environmentally friendly disinfectant. It rapidly decomposes into molecular oxygen, leaving minimal residues, and therefore exhibits only short-term effects, making it suitable for food preservation. Furthermore, the combined application of ozonation with other preservation techniques, such as pasteurization, ultraviolet treatment, high-pressure processing, membrane technologies, and freezing, has been reported to enhance microbial control and extend the shelf life of food products.

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RETHINKING COMMUNICATION IN INNOVATION: NETWORK BUILDING, SOCIAL LEARNING AND POWER DYNAMICS

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Abstract

Agricultural innovation has shifted from a linear knowledge transfer model to a more interactive and participatory approach. Traditional communication systems often failed to address the complex and diverse challenges faced by farmers. There is a need to rethink communication in agricultural innovation through network building, social learning and the management of power dynamics. This shows that innovation emerges from multi-stakeholder interactions and emphasizes the role of communication in facilitating collaboration, trust and knowledge exchange. This concept also explores the evolving role of extension professionals as facilitators and innovation brokers. Addressing power imbalances and promoting inclusive dialogue are essential for equitable development. So that, rethinking communication in innovation systems is essential for promoting sustainable and inclusive agricultural development.

Keywords: Agricultural innovation, Communication, Social learning, Innovation networks, Power dynamics

Introduction

Agricultural development has traditionally relied on a linear model of communication, where knowledge flows from researchers to extension agents and finally to farmers. This approach, strongly influenced by the work of Everett Rogers, assumes that farmers are passive recipients of information. However, this model has been widely criticized for its inability to address the diverse, complex and location specific challenges faced by farmers such as resource constraints, risk, socio-cultural factors and institutional barriers. In recent years, the agricultural sector has undergone significant transformation requiring more inclusive, participatory and

adaptive approaches to knowledge sharing and innovation. So that, innovation is no longer viewed as a simple transfer of technology but as a multi-actor, interactive and socially embedded process. As a result, the Organizations such as the Food and Agriculture Organization and the World Bank emphasize the need to adopt an Agricultural Innovation Systems (AIS) perspective, which recognizes innovation as a product of interaction among multiple stakeholders including farmers, researchers, policy makers and private sectors. Within this framework, communication is redefined as a process of dialogue, negotiation and collective learning, making it central to innovation. This article explores how communication must be rethought through network building, social learning and managing power dynamics and conflict.

Concept of innovation and communication

Innovation, as defined by the Organisation for Economic Co-operation and Development, refers to the implementation of new or significantly improved products, processes or organizational methods. In agriculture, innovation goes beyond technology to include institutional arrangements, market linkages and social changes. It emerges through the interaction of various stakeholders such as farmers, researchers, extension agents, private sector actors and policymakers. Communication plays a central role in enabling these interactions by facilitating the exchange of knowledge, coordinating actions and building mutual understanding among stakeholders. According to Rogers, communication is the process through which participants create and share information to reach a common understanding, highlighting its importance in innovation processes.

A key aspect of rethinking communication is the emphasis on network building. Innovation does not occur in isolation but through networks of interconnected actors who collaborate, share resources and jointly solve problems. Effective communication helps in creating and sustaining these networks by building trust, fostering relationships and enabling coordination. Innovation platforms, for example, provide spaces where stakeholders can come together to identify problems, share knowledge and co-develop solutions. In such settings, the role of extension workers shifts from that of information providers to facilitators and innovation brokers who connect different actors and support collaborative processes.

Social learning:

Another critical component of rethinking communication is the concept of social learning. Social learning refers to a process in which individuals learn collectively through interaction,

dialogue, reflection and shared experiences. It recognizes that learning is not just an individual activity but a social process that occurs within groups and communities. Social learning can be understood through several dimensions. The epistemological dimension focuses on the co-creation of knowledge by integrating scientific and local knowledge systems. The relational dimension emphasizes the importance of trust, cooperation and strong relationships among stakeholders. The collective or reflective dimension highlights the role of group reflection, discussion and joint decision-making in enhancing learning. The transformative dimension refers to the changes in attitudes, behaviours and social practices that result from collective learning. Mechanisms such as farmer field schools, farmer-to-farmer extension, participatory action research, digital platforms and reflective practice among extension workers facilitate social learning and contribute to innovation.

Dealing with power dynamics

In addition to networks and social learning, addressing power dynamics and conflict is crucial in innovation systems. Innovation processes are inherently political, as different stakeholders have varying interests, resources and levels of influence. Power determines who participates in decision-making, whose knowledge is valued and who benefits from innovation. Often, marginalized groups such as small farmers, women and landless labourers are excluded from these processes. Conflicts may arise due to competing interests, unequal resource distribution and differences in perspectives. If not managed effectively, such conflicts can hinder innovation. Communication plays a vital role in addressing these challenges by facilitating inclusive dialogue, ensuring participation and mediating conflicts. Participatory approaches such as focus group discussions and participatory rural appraisal help create spaces for dialogue and negotiation, enabling stakeholders to resolve conflicts and build consensus.

Conclusion

The changing nature of communication in innovation systems has also transformed the role of extension services. Traditionally, extension workers acted as instructors and technology transfer agents, delivering information to farmers. In the modern context, their role has evolved into that of facilitators, innovation brokers, network builders and conflict mediators. The Global Forum for Rural Advisory Services emphasizes that extension professionals need new competencies in facilitation, participatory communication and conflict management to effectively support innovation processes. So that, rethinking communication in innovation

systems is essential for promoting sustainable and inclusive agricultural development. It requires a shift from linear, top-down communication to interactive, participatory approaches that emphasize network building, social learning and the management of power dynamics and conflict.

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INTEGRATED FARMING: BRIDGING SUSTAINABILITY WITH PROFITABILITY

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1. Introduction

Name of farmer	Noor Mohmmad
Fathers name	Vali Mohammad
Village	Roon
Block	Mundwa
District	Nagaur
State	Rajasthan
Age	68
Education	8th

2. Situation Analysis:

He has 7.68 ha cultivable land, 35 years of experience in traditional farming and before the intervention of Krishi Vigyan Kendra, Nagaur-I, he was earning around Rs 3.0 lakh per year from agriculture and allied activities.

3. Technology, Implementation & Support:

After learning about the Integrated Farming System (IFS) model at his farm through Krishi Vigyan Kendra (KVK), Nagaur-I, the progressive farmer embraced scientific methods for cultivating both agricultural and horticultural crops along with livestock management. He actively participated in various training programmes organized by KVK, where he learned about soil preparation, nursery raising, crop management, and harvesting techniques. The trainings also helped him understand proper feeding, milking, and vaccination practices for animals. With regular support from KVK scientists, he started using fertilizers in a balanced way and improved

the productivity of his farm. At present, he grows pearl millet, clusterbean, onion, cumin, isabgol, paan methi, ber, and papaya, along with a nutrition garden for household use. He also rears hens, cows, and buffaloes, which provide milk, eggs, and manure. This integrated approach fulfills his family's needs and gives him additional income from the sale of surplus produce (Table:1.).

Table: 1. Economics of the Integrated Farming System model

S. No.	Component	Area (ha) / No.	Production (q / Litre / Nos.)	Cost of Cultivation (Rs.)	Gross Income (Rs.)	Net Income (Rs.)	B:C Ratio
1	Pearl Millet	1.25 ha	6.0 q	25,000	40,000	15,000	1.60
2	Mungbean	3.25 ha	11.4 q	75,000	1,40,000	65,000	1.87
3	Clusterbean	0.75 ha	3.0 q	20,000	45,000	25,000	2.25
4	Cumin (Var. GC-4)	1.75 ha	13.1 q	1,20,000	3,40,000	2,20,000	2.83
5	Onion	0.75 ha	280 q	90,000	2,50,000	1,60,000	2.78
6	Isabgol	4.5 ha	22.5 q	2,00,000	3,60,000	1,60,000	1.80
7	Ber (Gola & Umran)	0.25 ha	30 q	20,000	70,000	50,000	3.50
8	Papaya	1.75 ha	1,200 q	1,50,000	4,20,000	2,70,000	2.80
9	Cow (Milk: 10 L/day × 2 × 300 days)	2 Nos.	6,000 L	90,000	2,20,000	1,30,000	2.44
10	Nutri-garden (Vegetables & greens)	0.05 ha	10 q	5,000	15,000	10,000	3.00
11	Poultry (20 Birds × 200 Eggs)	20 Nos.	4,000 Eggs	25,000	40,000	15,000	1.60
	Total / Average		—	**8,20,000**	**19,40,000**	**11,20,000**	**2.4**

Technology Uptake & Benefits: During 2024–25, Noor Mohammad successfully implemented an Integrated Farming System (IFS) model under the scientific guidance of the KVK, Nagaur-I.

Fig.-1 Papaya orchard

Fig. 2 Cultivation of Onion

Fig. 3 Cultivation of Mungbean, Pearl millet, ber orchard with drip irrigation and animal husbandry

He adopted Integrated Nutrient Management (INM) practices in his major crops — cumin, isabgol, onion, mungbean, clusterbean, papaya, and ber — ensuring a balanced and efficient supply of nutrients that enhanced soil fertility and productivity. For his dairy unit, he regularly used a mineral mixture as advised by KVK scientists, resulting in improved animal health and milk yield. He followed the recommended improved seed varieties, optimum seed rates, balanced fertilization, and maintained timely irrigation, weed, and pest management across crops

and orchard systems. These scientific interventions not only boosted yields but also ensured efficient use of resources and ecological sustainability. Through the adoption of these improved and diversified Integrated Farming System practices, Noor Mohammad achieved a remarkable net return of ₹11,20,000 with a B:C ratio of 2.40, demonstrating that integration of crops, horticulture, livestock, and kitchen gardening can significantly enhance income and sustainability under semi-arid conditions of Nagaur, Rajasthan.

Technology Spread:

This innovative approach holds great potential to enhance the seed replacement ratio in the district, thereby leading to higher yields and improved farm profitability. Progressive farmer Noor Mohhammad has been instrumental in the horizontal spread of improved crop varieties, particularly cotton and cumin, by distributing quality seeds from his own harvest to around 60–75 farmers in nearby villages. His proactive efforts and farmer-to-farmer extension have significantly contributed to increasing productivity, promoting varietal adoption, and strengthening self-reliance among the farming community.

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CULTIVATION OF *GANODERMA LUCIDUM*: A PROMISING MEDICINAL MUSHROOM ENTERPRISE

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Abstract

Ganoderma lucidum, commonly known as Reishi or Lingzhi, is one of the most valuable medicinal mushrooms in the world. It possesses diverse therapeutic properties such as anti-cancer, anti-inflammatory, immunomodulatory, and antioxidant effects. Due to increasing global demand for natural health products, commercial cultivation of this mushroom has gained importance. The present article provides a simplified and practical overview of cultivation techniques, substrate preparation, environmental requirements, harvesting, and marketing opportunities based on recent research findings. The use of locally available agricultural wastes and sawdust substrates makes its cultivation economically viable for farmers and entrepreneurs. Proper management of environmental conditions and substrate composition plays a crucial role in achieving higher yield and biological efficiency.

Introduction

Medicinal mushrooms have been used in traditional systems of medicine for centuries, and among them, *Ganoderma lucidum* holds a unique place. It belongs to the Basidiomycetes group and is widely known as “Reishi” in Japan and “Lingzhi” in China. This mushroom has been used for more than 2000 years for treating various ailments including hypertension, diabetes, liver disorders, and cancer-related conditions.The growing awareness of herbal medicine and nutraceuticals has led to an increased demand for Ganoderma products worldwide. The global market value of Reishi mushroom is very high, and in India too, demand is increasing steadily. Since wild collection cannot meet this demand, artificial cultivation techniques have been developed using different substrates such as sawdust, agricultural residues, and wood logs.

Importance and Medicinal Value

Ganoderma lucidum is considered a "wonder mushroom" due to its wide range of bioactive compounds. It contains polysaccharides, triterpenoids, and antioxidants that contribute to its medicinal properties. Studies have shown that it exhibits anti-tumor, anti-inflammatory, anti-diabetic, hepatoprotective, and immune-enhancing activities.

Because of these benefits, it is not consumed as a regular food but processed into capsules, powders, teas, and extracts for medicinal use. The increasing preference for natural remedies makes it a highly profitable crop for cultivation.

Suitable Substrates for Cultivation

The success of Ganoderma cultivation largely depends on the type of substrate used. Research studies indicate that sawdust from broad-leaved trees such as mango, poplar, and coconut is highly suitable.

Different experiments have shown that:

- Sawdust supplemented with wheat bran or rice bran enhances growth and yield.
- Wheat bran is generally more effective than rice bran in improving biological efficiency.
- Certain substrates like *Swietenia mahagoni* sawdust produce higher yield compared to others.
- Agricultural by-products such as maize stem, coffee pulp, and bean residues can also be used, making cultivation cost-effective.

Preparation of Substrate and Spawning

The substrate is prepared by mixing sawdust with supplements like wheat bran (about 20%) and adjusting moisture content to around 65%. Calcium carbonate and gypsum are added to maintain pH around 5.5.

The prepared substrate is filled into polypropylene bags and sterilized at high pressure (autoclaving) to eliminate contaminants. After cooling, spawn (seed material) is added at about 3% of dry weight.

Incubation (Spawn Run)

After spawning, the bags are kept in dark conditions at temperatures between 28–35°C with high carbon dioxide levels. During this phase, the mycelium spreads throughout the substrate and completes colonization within 20–30 days.

Fruiting and Environmental Conditions

Once the substrate is fully colonized, the bags are opened to allow fruiting. Proper environmental conditions are essential:

Temperature: Around 28°C for pinhead formation

Relative Humidity: 90–95%

Light: Moderate light (about 800 lux)

CO_2 level: Around 1500 ppm initially

During cap development, humidity is reduced to about 80% and fresh air supply is increased. For maturation, temperature is lowered to around 25°C and humidity to 60%.

Harvesting and Yield

Fruiting bodies mature when the cap turns reddish-brown and spores begin to shed. Harvesting is done by careful plucking to avoid damage to the substrate.

Crop duration: About 3–4 months

Number of flushes: 2–3

Biological efficiency: Around 6–25% depending on substrate and management

Research studies reported yields up to 235 g/kg substrate under suitable conditions.

Post-Harvest Handling and Processing

After harvesting, mushrooms are washed and dried at low temperatures (below 50°C) to preserve bioactive compounds. Drying can be done using cabinet dryers or freeze drying for better quality.

The dried product is further processed into:

- Powder
- Capsules
- Extracts
- Herbal formulations

Marketing Opportunities

Ganoderma lucidum has excellent market potential due to its demand in the nutraceutical and pharmaceutical industries. Since it is used as a medicinal product rather than food, growers must target herbal medicine companies and health supplement industries.

Value addition through processing significantly increases profitability. Export potential is also high due to global demand.

Conclusion

The cultivation of *Ganoderma lucidum* offers a promising opportunity for farmers, entrepreneurs, and agri-startups. Its high medicinal value, increasing demand, and adaptability to low-cost substrates make it an ideal crop for diversification. Scientific cultivation practices, proper substrate selection, and environmental management are key factors for successful production. With growing interest in herbal medicine, Ganoderma cultivation can contribute to sustainable agriculture and rural income generation.

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VALUE ADDITIONS IN JACKFRUIT

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Introduction

Jackfruit, one of the underutilized fruit, has got the immense potential for value addition. A wide variety of items can be prepared from jackfruit right from immature stage to well-ripened stage. Each item has its own qualities in terms of taste, preference, shelf-life, etc. Because of its heaviness and large size, transportation and packaging are huge impediments to the successful marketing of jackfruit. Therefore, value-added products have more relevance for the commercial utility rather than the whole fruit. Jackfruit can be preserved by applying various techniques like drying, freezing, canning, or by converting it into various products.

Vacuum Fried Chips

Jackfruit chips are an immensely popular snack in Kerala, prepared by deep frying from fully mature and unripe jackfruit with a normal shelf life of more than a month. These chips are made with coconut oil commonly. In conventional frying, a higher frying temperature causes the charring of the fruit. High oil absorption and darkening of colour during deep-fat frying could be reduced significantly in Vacuum frying technology which is suitable for frying sugar-rich materials. It is carried out at pressures well below atmospheric level. It serves to reduce oil content, discolouration, and losses of vitamins and other compounds, normally associated with oxidation and high-temperature processing. Vacuum frying can be done with both matured and ripe jackfruit to produce a bright yellow and crunchy product. Oil retains its properties without change since low temperature and pressure are involved in the process thus the oil can be reused more than 60 times for vacuum frying through this technique. Nearly 90 % of oil use could be reduced compared to convention frying, making it a healthy alternative to conventional frying.

Jackfruit flour

The flour prepared by milling dried jackfruit bulbs extends the shelf life of jackfruit. Flour from matured bulbs has a yellowish-white colour. This can be used as an ingredient in many of the dishes like puttu, idly, chapati, kumbilappam, upma, pappad, etc. Jackfruit flour, as it is diabetic-friendly and gluten-free, can be used along with wheat flour for making soft chapattis and as a fortifier in every dish. Moreover, the nutritious fibre content in this flour can have several health benefits.

Ready to cook mature jackfruit

Mature jackfruit bulbs can be stored for a long time by the drying method. The packed RTC jackfruit extends the shelf life of jackfruit. It can be rehydrated and used for the preparation of dishes in offseason too. RTC jackfruit also gives additional income to farmers and processors.

Osmo-dried jackfruit

The ripening of jackfruit changes its texture. Softening of jackfruit bulbs adds more taste to the jackfruit. Different value-added products can be prepared from ripe jackfruit. One of the major traditional practices of preserving ripe jackfruits is dehydration. Jackfruit can be dried successfully to a sweet fruit snack. Dried jackfruit can be prepared easily through the process of osmotic dehydration of ripe jackfruit.

Osmotic dehydration of the fruits is one of the food preservation techniques used for partial removal of water from fruits by immersing in aqueous solutions of high osmotic pressure viz., sugar and salts. Intermediate moisture foods (IMF) are one of the major attractions in the current food market as this technology could preserve seasonally available fruits for a long period. This could be prepared by a two-stage drying process i.e. osmotic dehydration followed by any other secondary drying.

Osmo-dried jackfruit is an intermediate moisture food product, and is not only delicious but also conserves attractive colour and nutritional elements. This processed product has a six-month shelf life, which could reduce the wastage of surplus ripened jackfruit. The ripe jackfruit bulbs are deseeded and soaked in sugar syrup for osmotic dehydration and further dried using a cabinet dryer. The processing conditions like soaking time, the temperature of drying were also standardized. The second stage of drying could be done either by traditional drying, solar drying, cabinet drying, vacuum drying, or any other modern drying methods viz; fluidized drying, microwave drying, freeze-drying, etc.

Jackfruit 'Varatty'/'Halwa'

The 'varatty'/ 'halwa' can be prepared from ripe jackfruit pulp. Fruit pulper and concentrator can be utilised for the preparation of 'varatty' or 'halwa' with minimum time and efficiently. 'Varatty' can be preserved for three months by retort processing. 'Varatty' prepared from jackfruit is filled into retort pouches and then thermally treated for extension of shelf life.

Jackfruit Seed Powder

Jackfruit seeds are rich in nutrients and can be a supplement for wheat flour to some extent. Replacement of the wheat flour with jackfruit seed flour will give gluten-free products option. So, jackfruit seed powder is used to prepare cookies along with rice bran. The combination of wheat, jackfruit seed powder, and rice bran will give better acceptability. It is one of the best tastemakers for a healthy life. It can be fortified with flours of ragi, maize, rice, and banana and used for the preparation of pasta.

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SOIL MICROORGANISMS: KEY DRIVERS OF SOIL FERTILITY AND SUSTAINABLE AGRICULTURE

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Abstract

Soil microorganisms are essential components of the soil ecosystem and play a major role in maintaining soil fertility and agricultural sustainability. They participate in nutrient cycling, organic matter decomposition, nitrogen fixation, and soil structure improvement. Through their continuous biological activities such as decomposition, mineralization, and nutrient transformation, they ensure a steady supply of essential nutrients to plants. These organisms also contribute to plant growth and disease suppression. Their role in sustainable agriculture is increasingly important as they reduce dependence on chemical fertilizers and pesticides.

Introduction

Soil is a dynamic and living system inhabited by a wide range of microorganisms. Soil microbiology focuses on understanding these organisms and their functions in soil processes. Microorganisms influence soil fertility, plant growth, and overall soil health through their biological activities, including decomposition, nutrient transformation, and biological interactions within the soil environment.

Both plants and microorganisms interact closely in the soil ecosystem. Microorganisms decompose organic residues, release nutrients, and regulate their availability to plants. These processes ensure continuous nutrient cycling and maintenance of soil quality. Thus, microbial activities form the biological foundation for sustaining agricultural productivity.

Diversity of Soil Microorganisms

Bacteria

Bacteria are the most abundant microorganisms in soil and are actively involved in

nutrient transformation processes such as decomposition, mineralization, and nitrogen fixation. They convert organic materials into simpler forms and make nutrients available for plant uptake, thereby improving soil fertility.

Fungi

Fungi play a major role in the decomposition of complex organic substances such as cellulose and lignin. Through this process, they release nutrients into the soil and contribute to humus formation. Additionally, fungal associations like mycorrhizae enhance nutrient and water absorption in plants.

Actinomycetes

Actinomycetes are responsible for breaking down resistant organic materials and contribute to nutrient recycling. Their activity supports soil fertility and they also produce substances that influence microbial balance in soil.

Algae and Protozoa

Algae contribute to soil fertility through photosynthesis and add organic matter to the soil, while protozoa regulate bacterial populations. This microbial interaction helps maintain nutrient balance and supports continuous nutrient cycling.

Role of Microorganisms in Soil Fertility

Nutrient Cycling

Soil microorganisms play a central role in nutrient cycling by converting nutrients into plant-available forms. Through processes such as mineralization, ammonification, and nitrification, they ensure the continuous transformation of nutrients like nitrogen, phosphorus, and carbon within the soil system.

Organic Matter Decomposition

Microorganisms decompose plant residues and organic materials present in soil. This process leads to the formation of humus and the release of essential nutrients, thereby improving soil fertility and maintaining soil organic matter.

Nitrogen Fixation

Certain microorganisms have the ability to convert atmospheric nitrogen into usable forms. This biological nitrogen fixation enriches soil nitrogen content and reduces the dependence on synthetic fertilizers.

Important Soil Microorganisms and Their Functional Roles in Soil Fertility

Category	Microorganism	Key Function	Role in Soil Fertility
Bacteria	*Rhizobium leguminosarum*	Symbiotic nitrogen fixation	Converts atmospheric N_2 into usable form in legumes
	Azotobacter chroococcum	Free-living nitrogen fixation	Enhances soil nitrogen without host plant
	Azospirillum brasilense	Associative nitrogen fixation	Promotes root growth and nutrient uptake
	Nitrosomonas spp.	Ammonia oxidation	Converts $NH_4^+ \rightarrow NO_2^-$ (nitrification step)
	Nitrobacter spp.	Nitrite oxidation	Converts $NO_2^- \rightarrow NO_3^-$ (plant-available form)
	Bacillus megaterium	Phosphate solubilization	Converts insoluble P into available form
	Pseudomonas fluorescens	Plant growth promotion & biocontrol	Suppresses pathogens and enhances nutrient uptake
Fungi	*Trichoderma harzianum*	Biocontrol & decomposition	Suppresses pathogens and degrades organic matter
	Aspergillus niger	Organic matter decomposition	Breaks down complex organic substances
	Penicillium spp.	Phosphate solubilization	Enhances phosphorus availability
	Glomus spp.	Mycorrhizal association	Improves P uptake and water absorption
Actinomycetes	*Streptomyces spp.*	Decomposition & antibiotic production	Breaks down resistant materials and controls pathogens
	Nocardia spp.	Organic matter degradation	Supports nutrient recycling
Algae	*Anabaena spp.*	Nitrogen fixation	Adds nitrogen and organic matter to soil
	Nostoc spp.	Photosynthesis & nitrogen fixation	Improves soil fertility and structure
Protozoa	Protozoa (general)	Bacterial population regulation	Releases nutrients by grazing bacteria

Soil Structure Improvement

Microbial activities contribute to the formation of soil aggregates by producing binding substances. This improves soil structure, enhances aeration, increases water holding capacity, and creates a favorable environment for plant growth.

Microorganisms in Sustainable Agriculture

Microorganisms play a crucial role in sustainable agriculture by maintaining soil fertility through natural processes. Their involvement in nutrient cycling, decomposition, and nitrogen fixation reduces the need for chemical inputs. They also help maintain ecological balance and support long-term agricultural productivity.

Microbial Products in Agriculture

Biofertilizers

Biofertilizers contain beneficial microorganisms that enhance nutrient availability through biological processes. They improve soil fertility and provide an environmentally safe alternative to chemical fertilizers.

Biocontrol Agents

Microorganisms such as Trichoderma and Bacillus act as biocontrol agents by suppressing plant pathogens. They reduce disease incidence and minimize the use of chemical pesticides.

Organic Amendments

Organic materials such as compost support microbial growth and activity. They enhance nutrient availability, improve soil structure, and increase overall soil fertility.

Soil Microorganisms as Indicators of Soil Health

Soil microorganisms serve as important indicators of soil health. Parameters such as microbial biomass, enzyme activity, and soil respiration reflect the level of biological activity in soil. Higher microbial activity indicates improved soil fertility and better functioning of soil processes.

Agronomic Importance

Microorganisms enhance crop productivity by improving nutrient availability, maintaining soil structure, and supporting plant health. Their activities ensure efficient utilization of soil nutrients and contribute to sustainable agricultural practices.

Conclusion

Soil microorganisms are vital for maintaining soil fertility and ensuring sustainable agricultural production. Their role in nutrient cycling, organic matter decomposition, nitrogen fixation, and soil structure improvement makes them indispensable components of soil health. By naturally enhancing nutrient availability and reducing reliance on chemical inputs, microorganisms contribute significantly to sustainable agriculture. Promoting their use through biofertilizers and biocontrol agents can ensure long-term productivity and environmental sustainability.

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CLIMATE-SMART AGRICULTURE: A REVIEW OF INTERNATIONAL AND NATIONAL AGRICULTURAL POLICIES

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Abstract

Agriculture is an industry most vulnerable to climate risk and a significant contributor to greenhouse gas emissions. The article examines national and international policy solutions to this dual predicament. The role of agriculture and food security in climate governance has been reinforced by the Sharm el-Sheikh Joint Work, the Koronivia Joint Work on Agriculture, and the Paris Agreement. Climate-smart agriculture, soil restoration, methane reduction, and climate finance are becoming more popular in the European Union, India, Brazil, New Zealand, China, and African nations. The assessment concludes that although policy aspiration is steadily rising, institutional cooperation, funding, and access to technology continue to be barriers to execution. Resilient food systems require more synergy between agricultural practices and climate commitments.

Keywords: climate change, agriculture policy, climate-smart agriculture, food security, climate finance, adaptation

Introduction

Due to its significant contribution to greenhouse gas emissions and reliance on temperature, rainfall, and soil conditions, all of which are increasingly disrupted by climate change, agriculture plays a pivotal role in climate policy. While droughts, floods, heat stress, and changing seasons lower productivity and jeopardize food security, livestock methane, fertilizer use, land conversion, and ineffective resource management raise emissions. This article looks at the main international initiatives and policies aimed at lowering agricultural emissions and enhancing farming systems' resilience.

International Policy Frameworks

Global climate governance increasingly recognizes agriculture as both vulnerable and essential to food security. The Paris Agreement explicitly acknowledges the importance of safeguarding food security and ending hunger. It also provides the framework through which countries submit Nationally Determined Contributions that can include agricultural mitigation and adaptation targets. The Koronivia Joint Work on Agriculture created a dedicated UNFCCC process for discussing soils, nutrients, livestock systems, and socio-economic dimensions of climate action in agriculture. This was further strengthened by the Sharm el-Sheikh Joint Work on Agriculture and Food Security, which extended the institutional attention given to agricultural adaptation and knowledge sharing. In addition, voluntary initiatives such as the Global Methane Pledge, the 4 per 1000 Initiative, and the Global Alliance for Climate-Smart Agriculture have expanded international cooperation on methane reduction, soil carbon sequestration, and climate-smart farming, respectively.[1346]

National and Regional Responses

Global commitments require an inherent follow-up at the domestic level. The European Union uses its Common Agricultural Policy to promote greener farming practices, precision agriculture, and reduced fertilizer dependence. However, it still lacks quantifiable methane targets, owing to policy gaps on livestock emissions. India's sustainable agriculture missions promote water efficiency, resilient crops, and climate adaptation in rainfed areas. A notable initiative is The National Mission for Sustainable Agriculture. Brazil's Low-Carbon Agriculture (ABC) Programme supports no-till farming, integrated crop-livestock-forest systems, and restoration of degraded pastures. In 2022 Brazil launched ABC+ aligning with SDG 2 and SDG 13. New Zealand has created separate targets for biogenic methane. It aims for a 24-47% reduction in biogenic methane by 2050. China promotes soil carbon improvement, efficient irrigation, and methane reduction through its Five-Year Plans. A recent MoA in 2023 requires 90% of fertilizer and irrigation projects in key regions to use climate-friendly tech. Across Africa, regional and national strategies increasingly integrate climate resilience, agroforestry, drought-tolerant crops, and early warning systems into agricultural planning. The Comprehensive Africa Agriculture Development Programme (CAADP) embeds climate resilience as a key player in agricultural policies.[789]

Climate Finance and Support Mechanisms

Climate-resilient technologies require upfront investment. This makes funding and finance a core issue for implementation. The Green Climate Fund supports developing countries through projects on drought-resistant seeds, climate services, solar irrigation, and resilient value chains. The Global Environment Facility and its adaptation windows also aid nations in preparing and implement agriculture-focused adaptation programmes. It manages the Least Developed Countries Fund (LCDF), that finances NAPA (priority given to agriculture and food security). Development banks, bilateral donors, and blended finance mechanisms are increasingly used to scale climate-smart agriculture, especially where public budgets are limited. These mechanisms are important because they convert policy ambition into practical support for farmers, extension systems, and rural infrastructure.[510]

Collaborative Partnerships and Knowledge Systems

Research partnerships and multi-stakeholder platforms are central to policy delivery. CGIAR, the Global Research Alliance on Agricultural Greenhouse Gases, and national research institutions generate evidence on emissions reduction, crop breeding, soil health, and water management. Platforms such as FAO's climate-smart agriculture initiatives and adaptation support programmes help countries align agriculture with national climate plans. Farmer organizations, universities, extension workers, and civil society groups are equally important because they translate policy language into local practice. Organisations like the NDC Partnership and UN Adaptation Network help countries integrate agriculture into climate plans. Without these partnerships, international commitments remain too distant from the realities of farmers.[210]

Table 1. Major international initiatives linking agriculture and climate action[1345]

Initiative	Year	Area of focus	Relevance to agriculture
Paris Agreement	2015	Global warming and NDCs	Food security and climate action
Koronivia Joint Work	2017	Agriculture in UNFCCC	Soils, nutrients, livestock
Sharm el-Sheikh Joint Work	2022	Agriculture and food security	Knowledge sharing and adaptation
Green Climate Fund	2010	Climate finance	Finances resilient agriculture

Conclusion

It is imperative that agriculture be treated as a core sector of climate governance rather than a peripheral afterthought. International frameworks have greatly aided in increasing the visibility of agricultural mitigation and adaptation, but the translation of commitments into national action remains uneven. The upcoming phase of policy needs to focus on financing, institutional coordination, and practical support for farmers. Climate-smart agriculture, better soil management, reduced methane emissions, and stronger adaptation planning can together help safeguard food security under changing climate conditions.[15]

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GENETICS OF SICKLE CELL ANAEMIA

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01. INTRODUCTION

Sickle - cell disease or sickle cell anaemia (or depanocytosis) is a life -long blood disorder characterized by red blood cells that assume an abnormal rigid sickle shape. Sickling decreases the cells' flexibility and results in a risk of various complications. The sickling occurs because of a mutation in the haemoglobin gene. Life expectancy of 42 and 48 years for males and females. Sickle cell disease usually presenting in childhood, occurs more commonly in people from parts of tropical and sub-tropical regions where malaria is prevalent. Since the infestation of the malaria plasmodium is halted by the sideling of the cells which it infests, people with sickle cell anaemia are generally not affected by malaria. Sickle-cell disease or sickle cell anaemia is a life-long blood disorder characterized by red blood cells that assume an abnormal, rigid, sickle shape.

02. HISTORY

This collection of clinical findings was unknown until the explanation of the sickle cells in 1904 by the Chicago cardiologist and a professor of medicine (K James and B. Herrick, 1861-1954) whose intern Ernest Edward Irons (1877-1959) found "peculiar elongated and sickle - shaped" cells in the blood of Walter Clement Noel, a 20 year old first- year dental student from Canada after Noel was admitted to the Chicago Presbyterian Hospital in December 1904 suffering from anaemia. Noel was readmitted several times over the next three years for "Muscular rheumatism" and "bilious attack". Noel completed his studies and

returned to the capital of Grenada to practice dentistry. He died of pneumonia in 1906 and is buried in the catholic cemetery as Sauteurs in the north of Grenada. The disease was named "Sickle cell anaemia" by Vernon Mason in 1922. However, some elements of the disease have been recognized earlier: A paper in the Southern Journal of Medical Pharmacology in 1846 described the absence of a spleen' in the autopsy of a runaway slave. The African medical literature reported this condition in the 1870s, where it was known locally as ogbanjes ("Children who come and go") because of the very high infant mortality rate caused by this condition. A history of the condition tracked reports back to 1670 in one Ghanian family.

Linus Pauling and colleagues were the first in 1949, to demonstrate that sickle cell disease occurs as a result of an abnormality in the haemoglobin molecule. This was the first time a genetic disease was linked to a mutation of a specific protein, a milestone in the history of molecular biology and it was published in their paper "sickle cell Anaemia, a molecular Disease". The origin of the mutation that led to the sickle cell gene was initially thought to be in the Arabian Peninsula, spreading to Asia and Africa. It is now known, from evaluation of chromosome structures, that there have been at least four independent mutational events, three in Africa and a fourth in either Saudi Arabia or central India. These independently occurred between 3,000 and 6,000 generations ago, approximately 70 -150,000 years.

03. ETIOLOGY

Haemoglobin (Hb) is a major protein within the red blood cell (RBC). It is made up of four globin chains, two of which are derived from alpha-globin (locus on chromosome 16) and two from beta-globin (locus on chromosome 11). There are many subtypes of Hb. The most common ones that are found in adults without hemoglobinopathies are listed here:

- HbA1- comprises 2 chains of the alpha-globin and two chains of the beta-globin (a2b2) - This constitutes 95% of the adult haemoglobin.
- HbA2- comprises 2 chains of the alpha-globin and two chains of the delta-globin (a2d2) - This constitutes less than 4% of the adult haemoglobin.
- HbF- comprises two chains of the alpha-globin and two chains of the gamma-globin (a2g2) - This Hb is more prevalent in the foetus (due to high oxygen binding affinity that helps in extracting oxygen from maternal circulation).

The sickle cell mutation occurs when negatively charged glutamine is replaced by a neutral valine at the sixth position of the beta-globin chain. The mutation is transmitted via Mendelian

genetics and is inherited in an autosomal codominant fashion. A homozygous mutation leads to the severest form of SCD, *i.e.*, SCA- also called HBSS disease. The coinheritance of beta-naught thalassemia and sickle cell mutation leads to HBS-Beta-0 disease, which phenotypically behaves like HBSS disease.

A heterozygous inheritance leads to HbAS. Patients with HbAS are not considered within the spectrum of SCD as most of them never present with typical symptoms of SCA. They might only be detected during screening procedures conducted during childbirth, blood donation, etc. Several other compound heterozygotes exist where a single copy of the mutated beta-globin gene is co-inherited with a single copy of another mutated gene. The second most common variant of SCD is the HbSC disease, where the sickle cell gene is coinherited with a single copy of the mutated haemoglobin C gene. HbC is formed when glutamine is replaced by lysine at the sixth position on the beta-globin chain. HbSC disease accounts for 30% of patients in the United States.

04. PATHOPHSIOLOGY OF SICKLE CELL ANAEMIA

Sickle cell anaemia is caused by a point mutation in the β-globin chain of haemoglobin, causing the amino acid glutamic acid to be replaced with the hydrophobic amino acid valine at the sixth position. The β-globin gene is found on the short arm of chromosome 11. The association of two mutant β-globin subunits forms haemoglobin S (HbS). Under low-oxygen conditions, the absence of a polar amino acid at position of six of the β-globin chain promotes the non-covalent polymerization of haemoglobin, which distorts red blood cells into a sickle shape and decreases their elasticity. The loss of red blood cell elasticity is central of the pathophysiology of sickle cell disease.

- Normal red blood cells are quite elastic, which allows the cells to deform to pass through capillaries. In sickle cell disease, low oxygen tension promotes red blood cell sickling and repeated episodes of sickling damage the cell membrane and decreases the cell's elasticity.
- These cells fail to return to normal shape when normal oxygen tension is restored. As a consequence, these rigid blood cells are unable to deform as they pass through narrow capillaries, leading to vessel occlusion and Ischaemia.
- The actual anaemia of the illness is caused by haemolysis, the destruction of the red cells inside the spleen, because of their misshape.

- Although, the bone marrow attempts to compensate by creating new red cells, it does not match the rate of destruction.
- Healthy red blood cells typically live 90-120 days, but sickle cells only survive 10-20 days according to medicine.

05. GENETICS OF SICKLE CELL ANAEMIA

A single amino acid change causes haemoglobin protein to form fibres. Sickle cell gene mutation probably arose spontaneously in different geographic areas as suggested by restriction endonuclease analysis. These variants are known as Cameroon, Senegal, Benin and Saudi-Asian. Their clinical significance springs from the feet that some of them are associated with higher HbF levels, example Senegal and Saudi- Asian variants and tend to have Milder. In people heterozygous for HbS, the polymerization problems are minor, because the normal allele is able to produce over 50% of the haemoglobin. In people homozygous for HbS, the presence of long-chain polymers of HbS distort the shape of the red blood cell, from smooth dount-like shape to ragged and full of spikes making it fragile and susceptible to breaking within capillaries. Carriers have symptoms only if they are deprived of oxygen or while severely dehydrated. Under normal circumstances, these painful crises occur 0.8 times per year per patient. The sickle-cell disease occurs when the seventh amino acid (if we count the initial methionine), glutamic acid, is replaced by valine to change its structure and function. The gene defect is a known mutation of a single nucleotide (A to T) of the p-globin gene, which results in glutamate to be substituted by valine at position 6 of haemoglobin-S with this mutation are referred to as HbS, as opposed to the normal adult HbA. The genetic disorder is due to the mutation to a single nucleotide, from a GAG to GTG codon mutation. This is normally a benign mutation, causing no apparent effects on the secondary, tertiary, or quaternary structure of haemoglobin. What it does allow for, under conditions of low oxygen concentration, is the polymerization of the HbS itself. The deoxy form of haemoglobin exposes a hydrophobic patch on the protein between the E and F helices. The hydrophobic residues of the valine at position 6 of the beta chain in haemoglobin are able to associate with the hydrophobic patch, causing haemoglobin S molecules to aggregate and form fibrous precipitates.

The allele responsible for sickle cell anaemia is autosomal recessive and can be found on the short arm of chromosome II. A person that receives the defective gene from both father and mother develops the disease; a person that receives one defective and one healthy allele remains

healthy, but can pass on the disease and is known as a carrier. If two parents who are carriers have a child, there is a 1 - in - 4 chance of their child's developing the disease and a one in two chance of their child's being just a carrier since the gene is incompletely receive, carriers can produce a few sickled red blood cells, not enough to cause symptoms, but enough to give resistance to malaria. Because of this, heterozygotes have a higher fitness than either of the homozygotes. This is known as heterozygotes advantages. Due to the adaptive advantage of the heterozygotes the disease is still prevalent especially among people with recent ancestry in malarial–stricken areas, such as Africa, the Mediterranean, India and the Middle East. Malaria was historically endemic to southern Europe, but it was declared eradicated in the mid 20th century with the exception of rare sporadic cases. The malaria parasite has a complex life cycle and spends part of it in red blood cells. In a carrier, the presence of malaria parasite causes the red blood cells with defective haemoglobin to rupture prematurely making the plasmodium unable to reproduce. Further, the polymerization of Hb affects the ability of the parasite to digest Hb in the first place. Therefore, in areas where malaria is a problem, people's chances of survival actually increase if they carry sickle cell trait.

07. INHERITANCE OF SICKLE CELL ANAEMIA

Sickle cell anaemia is inherited from parent the same way as blood type, hair colour and texture, eye colour and other physical traits. The type of haemoglobin a person makes in the red blood cells depend upon what haemoglobin genes are inherited from the parents.

- If one parent has sickle cell anaemia (SS) and the other has sickle cell trait (AS), there is a 50% chance of a child's having sickle cell disease (SS) and a 50% chance of a child's having sickle cell trait (AS).
- When both parents have sickle cell trait (AS), they have a 25% chance of a child's having sickle cell disease (SS).

08. SIGNS AND SYMPTOMS

Sickle cell disease may lead to various acute and chronic complications, several of which are potentially lethal.

i. Vaso - occlusive crisis: The vaso -occlusive crisis is caused by sickle - shaped red blood cells that obstruct capillaries and restrict blood flow to an organ, resulting in ischaemia, pain and often organ damage. The frequency, severity, and duration of these crises vary considerably.

ii. Sequestration crisis: In sequestration crisis, there is massive pooling of red blood cells in visceral organs especially splenomegaly may be marked but sometimes disappears
in later childhood, splenectomy is indicated when there is hypersplenism

iii. Acute painful episode: An episode of acute pain was originally called a "Sickle cell crisis" by Diggs, who used the expression "crisis" to refer to any new rapidly developing syndrome in the life a patient with sickle cell disease. In modern parlance, the term acute painful episode is favoured over crisis. Acute pain is the first symptom of the disease in more than one - fourth of patients, the most frequent symptom after age of two years, and the complication for which patients with sickle cell disease most commonly seek medical attention. The frequency of pain peaks between the age of 19 and 39 years. After the age of 19, more frequent is associated with higher mortality rate. Pain may be precipitated by events such as cold, dehydration, infection, stress, menses, and alcohol consumption but most painful episodes have no identifiable cause and can affect any area of the body.

iv. Growth and development retardation: By the age of two years, children with sickle cell disease have detectable growth retardation, which affects weight more than height and has no clear gender difference. Normal height is achieved by adulthood, but weight remains lower than that of controls. Skeletal maturation is also delayed. Girls with sickle disease have retarded sexual maturation and are associated with elevated ganadotrophin levels for the stage of sexual development and with delayed menarche. Boys also have delayed sexual maturation due to primary hypogonadism, hypopituitarism, or hypothalamic insufficiency. It has been possible to restore normal growth by nutritional supplementation

v. Acute chest syndrome: Symptoms and signs of the acute chest syndrome include dyspnea, chest pain, less commonly abdominal pain, fever, tachypnoea, leucocytosis, and a pulmonary infiltrate on the chest radiograph. This event that has an approximate 10% risk of mortality. The process is usually due to infection or vaso-occlusion, but it may also be the result of non-cardiogenic pulmonary edema or of pulmonary remobilization from a distant thrombus or bone marrow infarction Whatever the etiology, the major danger of the acute chest syndrome is hypoxemia and its attendant wide spread sideling and vaso-occlusion, which create a risk of multi organ failure.

09. DIAGNOSIS OF SICKLE CELL ANAEMIA

- In HbSS, the fall blood count (FBC) reveals haemoglobin levels in the range of 6-8g/dl with a high reticulocyte count. In other forms of sickle cell disease, Hb levels tend to be higher. A blood film may show features of hyposplenism (target cells and Howell-Jolly bodies).
- Sickling of the red blood cells, on a blood film, can be induced by the addition of sodium metabisulfite. The presence of sickle haemoglobin can also be demonstrated with the "sickle solubility test".
- A mixture of haemoglobins (HbS) in a reducing solution (such as sodium dithionite) gives a turbid appearance, whereas normal Hb gives a clear solution. Abnormal haemoglobin form can be detected on haemoglobin electrophoresis, a form of gel electrophoresis on which the various types of haemoglobin move at varying speed. HbSS and HbSC can be identified here.
- The diagnosis can be confirmed with high-performance liquid chromatography (HPLC). Genetic testing is rarely performed, as other investigations are highly specific for HbS and HbC. An acute sickle cell crisis is often precipitated by infection. Therefore, a urinalysis to detect an occult UTI to look for occult pneumoniae should be routinely performed.

10. MANAGEMENT OF SICKLE CELL ANAEMIA

Many of the manifestations of sickle cell disease can be better managed if the diagnosis is made early and regular prospective follow up instituted. The management of sickle cell anaemia is in two phases quiescent stage and crisis stage

i. Therapy of infections: Once infections occur diagnosis and therapy should be prompt as possible. The hazards of overwhelming septicaemia are well recognized and must be remembered in any child with a high fever, or who looks lethargic and ill, and treated accordingly.

ii. Avoidance of adverse climatic conditions: The commonest precipitating factor for the painful crisis is cold and education and proper clothing may minimize its effect so that patients understand the importance of cold and keep warm at the cold wet periods of the year, and at night.

iii. Hydration: Dehydration and haemo concentration are known to precipitate painful crisis in some patients. The maintenance of adequate hydration is very important where febrile conditions increase fluid loss especially in countries with high ambient temperatures.

iv. Oxygen use: During the therapy of acute complications, the use of oxygen is frequently recommended. Patient with SS disease have lowered arterial oxygen saturation in the steady state and this may fall further during acute illness, especially the acute chest syndrome, under these conditions, high levels of inspired oxygen can only be beneficial.

v. Education: Two aspects of education are critical to the child with sickle cell disease education about the disease and the continuance of formal schooling. Patients learn to cope better with the disease if informed about its complications. With reassurance and understanding, patient can be taught to manage mild episodes of painful crisis at home. Education about the use of shoes and socks may reduce the prevalence of

trauma - induced led ulceration

11. FUTURE PERSPECTIVES

Gene editing is catching steam whereby researchers attempting to increase the HbF level in patients with SCA.

Thistechnique is being developed alongside HSCT. Many approaches to gene editing are in clinical trials right now.

1. Viral gene addition using lentivirus: The technique aims to add a modified beta or gamma-globin gene to reduce

the HbS component and increase the HbA (beta-globin gene) or the HbF (gamma-globin gene).

2. CRISPR (Clustered regularly interspaced short palindromic repeats): Targets the expression of BCL11A, which normally downregulates gamma-globin expression. By introducing insertions and deletions in the BCL11Aerythroid lineage-specific enhancer on chromosome 2, BCL11A is downregulated, resulting in increasedexpression of the gamma-globin gene, which subsequently increases HbF.

Conclusion

Sickle cell anaemia is a homozygous form of HbS(HbSS). This result from single point replacement of glutamine by valine at position 6 of β-globin chain. This reduces solubility of the red cells which in turn leads to polymerisation and vaso-occlussion in the vasculature. The association of two mutant β-globin subunits forms haemoglobin S (HbS). Under low-oxygen

conditions, the absence of a polar amino acid at position of six of the β-globin chain promotes the non-covalent polymerization of haemoglobin, which distorts red blood cells into a sickle shape and decreases their elasticity. As a consequence, these rigid blood cells are unable to deform as they pass through narrow capillaries, leading to vessel occlusion and Ischaemia. It will be pertinent to have wholistic care for those affected. Proper and adequate counselling should be given to intending couple before marriage and haemoglobin genetic counselling and education should be included in the curriculum of pupils and students from primary school to tertiary education levels to avert the pains and the crisis associated with the burden of sickle cell anaemia and the resources to take adequate care of them.

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GENETIC COUNSELLING IN HUMAN WELFARE

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01. INTRODUCTION

Genetic counselling is an educational process that aims to inform and advise patients and relatives at risk of a genetic condition about the nature of the disorder, the probability of developing it and the risk of passing it on to future generations. Through genetic counselling, individuals are empowered to make informed decisions regarding genetic testing, health management, treatment options, and family planning. The process emphasizes informed choice, ethical responsibility, and respect for individual autonomy.

02. GENERAL ETHICAL CONSIDERATION IN GENETIC COUNSELLING-

The ethical framework for genetic counselling is largely informed by the guidelines developed under the **World Health Organization (WHO) Human Genetics Programme (1998)**, which involved experts from fourteen countries. The primary objective of this document was to protect individuals and families affected by genetic diseases and to guide governments and health services in integrating genetic information into medical practice within ethically acceptable limits. A secondary objective was to address public concerns regarding potential misuse of genetic information and to reassure society that adequate safeguards exist to prevent discrimination and unethical practices. The WHO recognized that advances in genetics have the potential to significantly improve health outcomes when applied appropriately at the individual, family, and community levels, while respecting cultural, religious, and social diversity.

The WHO explicitly endorses **non-directive genetic counselling**, grounded in two fundamental elements. First, individuals must be provided with accurate, complete, and unbiased information

to enable informed decision-making. Second, counselling should be based on an empathetic and supportive relationship that respects personal values and autonomy, allowing individuals and families to reach decisions independently.

The following ethical principles are considered central to genetic counselling:

1. Respect for individuals and families, including truthfulness, self-determination, and the provision of precise and unbiased information (**autonomy**).
2. Preservation of family integrity (**autonomy, non-maleficence**).
3. Full disclosure of all health-relevant genetic information to individuals and families (**autonomy, non-maleficence**).
4. Protection of confidentiality against unjustified access by employers, insurers, educational institutions, or other third parties (**non-maleficence**).
5. Recognition of an ethical responsibility to inform relatives who may be at genetic risk (**non-maleficence**).
6. Disclosure of carrier status to partners when reproductive decisions are involved, while acknowledging potential relational consequences (**non-maleficence**).
7. Disclosure of genetic information when public safety may be affected (**non-maleficence**).
8. Presentation of genetic information in an unbiased and balanced manner (**autonomy**).
9. Use of non-directive counselling approaches, except when discussing treatment options (**autonomy, beneficence**).
10. Involvement of children and adolescents, where appropriate, in decisions affecting them (**autonomy**).
11. Responsibility of health services to provide follow-up care when desired and appropriate (**autonomy, beneficence, non-maleficence**).

03. PATTERNS OF GENETIC INHERITANCE AND THEIR CLINICAL SIGNIFICANCE

DNA molecules are tightly packed around histone proteins and organized into thread-like structures known as chromosomes. The human genome consists of 23 pairs of chromosomes, with one chromosome of each pair inherited from the mother and the other from the father. The 23rd chromosome pair determines biological sex and is referred to as the sex chromosomes. Biological females possess two X chromosomes, whereas biological males have one X and one

Y chromosome. Genetic diseases may be inherited within families according to well-defined inheritance patterns. The five primary modes of genetic inheritance are described below.

i. Autosomal dominant inheritance: Occurs when a single pathogenic or likely pathogenic (P/LP) variant in one allele of a gene is sufficient to cause disease. An affected individual has a 50% probability of transmitting the pathogenic variant to each offspring. Dilated cardiomyopathy caused by P/LP variants in the *LMNA* gene is an example of this inheritance pattern.

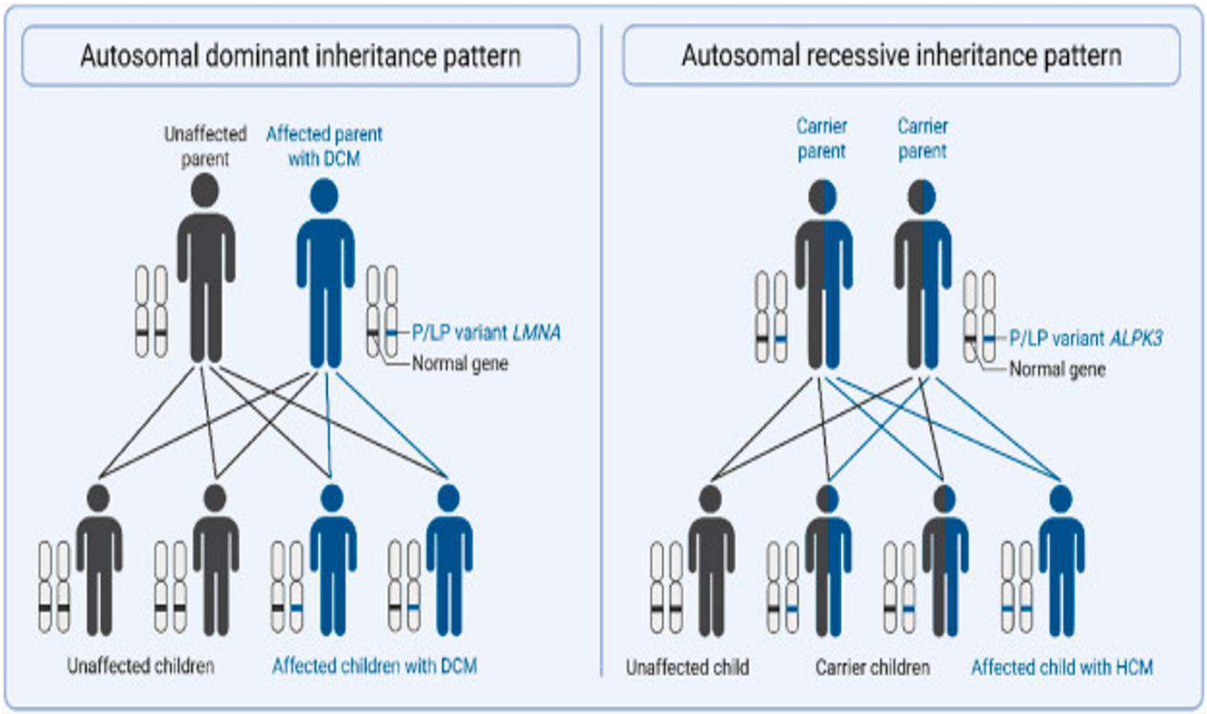

Fig. 1. Autosomal dominant and autosomal recessive inheritance pattern in human

ii. Autosomal recessive inheritance: These require pathogenic variants in both alleles of a gene (homozygous) for the phenotype to develop. When only one allele carries a pathogenic variant, the individual usually does not develop the disease and is considered a heterozygous carrier. An affected homozygous individual has a 100% chance of transmitting an affected gene to their child. In such cases, the child will be a carrier and will not develop the disease unless the other parent is also a carrier or affected. A heterozygous carrier has a 50% chance of transmitting the affected gene to their offspring. If both parents are carriers, there is a 25% chance that the child will be homozygous and develop the disease. An example of an autosomal recessive disorder is hypertrophic cardiomyopathy caused by pathogenic or likely pathogenic variants in the *ALPK3* gene.

iii. **X-linked dominant Inheritance:** Occur when the pathogenic gene variant is located on the X-chromosome. Due to the dominant nature of inheritance, both males and females with the variant will develop the disease. However, fathers will always transmit the disease to their daughters and never to their sons. Mothers have a 50 % chance of transmitting the disease to their children, regardless of the sex of the child. An example of a x-linked dominant disease is Danon disease caused by P/LP variants in *LAMP2* . results from pathogenic variants on the X chromosome. Both males and females may be affected, although affected fathers transmit the disease to all daughters and none of their sons. Danon disease caused by *LAMP2* variants is an example.

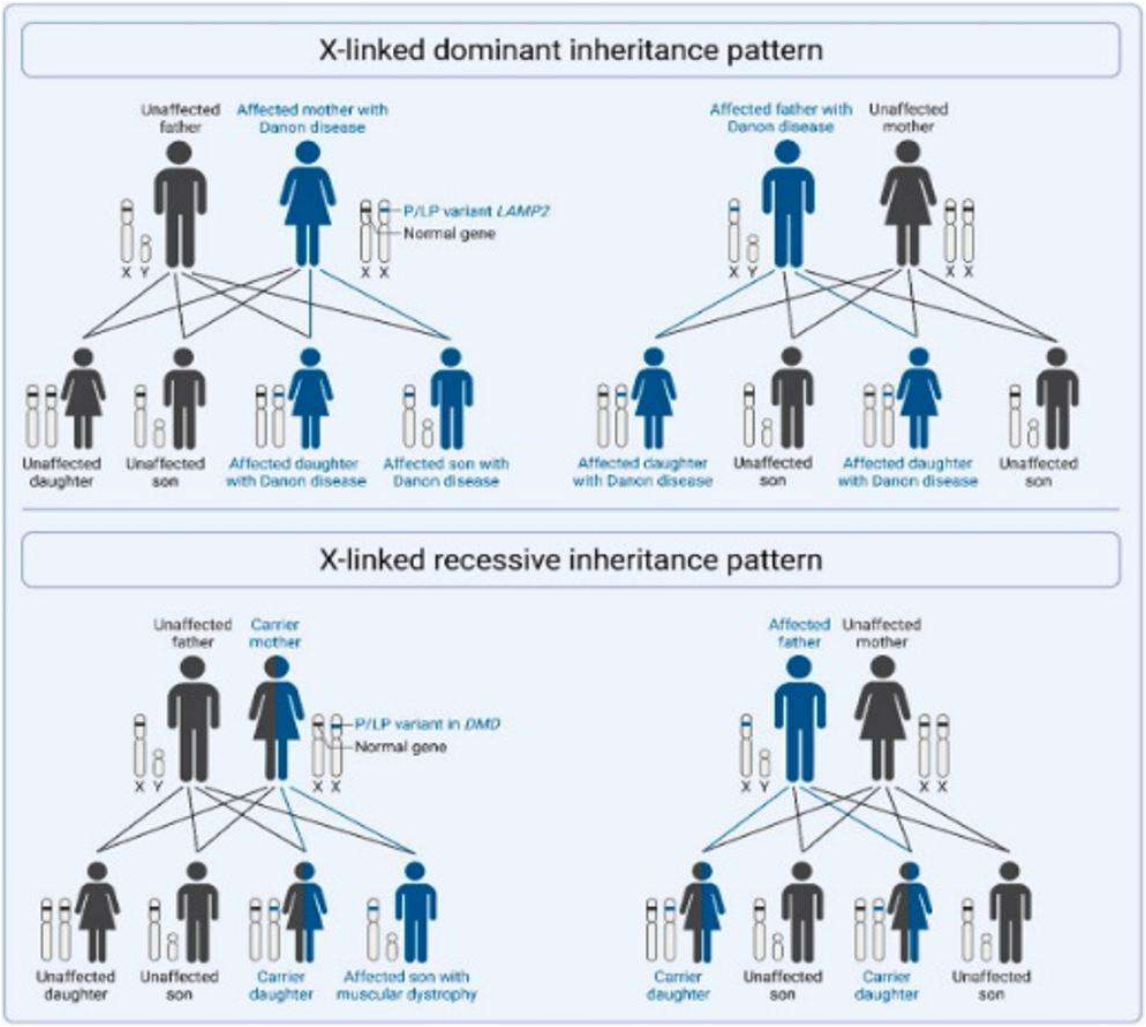

Fig. 2. X-linked Dominant and X-linked Recessive inheritance pattern in human

iv. **X-linked recessive inheritance:** In this case, the pathogenic disease is located on the X-chromosome. Therefore, all males, who only have one X-chromosome, will develop the disease. Females, who have two X-chromosomes, can be unaffected or may have a variable expression of the disease, due to their second unaffected X-chromosome. primarily affects males, as they possess only one X chromosome. Females are usually carriers with variable expression. Muscular dystrophy with cardiac involvement due to *DMD* variants exemplifies this pattern.

v. **Mitochondrial DNA:** This involves pathogenic variants in mitochondrial DNA, which is transmitted exclusively through the maternal line. Disease expression depends on heteroplasmy levels. MELAS syndrome associated with *MTTL1* variants illustrates this inheritance.

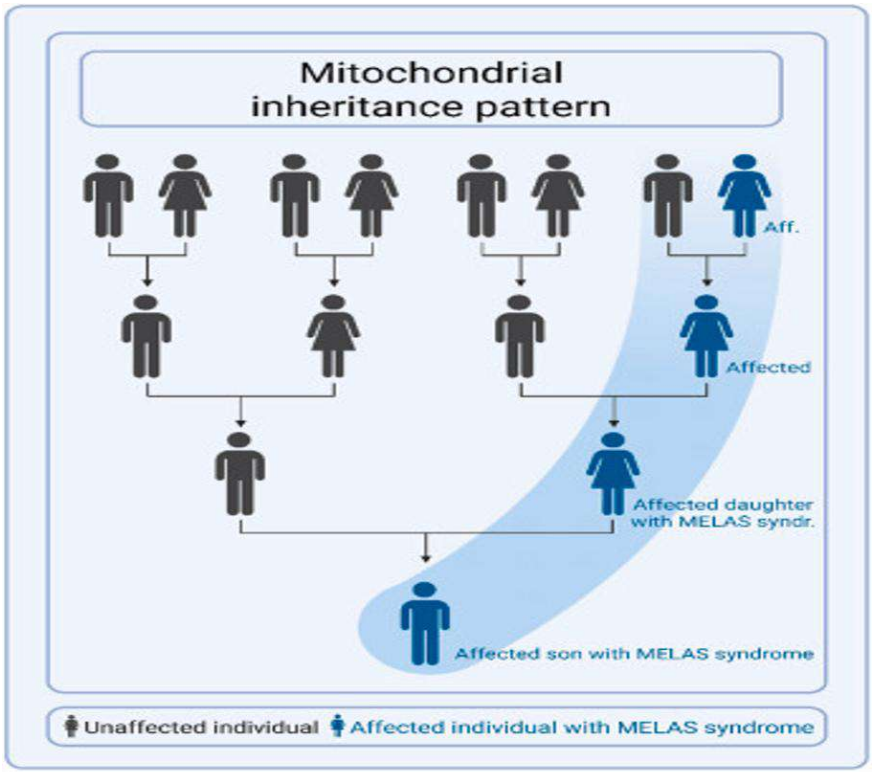

Fig. 3. Mitochondrial inheritance pattern in human

While these five modes represent the most commonly described inheritance patterns, there are many more modes of inheritance patterns that exist (*e.g.*, digenic, oligogenic inheritance). The majority of inherited cardiac diseases follow an autosomal dominant inheritance pattern. However, not everyone with a pathogenic gene variant will develop the disease, a phenomenon referred to as incomplete penetrance.

There can also be great variety in the severity of disease among individuals with the same pathogenic gene variant, even within families, an observation referred to as variable expression. Although the exact factors that can explain the incomplete penetrance and variable expression of genetic diseases remain largely unknown, the disease will probably develop due to a combination of the individuals genetic predisposition, environmental factors, disease modifiers, and/or co-morbidities.

Another important aspect in genetics is the phenomenon of pleiotropy, where a single pathogenic or likely pathogenic variant can cause multiple diseases. For example, variants in the *LMNA* gene can lead to dilated cardiomyopathy, arrhythmias and conduction abnormalities, or even non-cardiac diseases such as progeria and neuropathies.

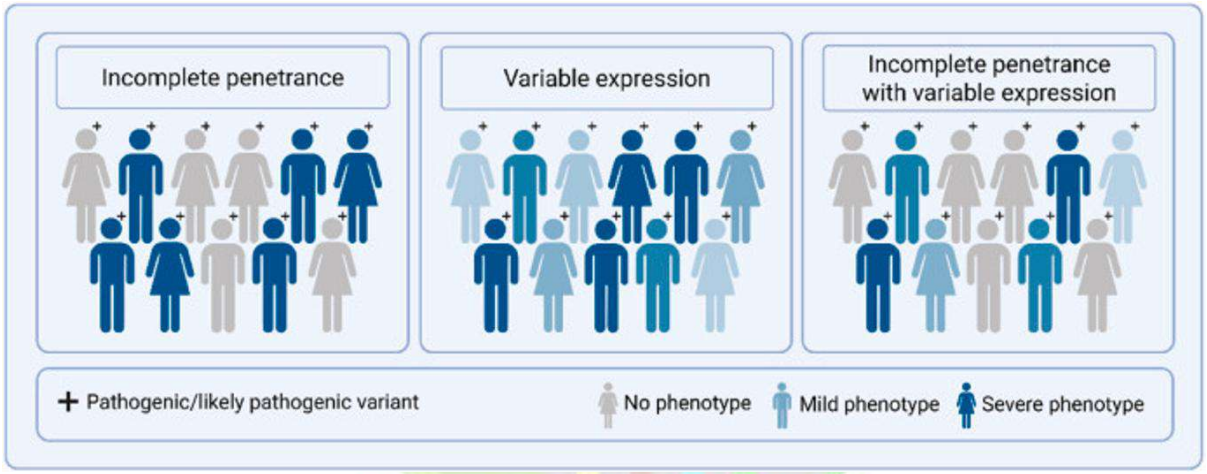

Fig. 4. Variation in penetrance and expressivity pathogenicity in human

04. METHODS OF GENETIC TESTING-

Genetic testing refers to the analysis of an individual's DNA to identify variations in genes that may cause disease. The most common and reliable method for detecting genetic disorders involves analysis of DNA isolated from a peripheral blood sample. In this process, DNA is extracted from leukocytes present in the blood. Alternative sampling methods include saliva swabs, skin or muscle biopsies, and prenatal samples such as amniotic fluid or chorionic villus sampling.

Genetic testing can be performed using several different techniques. The choice of method depends on the genetic basis of the disease, the clinical presentation, and the availability of prior genetic information. In some cases, the pathogenic variant may be present only in certain cell types, a phenomenon known as genetic mosaicism. In such situations, DNA obtained from

blood may not detect the variant, and testing of the affected tissue becomes necessary. Multiple approaches to genetic testing are therefore available.

Single-gene testing targets one specific gene using fluorescent probes to label nucleotides, allowing precise identification of the nucleotide sequence. This method can analyze individual exons, exon–intron boundaries, or the complete gene sequence. Exons are coding regions of DNA, while introns are non-coding sequences removed during RNA splicing. Single-gene testing is highly accurate for well-defined monogenic disorders but may fail when the causative gene is unknown or when multiple genes contribute to the disease.

Multigene panel testing analyzes a selected group of genes known to be associated with a specific phenotype. These panels are regularly updated as new gene–disease associations are discovered. Compared to single-gene testing, multigene panels have a higher diagnostic yield but also increase the likelihood of detecting variants of uncertain significance.

Whole-exome sequencing (WES) examines all protein-coding regions of the genome. It is typically used when previous testing is inconclusive or when the genetic cause of disease is unknown. While WES enables identification of novel variants, it also increases the chance of incidental findings and variants of uncertain significance.

05. CLINICAL SITUATION IN CHILDREN WHERE GENETIC COUNSELLING IS NECESSARY

Pediatricians are often the first healthcare professionals to encounter children and families who may require genetic assessment. Therefore, they must remain vigilant for clinical situations in which genetic counselling is indicated. Genetic counselling should be considered particularly in the following circumstances:

1. Cases of stillbirth and neonatal mortality require thorough evaluation to determine the underlying etiology, as this information is essential for assessing the risk of recurrence within the family. In such cases, autopsies should be requested, and pediatricians should support families in understanding the importance of this procedure. The autopsy should be performed by a specialized team trained in identifying genetic, dysmorphologic, and metabolic disorders.
2. Children presenting with congenital defects, especially those with multiple congenital anomalies, should be referred for genetic counselling to evaluate potential genetic causes.

3. Genetic counselling is also indicated in children who are severely ill when there is suspicion of inherited metabolic disorders.
4. Children with genital ambiguity or abnormal sexual development require genetic evaluation to identify possible chromosomal or genetic abnormalities.
5. Children with neuropsychomotor delay or intellectual disability of unknown cause, or where a genetic etiology is suspected, should undergo genetic assessment.
6. Additionally, children with abnormal growth patterns, including unexplained growth deficiency or excessive growth, or when a genetic disorder is suspected, should be considered for genetic counselling.

06. PRE-GENETIC COUNSELLING

Before offering genetic testing, it is essential to obtain a detailed family history and construct a pedigree to assess potential implications for other family members. Education about basic genetic principles is necessary to ensure that the patient or caregivers understand how a pathogenic or likely pathogenic (P/LP) variant may be inherited within the family.

The process and logistics of genetic testing should be clearly explained, including possible outcomes such as identification of a P/LP variant, a variant of uncertain significance (VUS), or no detectable variant, along with their implications for clinical management and lifestyle. Depending on the testing method selected, the possibility of incidental or secondary findings should also be discussed.

It is equally important to explore the patient's or family's beliefs, expectations, and understanding of genetic testing. Where required, additional psychosocial support should be offered. Ensuring informed decision-making is crucial, so patients and families fully understand the potential clinical and familial implications of genetic testing.

07. POST-GENETIC COUNSELLING

When communicating genetic test results, several key aspects must be addressed. If a genetic variant is identified, its classification—pathogenic, likely pathogenic, or VUS—should be clearly explained, along with its clinical implications for the patient. In cases where a VUS is detected, options for collecting additional evidence to clarify its significance should be discussed.

The implications of the results for family members should then be reviewed, including how relatives can be informed of their potential risk and how they can access genetic counselling

and, if appropriate, further genetic testing. Reproductive considerations should also be addressed, including the patient's desire for biological children and the available reproductive options.

Receiving a diagnosis involving a P/LP variant can be emotionally challenging and may evoke feelings such as guilt, fear, and uncertainty. These emotional responses and the patient's understanding of the information should be explored carefully, and psychosocial support should be offered when needed. In some cases, scheduling a follow-up consultation after a period of reflection may be beneficial.

Trained and certified genetic healthcare professionals should prioritize the needs and preferences of the patient. Genetic counselling serves as a foundation for shared decision-making and plays a vital role in guiding patients and families through the genetic testing process.

08. THE CALL FOR RISK MANAGEMENT

Although the genetic counsellor is a trained physician, he cannot diagnose or treat the unborn child. The only possible medical intervention he could suggest is termination of pregnancy, so his role is limited to presenting statistical risk estimates. He claims neutrality by saying he can explain available options but cannot advise what decision should be made. However, this approach forces Ms G. into making a difficult choice about genetic testing and her pregnancy—something she never intended. She originally sought reassurance, not a decision. By framing both testing and not testing as risky options, the counsellor turns pregnancy into a problem of risk management rather than a natural process.

09. EVALUATION OF THE OUTCOMES OF GENETIC COUNSELLING

During the 1970s and 1980s, several studies were conducted worldwide to evaluate the outcomes of the genetic counselling (GC) process. These early evaluations frequently encountered methodological limitations, and their conclusions were often subject to criticism. In recent years, there has been renewed interest in evaluating genetic counselling outcomes, particularly in emerging fields such as cancer genetics, late-onset genetic disorders, and predictive genetic testing.

Pina-Neto and Petean conducted an extensive evaluation of the genetic counselling process in a Brazilian public hospital, reporting findings consistent with studies from other countries. Their results demonstrated that the majority of families (74%) were referred to genetic services without adequate knowledge of the nature or purpose of the service. Overall comprehension and retention of genetic information were low, with 48.7% of individuals

exhibiting inadequate understanding. Although many participants could identify whether their recurrence risk was high or low, only 34.9% accurately recalled the numerical risk.

A significant association was observed between the level of understanding and socioeconomic status, indicating disparities in access to and comprehension of genetic information. Reproductive decision-making was strongly influenced by perceived risk, with 64.4% of couples choosing not to have children irrespective of the actual recurrence risk. This decision was more prevalent among high-risk couples (85.7%) compared to low-risk couples (52.9%). High-risk couples also demonstrated greater use of permanent contraceptive methods and higher acceptance of pregnancy termination.

Birth rates were reduced across all families receiving genetic counselling, with markedly lower rates among high-risk families. Disease recurrence occurred exclusively in high-risk families, while no recurrence was observed among low-risk families. Adoption rates were low, and marital disruption following counselling was rare.

10. CONCLUSION AND RECOMMENDATIONS

All families affected by genetic diseases should be informed of the importance of genetic counselling. Referring physicians play a crucial role in explaining the reasons for referral and clarifying the objectives and scope of genetic counselling services. Clear communication regarding disease etiology, evaluation of family members, and estimation of occurrence and recurrence risks is essential.

Genetic counselling should be non-directive, delivered by trained and qualified professionals, and structured as an ongoing process rather than a single intervention. Genetic services should place greater emphasis on counselling and long-term follow-up. It is essential to balance scientific and technological advancements with compassionate, patient-centered care.

Improving communication between genetic counselling professionals and families is fundamental to enhancing understanding and facilitating informed, shared decision-making. With rapid advancements in genomic sequencing and expanding clinical applications of genetic testing, a foundational understanding of genomics and genetic counselling is essential to integrate genetics effectively into routine clinical practice and to improve the quality of life of patients and their families.

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SIGNIFICANCE OF Y CHROMOSOME IN HUMAN

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01. Introduction

Chromosomes are organized DNA–protein complexes that ensure accurate transmission of genetic information across generations. In eukaryotes, chromosomes are classified into autosomes and sex chromosomes. In humans and most mammals, sex determination follows the XX–XY system, where females are homogametic (XX) and males are heterogametic (XY). The Y chromosome, though smaller than the X chromosome, exerts a decisive influence on sexual differentiation and male fertility. In the context of genetics and plant breeding, the study of sex chromosomes provides insights into inheritance patterns, genome evolution, gene regulation, and breeding strategies. Although flowering plants commonly exhibit hermaphroditism, sex chromosomes are present in several dioecious plant species, making Y chromosome research relevant in crop improvement and evolutionary genetics.

02. HISTORICAL BACKGROUND AND DISCOVERY

The chromosomal basis of sex determination was independently proposed in 1905 by Nettie Stevens and Edmund Beecher Wilson. Stevens demonstrated that male insects produce two types of gametes, one containing an X chromosome and the other containing a smaller Y chromosome. This discovery established the role of the Y chromosome in determining male sex. Subsequent cytogenetic and molecular studies have refined our understanding of the Y chromosome, particularly after the complete sequencing of the human Y chromosome in the early 21st century. These advances have transformed the perception of the Y chromosome from a degenerated chromosome to a functionally dynamic genetic element.

03. STRUCTURAL ORGANIZATION OF THE Y CHROMOSOME

The human Y chromosome is one of the smallest chromosomes (~57–62 million base pairs), representing about 2% of the haploid genome, and is characterized by a unique, highly repetitive structure. Its structural organization is primarily defined by a lack of recombination across most of its length, allowing it to maintain genes specifically required for male sex determination and spermatogenesis.

i. Pseudoautosomal Regions (PARs): The Pseudoautosomal regions (PAR): PAR1 is located at the terminal region of the short arm (Yp), and the PAR2 at the tip of the long arm (Yq). PAR1 and PAR2 cover approximately 2600 and 320 kb of DNA, respectively. The pseudoautosomal regions, and in particular PAR1, are where the Y chromosome pairs and exchanges genetic material with the pseudoautosomal region of the X chromosome during male meiosis. Consequently, genes located within the PAR are inherited in the same manner as autosomal genes. The euchromatic region is distal to the PAR1 and consists of the short arm paracentromeric region, the centromere and the long arm paracentromeric region. Finally, the heterochromatic region comprises distal Yq corresponding to Yq12. This region is assumed to be genetically inert and polymorphic in length in different male populations, since it is composed mainly of two highly repetitive sequences families, DYZ1 and DYZ2, containing about 5000 and 2000 copies of each respectively.

ii. Male-Specific Region of the Y (MSY): The MSY constitutes nearly 95% of the Y chromosome and does not recombine with the X chromosome. It contains:

- X-degenerate regions
- Ampliconic regions rich in palindromic sequences
- Euchromatic gene-rich segments

iii. Heterochromatin region: A significant portion of the Y chromosome consists of constitutive heterochromatin containing repetitive DNA. Though transcriptionally inactive, heterochromatin contributes to chromosomal integrity, meiotic pairing, and epigenetic regulation.

04. GENE CONTENT AND FUNCTIONAL GENES

Despite its limited number of genes, the Y chromosome harbours genes essential for male development and fertility.

i. SRY Gene: The first indices that the Y chromosome was involved in male sex determination came from the observation that XY or XYY (Klinefelter syndrome) individuals develop testes

whereas XX or XO (Turner's syndrome) individuals develop ovaries. Later, studies showing that mice XX presenting a male phenotype carried a small portion of the Y chromosome supported the proposition that a master gene involved in male sex determination was carried by the Y chromosome. In 1990, the gene responsible for testicular determination, named SRY (Sex-determining Region on the Y chromosome), was finally identified. *SRY* was cloned by isolation of small fragments of translocated Y on XX sex-reversed patients. This gene is located on the short arm of the Y chromosome close to the pseudoautosomal boundary. It comprises a single exon encoding a protein of 204 amino acids which presents conserved DNA-binding domain (the HMG-box: High Mobility Group), suggesting this protein regulates gene expression.

ii. Azoospermia Factor (AZF) Regions: The AZFa, AZFb, and AZFc regions are indispensable for spermatogenesis. Microdeletions in these regions are a major genetic cause of male infertility and are routinely screened in clinical genetics. The AZFa region is located in proximal Yq within the deletion interval 5 and its molecular extension has been roughly estimated between 1 and 3Mb. Several genes have been identified in this region; Dead Box Y (*DBY*), Ubiquitous TPR motif Y (*UTY*), Tymosin B4Y isoform (*TB4Y*), and the homologue of the Drosophila Developmental gene Fats Facets (*DFFRY*). The first three genes have no apparent specialised functions and they seem to be involved in cellular "housekeeping." By contrast, the *DFFRY* gene has been proposed to play a role in gametogenesis. The AZFb region is located between deletion interval 5 and proximal deletion interval 6, and its molecular extension has been estimated to be similar to that of the AZFa region (1–3 Mb). Five genes have been so far described within this interval; RNA-binding motif (RBM), Chromodomain Y (*CDY*), XK Related Y (*XKRY*), eukaryotic translation initiation factor 1A (*eIF-1A*), and Selected Mouse cDNA on the Y (*SMCY*). The *RBM* gene encode germ cell specific nuclear proteins containing RNA-binding motif and it is present in multiple copies along the Y. The AZFc region is located in the proximity of the heterochromatin region distal to Yq11 and its molecular extension is about 500 kb. This region contains the DAZ (Deleted in Azoospermia) gene cluster, two copies of the PTP-BL Related Y (*PRY*), Basic Protein Y2 (*BPY2*), as well as copies of CDY and RBM. DAZ encodes a testis-specific RNA binding protein and contains seven tandem repeats of 24 aa unit. DAZ is present in at least six to nine copies, all being located within AZFc. It is homologous to an autosomal gene on chromosome 3, with a single DAZ repeat, named DAZL1 (DAZ like-

autosomal 1) which is also specifically expressed in the testis. It has been hypothesized that DAZ originated from a translocation and subsequent amplification of this ancestral autosomal gene.

iv. Anti-Turner syndrome effect

Turner syndrome is characterised by a female 45 X karyotype or monosomy X. The principal manifestations of this syndrome are growth failure, infertility, anatomic abnormalities, and selective cognitive deficits. This human genetic disorder is ascribed to haplo-insufficiency of genes of the X chromosome that are common to both X and Y. These genes must escape X-inactivation because otherwise no difference will be observed between 45, X and 46, XX females. Secondly, in 46, XY these genes must have a male counterpart on the Y responsible to simulate the effects of their X homologues. Although there is no formal identification of genes involved in Turner syndrome, there appear to be different loci on the X and Y chromosome associated with Turner characteristic features, such as *SHOX/PHOG*

05. MOLECULAR FUNCTIONS OF THE Y CHROMOSOME

The Y chromosome contributes to:

- Primary sex determination
- Testis development and differentiation
- Regulation of spermatogenesis
- Modulation of gene expression through epigenetic mechanisms

Emerging evidence suggests Y-linked genes influence immunity, stress response, and susceptibility to certain diseases, highlighting pleiotropic effects beyond reproduction.

06. INHERITANCE AND POPULATION GENETICS

The Y chromosome is transmitted exclusively from father to son, making it a powerful tool in studying paternal lineage. The absence of recombination enables accumulation of stable mutations, forming Y-chromosome haplogroups used in population genetics, evolutionary biology, and forensic science.

07. EVOLUTIONARY ORIGIN AND DYNAMICS

The Y chromosome originated from a homologous pair of autosomes approximately 300 million years ago. Progressive suppression of recombination led to gene loss and structural divergence.

i. Degeneration and Stabilization: Although early theories predicted complete degeneration of the Y chromosome, recent studies indicate evolutionary stabilization through selective retention of essential genes.

ii. Palindromic Sequences and Gene Conversion: Large palindromic repeats allow intra-chromosomal recombination, facilitating gene conversion and preservation of functional integrity.

08. Y CHROMOSOME ABNORMALITIES AND DISORDERS

Y chromosome abnormalities include the following

- Y chromosome microdeletions
- XX male syndrome (SRY translocation)
- XYY syndrome
- Mosaicism involving Y chromosome loss

These abnormalities have implications in infertility, developmental disorders, and genetic counselling.

09. RESEARCH TECHNIQUES FOR Y CHROMOSOME ANALYSIS

Modern approaches include:

- Karyotyping and banding techniques
- Fluorescence in situ hybridization (FISH)
- Polymerase chain reaction (PCR)
- Next-generation sequencing (NGS)
- Bioinformatic analysis of Y-linked genes

These tools are integral to both clinical genetics and advanced breeding research.

11. SIGNIFICANCE OF APPLICATIONS OF Y CHROMOSOME

i. Medical Genetics: Y chromosome analysis is essential in diagnosing male infertility and disorders of sex development.

ii. Forensic Science: Y-STR markers are widely used in forensic identification, especially in mixed DNA samples.

iii. Evolutionary and Breeding Applications: Y chromosome markers assist in evolutionary studies and sex-linked trait analysis, contributing to efficient breeding strategies.

Conclusion

The Y is unique under many aspects. It is always in the haploid state, is full of repeated sequences but it is responsible for important biological roles such as sex determination and male fertility. Moreover, the Y chromosome is a powerful tool to study human populations and evolutionary pathways. The nonrecombining portion of the Y retains a record of the mutational events that have occurred along male lineages throughout evolution. This is because it is holoandrically transmitted, from father to son, without recombination at meiosis. Thus, the study of the different mutations this molecule has accumulated along its evolution may be highly informative in deducing the histories of human populations. The Y has not only demonstrated to be extremely informative in disentangling the history of human populations but it also has essential biological roles that make this chromosome an important component of the human genome.

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KLINEFELTER SYNDROME IN BIOLOGICAL MALE

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01. INTORDUCTION

Klinefelter syndrome is a genetic condition that affects males and is characterized by the presence of 2 or more X chromosomes. The clinical phenotype was first described in 1942 by American physician Dr. Harry Klinefelter. Affected individuals often present with tall stature, small testes, gynecomastia, and azoospermia. The genetic etiologic-supernumerary X chromosomes, typically 47, XXY was identified in 1959. Additional X chromosomes contribute to testicular hyalinization, fibrosis, and hypofunction, leading to genital abnormalities, most commonly hypogonadism and infertility. Neurocognitive differences began to gain broader recognition during the mid-to-late 20th century. Androgen replacement, along with neuropsychological and adaptive therapies, often supports effective clinical management. However, clinical care remains inconsistent due to delayed diagnosis, lack of standardized treatment protocols, and limited access to affordable therapies.

02. HISTORY OF KLINEFELTER SYNDROME

The syndrome was named after American endocrinologist Harry Klinefelter, who in 1942 worked with Fuller Albright and E. C. Reifenstein at Massachusetts General Hospital in Boston, Massachusetts, and first described it in the same year. The account given by Klinefelter came to be known as Klinefelter syndrome as his name appeared first on the published paper, and seminiferous tubule dysgenesis was no longer used. Considering the names of all three researchers, it is sometimes also called Klinefelter–Reifenstein–Albright syndrome. In 1956, Klinefelter syndrome was found to result from an extra chromosome. Plunkett and Barr found the sex chromatin body in cell nuclei of the body. This was further clarified as XXY in 1959

by Patricia Jacobs and John Anderson Strong. The first published report of a man with a 47,XXY karyotype was by Patricia Jacobs and John Strong at Western General Hospital in Edinburgh, Scotland, in 1959. This karyotype was found in a 24-year-old man who had signs of KS. Jacobs described her discovery of this first reported human or mammalian chromosome aneuploidy in her 1981 William Allan Memorial Award address. Klinefelter syndrome has been identified in ancient burials. In August 2022, a team of scientists published a study of a skeleton found in Bragança, north-eastern Portugal, of a man who died around 1000 AD and was discovered by their investigations to have a 47,XXY karyotype. In 2021, bioarchaeological investigation of the individual buried with the Suontaka sword, previously assumed to be a woman, concluded that person "whose gender identity may well have been non-binary", had Klinefelter syndrome.

03. KLINEFELTER SYNDROME

The most common karyotype in Klinefelter syndrome is 47, XXY, accounting for >90% Mosaic karyotypes, such as 46, XY/47, XXY, and other aneuploidies, including 48, XXXY and 49, XXXXY, have also been reported. The acquisition of the extra X chromosome is random, typically resulting from meiotic nondisjunction or postzygotic nondisjunction. Klinefelter

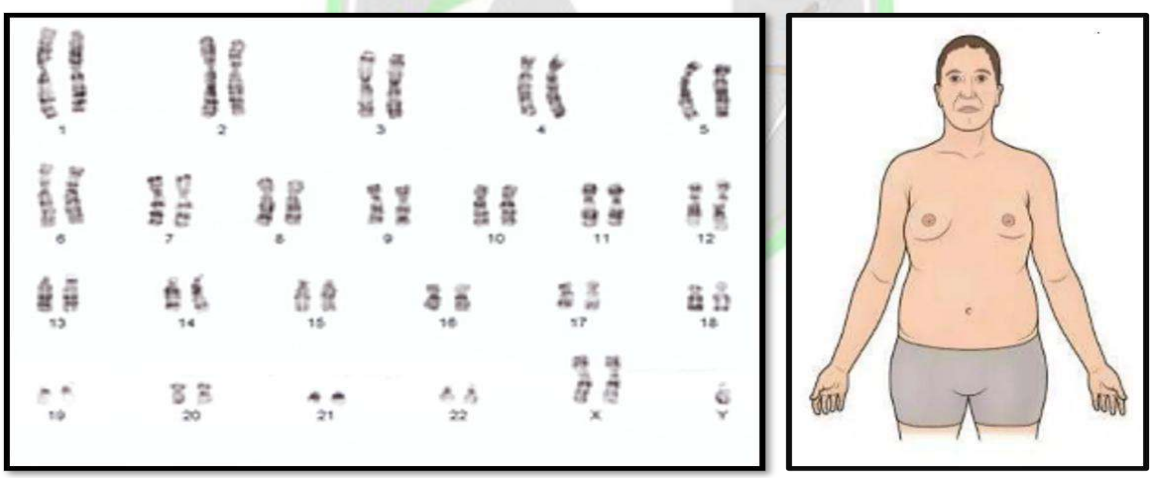

Fig. 1. Klinefelter syndrome in biological male of human

syndrome typically arises from a de novo non-disjunction event rather than being inherited, though inherited cases have been reported. To date, 12 cases of healthy infants born to non-mosaic fathers with Klinefelter syndrome have been documented in the literature. A 2020 case report by Ron-El et al described the retrieval of motile spermatozoa from a non-mosaic father with Klinefelter syndrome. After fertilizing 14 eggs, 3 embryos were transferred, resulting in a triplet pregnancy. Chorionic villus sampling revealed a chromosomal analysis of 46, XX, 46,

XY, and 46, XXY. One foetus affected by the 46, XXY pattern was reduced during early pregnancy, leading to the birth of 1 boy and 1 girl with normal chromosomal patterns. The report emphasized the value of genetic testing. The severity of the phenotype correlates with the amount of additional X chromosome material present.

A similar but less common condition, Jacobs syndrome, is characterized by the 47, XYY genotype. Affected individuals are phenotypically male and may present with antisocial tendencies, asthma, autism, seizures, infertility, tall stature, macrocephaly, and hypertelorism.

04. EPIDEMIOLOGY

Klinefelter syndrome (KS) is the most common male chromosomal abnormality, affecting approximately 1 in 500 to 1,000 males, with a 47, XXY karyotype resulting from meiotic non-disjunction. It is highly underdiagnosed, with only 25–50% of cases identified, often in adulthood due to infertility (3% of cases) or hypogonadism. The only known risk factor is advanced maternal age.

i. Epidemiological Data

- **Prevalence:** 1 in 500-600 male births.
- **Diagnosis Rate:** Up to two-thirds of individuals remain undiagnosed.
- **Mortality/Morbidity:** Increased mortality risk of 40% (hazard ratio 1.40), with a reduced median survival of approximately 2.1 years.
- **Age Factor:** Highest prevalence in children under 1 year (49.5 per 100,000), lowest in adolescents 15–19 (17.6 per 100,000).
- **Global Trends:** The number of cases is rising due to population growth, though the prevalence rate remains relatively stable.

ii. Genetic and Etiological Factors

- **Karyotype:** 47, XXY is classic (80-90%), while 46, XY/47, XXY mosaicism occurs in 10–20%.
- **Origin:** The extra X chromosome originates from paternal meiosis I in ~50% of cases and maternal meiosis (I or II) in the remaining 50%.
- **Maternal Age:** Risk increases with maternal age; women aged 40 have a four-times-higher risk than those aged 24.

iii. Associated Conditions (Morbidity)

- **Reproductive/Endocrine:** Infertility, azoospermia, hypogonadism, and gynecomastia (50-75% of patients).
- **Metabolic/Cardiac:** Increased risk of type 2 diabetes, cardiovascular diseases, and venous thromboembolism.
- **Cognitive/Psychiatric:** Deficits in language development, learning disabilities, and a higher risk of autism, ADHD, and depression.
- **Cancer:** Increased risk of germ cell tumours and a 50-fold higher risk of breast cancer compared to 46, XY males.

iv. Underdiagnosis

- Subtle clinical features in many patients lead to low diagnosis rates until the investigation of infertility in adulthood.
- Higher prevalence is reported in high-SDI (Social Development Index) countries, likely due to better diagnostic capabilities.

v. Recognition often begins during evaluation for specific clinical features across different life stages, such as in the following:

- Prenatal testing or observation of genital abnormalities in a newborn with hypotonia
- Documentation of learning or behavioural difficulties in an adolescent
- Evaluation for tall stature, small testicular size, or incomplete puberty in an adolescent
- Evaluation for infertility (3% of men evaluated for infertility have Klinefelter syndrome) or hypogonadism in a male adult

05. PATHOPHYSIOLOGY

i. The molecular basis of primary testicular failure and the phenotypic heterogeneity of somatic and neurocognitive features in Klinefelter syndrome remains incompletely elucidated. Ongoing investigations focus on the contribution of genetic polymorphisms, skewed X-chromosome inactivation, parental origin of the supernumerary X chromosome, and gene dosage effects.

ii. The presence of additional X-chromosome material results in progressive testicular hyalinization and fibrosis, culminating in primary gonadal failure that typically develops during adolescence and early adulthood. Hypogonadism is a hallmark of the condition, with a reported prevalence of approximately 65% to 85% in adult males.

iii. Clinical features may be evident in the neonatal period, including microphallus, hypospadias, cryptorchidism, and reduced testicular volume. As affected individuals progress through puberty, evolving hypogonadism may lead to incomplete pubertal development and gynecomastia. In adulthood, infertility and persistent hypogonadism are characteristic clinical manifestations.

iv. Individuals with Klinefelter syndrome exhibit a higher prevalence of reduced bone mineral density compared with unaffected males. Osteoporosis has been reported in approximately 6% to 15% of cases, while osteopenia affects 25-48%. These skeletal abnormalities often emerge during adolescence and are attributed to increased bone resorption and diminished bone formation. Although hypogonadism is a major contributing factor, additional mechanisms, including vitamin D deficiency, may also be involved.

v. Increased dosage of the SHOX gene located within the pseudoautosomal region of the X chromosome contributes to tall stature, elongated limbs, and a decreased upper-to-lower body segment ratio. The pathophysiological mechanisms underlying the neuropsychological features associated with Klinefelter syndrome remain poorly defined.

06. PHYSICAL MANIFESTATIONS

As babies and children, those with XXY chromosomes may have lower muscle tone and reduced strength. They may sit up, crawl, and walk later than other infants. An average KS child will start walking at 19 months of age. They may also often have less muscle control and coordination than other children of their age.

During puberty, KS subjects show less muscle mass, less facial and body hair, and broader hips as a consequence of low levels of testosterone. Delays in motor development may occur. As teens, persons with XXY may develop more breast tissue, have weaker bones, and a lower energy level than others. Testicles are affected and are usually less than 2 cm in length (and always shorter than 3.5 cm), 1 cm in width, and 4 ml in volume. By adulthood, individuals with KS tend to become taller than average, with proportionally longer arms and legs, less-muscular bodies, more belly fat, wider hips, and narrower shoulders. Some will show few or no symptoms, a lanky, youthful build and facial appearance, or a rounded body type. Gynecomastia (increased breast tissue) in males is common, occurring in up to 80% of cases. Approximately

10% of males with XXY chromosomes have gynecomastia noticeable enough that they may choose to have surgery. Individuals with KS are often infertile or have reduced fertility. Advanced reproductive assistance is sometimes required in order to produce offspring since approximately only 50% of males with Klinefelter syndrome can produce sperm.

07. PSYCHOLOGICAL CHARACTERISTICS

i. Cognitive Development: Individuals with Klinefelter syndrome may exhibit varying degrees of language-based learning and reading impairments, and neuropsychological assessment frequently identifies deficits in executive functioning. Approximately 10% of affected individuals meet criteria for autism spectrum disorder. Additional neurocognitive features may include impaired attention, reduced organizational and planning abilities, and deficits in judgment, often manifested as a tendency to perceive neutral or non-threatening stimuli as threatening. Abnormalities in decision-making processes have also been reported. Delays in language development are common, particularly when compared with age-matched peers. An estimated 25 to 85% of individuals with an XXY karyotype experience some form of language-related difficulty, including delayed speech acquisition, impaired expressive language, reading difficulties, and auditory processing deficits. These challenges may contribute to academic difficulties, particularly in tasks requiring reading and writing. Nevertheless, most individuals with Klinefelter syndrome are able to achieve gainful employment and maintain successful professional careers.

ii. Behaviour and Personality Traits: Compared with individuals with a typical chromosomal complement, males with Klinefelter syndrome may exhibit distinct behavioural and psychosocial characteristics. These features commonly include increased levels of anxiety and depressive symptoms, mood dysregulation, impaired social functioning, emotional immaturity during childhood, and reduced frustration tolerance. Evidence from animal models carrying an additional X chromosome suggests that these neurobehavioral differences are largely attributable to the presence of supernumerary X-chromosome material. A landmark study conducted in 1995 evaluating psychosocial adaptation in adolescents with sex chromosome aneuploidies reported that individuals with an XXY karyotype were more likely to be quiet, shy, and compliant. Compared with age-matched peers, they were described as less self-confident and less physically active, yet more helpful and obedient. Difficulties in academic performance and athletic participation were also observed, potentially contributing to challenges with peer integration. In

adulthood, most individuals with Klinefelter syndrome lead lives comparable to those of unaffected individuals, maintaining social relationships, friendships, and family roles. However, some may continue to experience social and emotional difficulties, often related to earlier developmental challenges. Reduced libido and low self-esteem have been reported in some adults, frequently associated with hypogonadism and feminized physical characteristics.

iii. Concomitant Illnesses: Individuals with an XXY karyotype have an increased prevalence of several comorbid medical conditions, including autoimmune disorders, breast cancer, venous thromboembolic disease, and osteoporosis. Although the relative risk of breast cancer is elevated compared with that of the general male population, it remains substantially lower than the risk observed in females. Individuals with Klinefelter syndrome are also at increased risk for cardiovascular disease, largely attributable to metabolic abnormalities such as dyslipidemia and type 2 diabetes mellitus. Current evidence does not support a clear association between Klinefelter syndrome and hypertension. In contrast, X-linked recessive disorders appear to occur less frequently in individuals with an XXY karyotype than in those with a single X chromosome. Because these conditions are caused by pathogenic variants on the X chromosome, the presence of a second X chromosome typically confers carrier status rather than phenotypic expression.

08. HOW KLINEFELTER ORIGINATES?

The birth of a cell with karyotype XXY due to a nondisjunction event of one X chromosome from a Y chromosome during meiosis I in the male. Otherwise the birth of a cell with karyotype XXY due to a nondisjunction event of one X chromosome during meiosis II in the female. Klinefelter syndrome is a sporadic chromosomal condition and is not inherited. In approximately 50% of cases, the supernumerary X chromosome is of maternal origin. Advanced maternal age is the only well-established risk factor; women aged 40 years have an approximately fourfold increased risk of having a child with Klinefelter syndrome compared with women aged 24 years. The additional X chromosome results from a non-disjunction event occurring during gametogenesis, which may arise during paternal meiosis I, maternal meiosis I, or maternal meiosis II. Non-disjunction during meiosis I occurs when homologous sex chromosomes (X and Y in males or two X chromosomes in females) fail to segregate properly, producing gametes with an abnormal number of sex chromosomes. Fertilization of a normal X-bearing oocyte by a sperm containing both X and Y chromosomes, or fertilization of a normal sperm by an oocyte containing two X chromosomes, results in an XXY karyotype. Alternatively,

nondisjunction may occur during maternal meiosis II, when sister chromatids of the X chromosome fail to separate, resulting in an oocyte with two X chromosomes. Fertilization of this oocyte by a Y-bearing sperm likewise produces an XXY offspring. The XXY karyotype represents one of the most common sex chromosome aneuploidies, occurring in approximately 1 in 500 live male births. In mammals with more than one X chromosome, transcriptional silencing of all but one X chromosome occurs through a process known as X-chromosome inactivation. This mechanism operates in XXY males as well as in typical XX females. However, genes located within the pseudoautosomal regions of the X chromosome escape inactivation and are expressed from both sex chromosomes, contributing to the phenotypic features associated with Klinefelter syndrome.

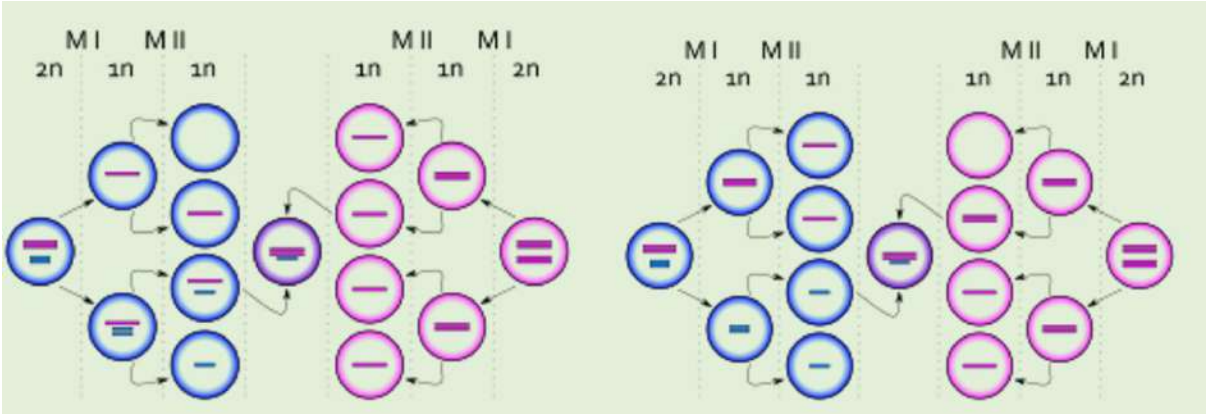

Fig. 2. Origin of Klinefelter syndrome in biological male due to non-disjunction of allosomes in human

09. VARIANTS IN KLINEFELTER SYNDROME

Rare sex chromosome aneuploidies such as 48, XXYY and 48, XXXY occur with an estimated frequency of approximately 1 in 18,000 to 50,000 male births. The 49, XXXXY karyotype is even less common, with an incidence of approximately 1 in 85,000 to 100,000 male births. These variants are exceedingly rare and are typically associated with more severe clinical manifestations. The presence of additional sex chromosome material may contribute to a broad spectrum of anomalies, including cardiac, neurological, orthopedic, and urogenital abnormalities. Rare cases of individuals with a 47, XXY karyotype and a female phenotype have also been reported in the literature.

10. MOSAICISM

Approximately 15 to 20% of individuals with Klinefelter syndrome exhibit constitutional mosaicism, most commonly a 47, XXY/46, XY karyotype, and demonstrate variable degrees of

spermatogenic impairment. Clinical features in mosaic cases are often milder, with preservation of typical male secondary sexual characteristics and testicular volumes that may fall within normal adult ranges. A less common form of mosaicism, 47,XXY/46,XX, has been described in individuals with a male phenotype and features suggestive of Klinefelter syndrome; however, this presentation is extremely rare, with only a limited number of cases reported.

11. RANDOM AND SKEWED X-CHROMOSOME INACTIVATION

In individuals with more than one X chromosome, one X chromosome undergoes transcriptional silencing early in embryonic development through a process known as X-chromosome inactivation. This mechanism occurs in both typical XX females and individuals with Klinefelter syndrome. While X inactivation is generally random, a subset of individuals exhibits skewed inactivation patterns, resulting in unequal expression between the two X chromosomes. The clinical significance of skewed X-chromosome inactivation in Klinefelter syndrome remains incompletely understood.

12. DIFFERENTIAL DIAGNOSIS

The differential diagnosis for Klinefelter syndrome includes a range of conditions with overlapping clinical features. These clinical entities include both genetic syndromes and endocrinological disorders that can mimic or coexist with the phenotype of Klinefelter syndrome.

- Acromegaly
- Adrenogenital and gonadal-secreting tumours
- Azoospermia
- Beckwith-Wiedemann syndrome
- Constitutional gigantism
- Diabetes mellitus
- Fragile X syndrome
- Hyperprolactinemia
- Hypogonadism
- Male infertility
- Marfan syndrome
- Mosaicism
- Neurofibromatosis

- Primary testicular failure
- Sanfilippo syndrome
- Simpson-Rosan-Golabi syndrome

Accurate diagnosis requires careful consideration of these differential conditions through a comprehensive clinical evaluation, genetic testing, and appropriate screening. Early identification ensures effective management and intervention, improving outcomes for individuals affected by these syndromes.

13. TREATMENT

The underlying chromosomal abnormality in Klinefelter syndrome is irreversible, no curative therapy is available. Management is therefore directed toward mitigating clinical manifestations and preventing long-term complications. From the onset of puberty, testosterone deficiency can be addressed with hormone replacement therapy to promote the development and maintenance of secondary sexual characteristics, improve bone mineral density, and support overall metabolic health. Testosterone is available in multiple formulations, including intramuscular injections, transdermal patches, and topical gels. In individuals with clinically significant gynecomastia, surgical reduction mammoplasty may be considered for psychological well-being and to reduce the risk of breast malignancy. Early intervention with behavioral and educational therapies can improve language development, academic performance, and social functioning. Speech and language therapy, behavioral therapy, and educational support are particularly beneficial for addressing learning difficulties and social challenges. Occupational therapy is especially valuable in children with motor coordination impairments, including dyspraxia.

14. MANAGEMENT OF INFERTILITY

Advances in assisted reproductive technologies have enabled some individuals with Klinefelter syndrome to achieve biological paternity. Techniques such as testicular sperm extraction (TESE), followed by intracytoplasmic sperm injection (ICSI), allow for the retrieval and use of viable sperm in selected cases. By 2010, more than 100 successful pregnancies had been reported using in vitro fertilization with surgically retrieved sperm from men with Klinefelter syndrome. Individuals with Klinefelter syndrome are at increased risk for a wide range of medical and neuropsychological complications affecting multiple organ systems,

underscoring the need for coordinated, interprofessional care. The following are different complications that need to be addressed.

i. Reproductive Complications: Androgen deficiency and progressive testicular failure are central features of Klinefelter syndrome and underlie most reproductive abnormalities. Common manifestations include azoospermia, infertility, reduced testicular volume, micropenis (penile length <8 cm), decreased libido, gynecomastia, and sparse facial and body hair. These findings reflect impaired spermatogenesis, and most affected individuals experience significant challenges in achieving biological paternity.

ii. Behavioural and Neurodevelopmental Effects: Neuropsychiatric and behavioural complications are common and include increased rates of anxiety, depression, attention-deficit/hyperactivity disorder, relationship difficulties, and autism spectrum disorder. Cognitive impairments, including lower intelligence quotient scores and specific learning disabilities, are also observed in a subset of affected individuals.

iii. Metabolic Abnormalities: Individuals with Klinefelter syndrome have a higher prevalence of metabolic dysfunction, including type 2 diabetes mellitus. Contributing factors include hypogonadism, increased visceral adiposity, and greater waist circumference. Additional metabolic abnormalities include dyslipidemia—characterized by elevated low-density lipoprotein and reduced high-density lipoprotein levels—as well as obesity. These factors collectively increase the risk of cardiovascular disease. Hypertension has been reported but does not appear to be independently associated with the syndrome.

iv. Oncologic Complications: Klinefelter syndrome is associated with an increased risk of certain malignancies. Hormonal dysregulation has been proposed as a contributing factor to the elevated incidence of breast and prostate cancers. Increased risks of germ cell tumours, non-Hodgkin lymphoma, and lung cancer have also been reported.

v. Endocrinologic Disorders: In addition to primary hypogonadism, Klinefelter syndrome has been associated with hypopituitarism, which may be partial or complete. Clinical manifestations can include headaches, visual disturbances, and dizziness. Deficiencies in pituitary hormones, such as growth hormone and thyroid-stimulating hormone, have been documented. Case reports describing concomitant hypogonadism and hypopituitarism highlight the importance of considering pituitary dysfunction in affected individuals presenting with suggestive symptoms.

vi. Musculoskeletal Complications: Musculoskeletal abnormalities arise from the combined effects of chromosomal, hormonal, and growth-related factors. Increased dosage of X-linked genes involved in skeletal growth contributes to tall stature and disproportionately long limbs. Delayed epiphyseal closure due to testosterone deficiency results in eunuchoid body proportions. Hypogonadism leads to reduced muscle mass and decreased bone mineral density, while normal or elevated growth hormone levels further promote linear growth. Osteopenia and osteoporosis result from impaired bone formation and increased resorption, compounded by altered vitamin D metabolism and reduced insulin-like peptide 3 levels. Although testosterone replacement therapy and physical rehabilitation can improve muscle mass and bone density, these interventions may not fully reverse established skeletal abnormalities.

vii. Associated Autoimmune Conditions: Individuals with Klinefelter syndrome demonstrate increased susceptibility to autoimmune diseases, potentially related to the presence of an additional X chromosome and associated hormonal disturbances. Reported conditions include systemic lupus erythematosus, rheumatoid arthritis, autoimmune thyroid disease, and nodular thyroid disorders. Type 1 diabetes mellitus has also been described, although less frequently, supporting the need for vigilance and appropriate screening for autoimmune endocrinopathies in this population.

viii. Vascular and Thromboembolic Complications: Klinefelter syndrome is associated with an elevated risk of venous thromboembolic disease, including deep vein thrombosis, pulmonary embolism, and chronic venous insufficiency with varicosities. This increased risk is attributed to a combination of prothrombotic abnormalities, hypogonadism-related hormonal effects, and X-linked genetic factors. Thrombophilia assessment and careful clinical monitoring are recommended, particularly during testosterone therapy or periods of prolonged immobilization.

Conclusion

Klinefelter syndrome is the most common sex chromosome aneuploidy in males, typically characterized by a 47, XXY karyotype. The condition manifests with a spectrum of physical, endocrine, neurocognitive, and psychosocial features, including primary hypogonadism, infertility, tall stature, learning difficulties, and behavioural differences. Phenotypic severity varies, particularly in cases of mosaicism or additional X-chromosome variants. While the underlying genetic abnormality is irreversible, early diagnosis and a multidisciplinary management approach including testosterone replacement, educational and

behavioural interventions, fertility treatments, and monitoring for metabolic, musculoskeletal, autoimmune, and oncologic complications can significantly improve quality of life and long-term outcomes. Continued research into the molecular mechanisms, genotype–phenotype correlations, and optimal therapeutic strategies remains essential to further enhance patient care.

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MODERN CONCEPT OF GENE

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01. INTRODUCTION

The concept of gene first came from the work of Mendel. Although the term 'gene' was not used at that time, Mendel from his experiments on pea plants, suggested that the characters of an organism are controlled by factors located within its body. Flemming recorded certain deeply stained bodies within the cell, which he termed 'chromosomes'. Meischer on the other hand, extracted 'nuclein' a nucleoprotein constituent from the sperm. Afterwards, due to researches by subsequent workers (Kossel and others), an idea gradually developed on the chemical structure of chromosome. After the chemical analysis of chromosome carried out by Meischer and his successors, chromosomes were found to consist chiefly of protein and nucleic acid. It was regarded as continuous frame-work of basic protein or histone, having active regions located on DNA the genes, the hereditary material.

02. FROM CLASSICAL TO MODERN CONCEPTS

The changing concept of gene from classical to molecular level may be summarized as follows:

i. Gene governs the inheritance which is bi-parental, i.e., both male and female parents contribute equally in the inheritance of characters to next generation (exception cytoplasmic inheritance or maternal inheritance).

ii. Characters of an individual are determined by paired genes, situated in definite number of chromosome pairs or linkage groups.

iii. Many genes are present on each chromosome and are inherited together, called linked genes.

iv. Each gene-has a particular position on a particular chromosome being called as locus. Chromosomal aberration of translocation or inversion type may change the position of a locus.

v. During gamete formation each pair of genes gets segregated and gametes possess only one gene of that kind.

vi. Pairs of genes which are in different chromosomes or in different linkage groups are assorted independently.

vii. Genes lie in a linear order on a chromosome and the order remains same unless translocation or inversion takes place.

viii. A single gene may occur in several forms called alleles. Normally it has two forms — dominant and recessive; when more than two forms occur, called multiple alleles.

ix. The number of a particular gene may be increased in a 'cell due to polyploidy. Aneuploidy also causes increase (hyperploidy) or decrease (hypoploidy) in the number of a particular gene in a cell.

x. Mutation causes a gene to be changed from its wild form.

xi. Genes in a particular chromosome may be shifted to its homologous pair due to crossing over causing recombination.

xii. Sometimes two or more genes interact together to produce a trait (interaction of genes).

xiii. Replication of each chromosome during cell division causes the self-duplication of genes of that chromosome.

xiv. Inbreeding causes homozygosity within the gene pair, whereas outbreeding leads to heterozygosity of the gene pairs.

xv. Genes are chemically DNA, a double helical structure composed of nucleotides containing adenine, guanine, thymine and cytosine together with deoxyribose sugar and phosphate. The nucleotides are grouped into triplets presenting 64 combinations called as genetic code.

03. *CIS-TRANS* EFFECT (POSITION PSEUDOALLELISM):

Though the appearance of wild type in F_2 generation could be explained on the basis of pseudo-allelism, but it was difficult to explain why F_1 was not wild type. This could be explained on the basis of lack of complementation due to different arrangements (cis-trans) of mutant alleles. In F_1 heterozygotes, two arrangements are possible

i) Both mutant alleles on the same chromosome and their wild counterparts on the other homologue (cis),

(ii) Two mutant alleles on two different homologues (trans).

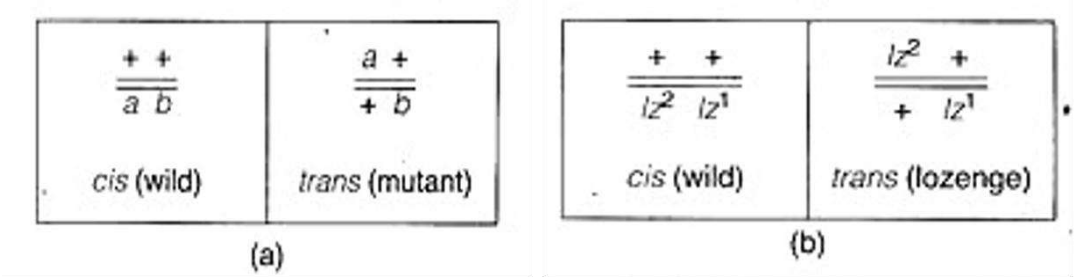

Fig. 1. (a). Cis and trans arrangement of alleles a and b in heterozygote condition and (b). Cis and trans arrangement of heterozygotes involving two alleles lz^1 and lz^2 at lozenge locus

Heterozygote for Iz^1, and Iz^2 (two mutants) may show both cis and trans arrangements. In cis configuration wild phenotype expresses, but trans configuration in F_1 individuals does not allow the wild type to be expressed.

This may presumably be due to position effect, where a mutant allele does not allow adjacent region to express wild phenotype, so it may be called as position pseudo-allelism. This has been termed as cis-trans effect by Lewis. Since intragenic inter-allelic crossing over is possible, as a result + + and Iz^1lz^2 gametes are produced from F_1 individuals (trans). Thus, in F_2 generation, the wild type will express.

04. FINE STRUCTURE OF GENE

The concept of gene controlling a single character must involve the expression of several reactions and in its constituents involves a number of proteins. The work of Beadle and Tatum demonstrated that the relationship between gene and enzyme is 1:1. Evidently, if a gene is responsible for the synthesis of a single polypeptide then the gene as visualized by Mendel is certainly not the ultimate unit of inheritance. The concept of ultimate indivisible unit of gene underwent complete change following the work of different scientists.

Concept of Cistron, Recon, Muton (Rll Locus in T4 Phage):

Benzer carried out most refined analysis of rll locus in T4 bacteriophage. A mutant at this locus is responsible for the formation of rough plaques or colonies on B strain of E. coli, but unable to produce any plaques on K strain.

i. Complementation Test:

This test was carried out by Benzer in order to find out complementation relations between different rll mutant alleles. He allowed mixed infection of K strain of E. coli by two rll mutants. In most cases it did not result in plaque formation, but in some cases plaque formation occurred.

If two mutants did not form plaques on mixed infection, they were placed in the same complementation group, but if plaques were produced, the two mutants involved in mixed infection were placed in two different groups. In this manner, two groups A and B could be established in rll region. All mutants with the help of complementation test could be classified in these two groups, in such a manner that two mutants from group A or two mutants from group B could not cause plaque formation but mixed infection by one mutant of group A and another of group B, could cause plaque-formation. Since groups A and B are distinguished on the basis of cis-trans test, these were termed as cistron A and cistron B. Two mutants from different cistrons (A and B) would give wild type (plaque formation) even in trans configuration, which in other words is called complementation.

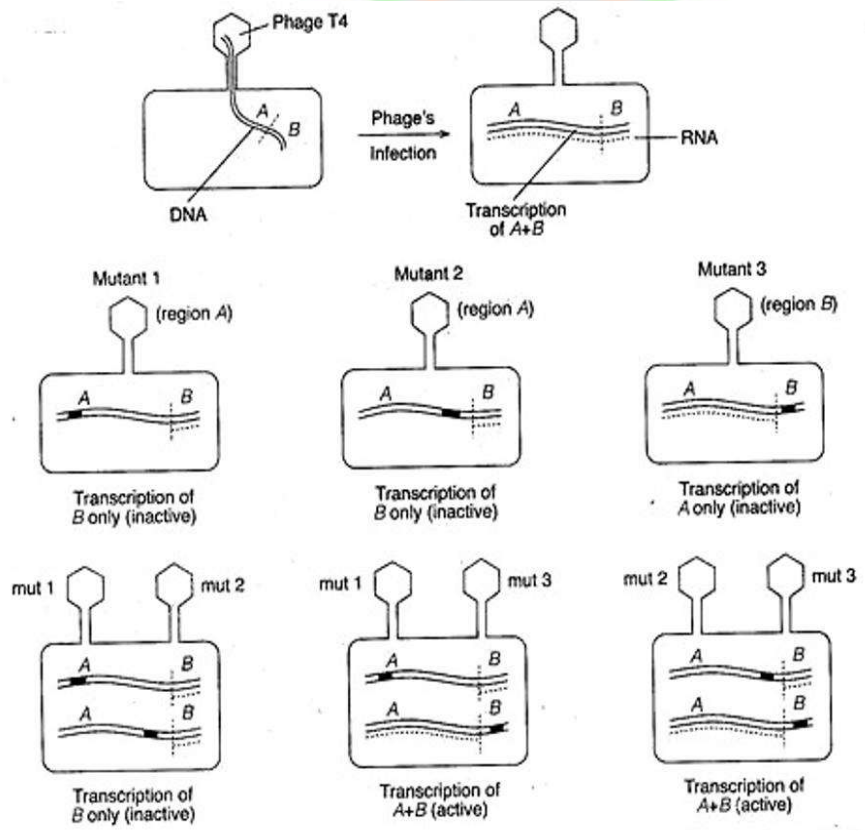

Fig. 2. Complementation test between mutants to find out if they belong to same or different cistrons

From the complementation test, it is obvious that in rll region, two cistrons A and B (Fig. 14.10) of 2500 and 1500 nucleotide pairs respectively are independent functionally and must be responsible for sequential synthesis of two separate products, which presumably are polypeptide

chains. Therefore, all mutants belonging to one cistron share a common deficiency, which is different from the deficiency due to mutations belonging to the second cistron. When two mutants belong to same cistron, both are deficient for same product and, therefore, they cannot complement, but when two mutants belong to two different cistrons, they, being deficient for different products, can complement, and may express wild phenotype, i.e., lysis and plaque formation.

ii. Recombination Test:

After rll mutants were classified in cistron A and cistron B, Benzer was interested in analysing mutants, belonging to same cistron. It was, therefore, necessary to subject them to recombination test to find out whether they are located on same site or different sites separable by recombination. Deletion mutation of rll locus were arranged in a sets overlapping deletion

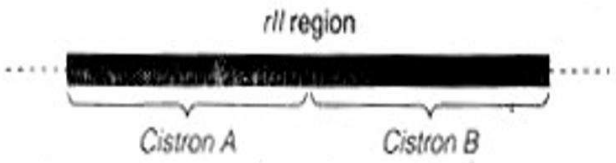

Fig. 3. rll region of T4 phage showing two cistrons

representing segments of different sizes. The principle involved in this technique was that if a particular point mutant lies in the region of a deletion represented by a rIl mutant, then on mixed infection with this deletion mutant, the point mutant will not be able to give rise to a wild type, but if it falls outside the deletion region, it will be able to give wild type recombinant. Using deletion mutants having successive overlapping deletions of smaller lengths, one could locate a mutant to a fairly small region. All point mutants located in this particular small segment of rll region, could then be subjected to recombination test. For this purpose, two mutants at a time were used for mixed infection on E. coli B strain and the lysate produced on plaques formed on B strain was used for infection on K strain to find out the frequency of wild type phage particles produced. Benzer eventually estimated 400-500 mutational sites in rll region and called each of them a unit of mutation or a muton. Thus, Benzer was not only able to divide rll region into cistrons A and B, but was able to classify mutants belonging to same cistron into hundreds of mutational sites separable due to recombination.

iii. Cistron, Recon, Muton:

Thus, a gene is not a unit of either function or recombination or mutation. Benzer, in view of his work, coined the terms cistron (unit of function), recon (unit of recombination) and muton (unit of mutation). Cistron was defined as a unit, the elements (alleles) of which exhibit cis-trans phenomenon. The smallest unit capable of undergoing recombination is called recon. A recon is further sub-divisible into units of mutations called mutons, and several mutons in a recon will not be separable due to recombination. Therefore, cistron, recon and muton are the units, in the descending order of size and structurally the gene of classical authors is comparable to cistron of Benzer.

iv. Deletion Mapping:

At the intragenic level, with the help of recombination studies, micro-maps have been prepared for different genes. Deletion mutations have a critical use in genetic mapping. The deletion can recombine with point mutations on either side. By obtaining a series of partially overlapping deletions, any point mutation can be mapped by testing the ability to recombine among them. When two deletions both fail to recombine with a point mutation, the site of mutation must lie in the region common to the deletions. When one deletion recombines and other does not, the site of mutation must lie in the region in which the deletions do not overlap. When a new mutant carrying a point mutation is isolated, the mutation can quickly be mapped to a defined interval by crossing the mutant strain with each of the overlapping deletion mutants. Suppose a new point mutation r_1 has been obtained and recombination experiment shows no recombination with deletion I segment but can recombine with other deletion II, III ad IV, so the site of point mutation must be within the segment A.

05. OVERLAPPING GENES

Overlapping genes are those genes which can be read or translated in two different ways to produce two different proteins. From the information about proteins coded by the genome of φx174, an estimate could be made of the number of nucleotides required (number of bp should be 3 times the number of amino acids in protein). This estimate of number of nucleotides exceeds 6000 which is much higher than the actual number of nucleotides present in single stranded DNA of φx174 (the actual number of nucleotide is 5400). Therefore, it was difficult to explain how these proteins could be coded from a DNA segment which is not long enough to code the required number of amino acids. On detailed study of the system, it was discovered that

a single sequence can be utilized by two different cistrons coding different proteins. Such overlapping of cistrons will be theoretically possible if the two cistrons have to function at different times and their nucleotide sequences are translated in two different reading frames.

In 1976 Barnell and his co-workers discovered that the genome of φ x 174 consists of 9 cistrons (A, B, C, D, E, F, G, H, J). Cistron E is present between C and J, and that cistron E overlaps cistron D. Again, stop codon of gene D is overlapping with the start codon of gene J (Fig. 4). Gene B also overlaps with gene A.

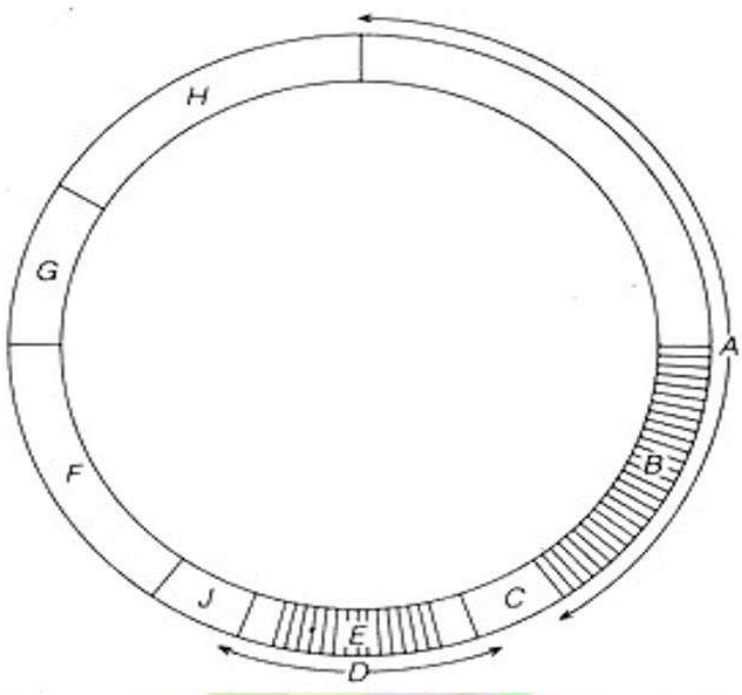

Fig. 4. Genetic map of the bacteriophage φ x 174 showing overlapping gene of E over gene D and of gene B over gene A

In the base sequence TAATG, the first triplet code TAA, is the stop codon of gene D and last three (ATG) is the start codon of gene J (Fig. 5). Here the middle base (third from left) is the base where both codons meet. Secondly, it has also been shown that gene E and B are completely included in gene D and A respectively. Both these genes produce their own protein in considerable amount. Such genes are named as included genes. Probable significance attributed to these genes is to meet the economy of space or area without affecting the production of needed proteins.

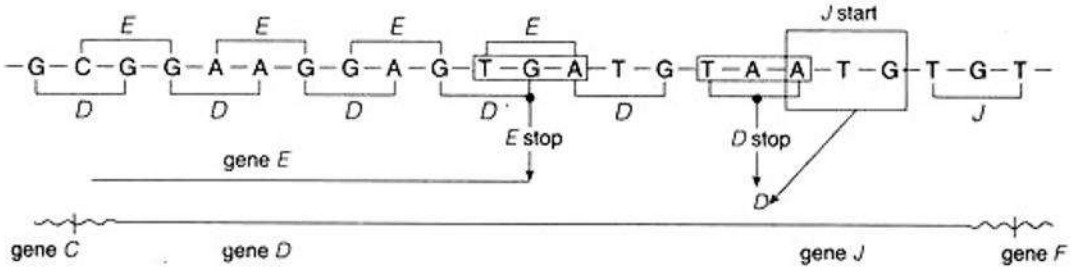

Fig. 5. Overlapping and included genes

The term gene was introduced by Johanssen in 1909. Prior to him Mendel had used the word factor for a specific, distinct, particulate unit of inheritance that takes part in expression of a trait. Johanssen has defined gene as an elementary unit of inheritance which can be assigned to a particular trait. Morgan's work suggested gene to be the shortest segment of chromosome which can be separated through crossing over, can undergo mutation and influence expression of one or more traits. Presently, a gene is defined as a unit of inheritance composed of a segment of DNA or chromosome situated at a specific locus (gene locus) which carries coded information associated with a specific function and can undergo crossing over as well as mutation.

A gene is:

- A unit of genetic material which is able to replicate,
- It is a unit of recombination, i.e., capable of undergoing crossing over,
- A unit of genetic material which can undergo mutation,
- A unit of heredity connected with somatic structure or function that leads to a phenotypic expression.
- Modern concept of gene (Cistron, muton, recon, viral genes).
- After the discovery of DNA, the gene has been defined as cistron, recon and muton. The classical gene is the smallest unit that could undergo a mutational change. A gene further divided into smaller units of function, mutation and recombination.
- Symour Benzer (1955-USA) coined the terms cistron, recon, and muton to explain the relationship between DNA and genetic phenomena.

(a) Cistron: It is the unit of function. Cistron represents a segment of the DNA molecule and consists of a linear sequence of nucleotides, which controls some cellular function. In E. Coli cistron may contain about 1500 base pairs. Some cistrons may contain as many as 30,000 base

pairs. The cistron begin with initiation codon and ends with a terminating codon. Each cistron is responsible for coding one m-RNA molecule which in turn controls the formation of one polypeptide chain. Each cistron consists of hundreds of mutons and recons.

(b) Recon: It is a unit of recombination. It is the smallest unit capable of recombining genetically. Recombination studies on microbes indicate that structurally the recon consists of one or two pairs of nucleotides, possibly only one pair.

(c) Muton: It is a unit of mutation. The shortest chromosomal unit capable of undergoing mutation has been called the muton. The muton consists of one or many pairs of nucleotides within the DNA molecule.

06. TYPES OF GENES

1. House Keeping Genes (Constitutive Genes): They are those genes which are constantly expressing themselves in a cell because their products are required for the normal cellular activities, e.g., genes for glycolysis, ATP-ase.

2. Non-constitutive Genes (Luxury Genes): The genes are not always expressing themselves in a cell. They are switched on or off according to the requirement of cellular activities, e.g., gene for nitrate reductase in plants, lactose system in Escherichia coli. Non- constitutive genes are of further two types, inducible and repressible.

3. Inducible Genes: The genes are switched on in response to the presence of a chemical substance or inducer which is required for the functioning of the product of gene activity, e.g., nitrate for nitrate reductase.

4. Repressible Genes: They are those genes which continue to express themselves till a chemical (often an end product) inhibits or represses their activity. Inhibition by an end product is known as feedback repression.

5. Multi-genes (Multiple Gene Family): It is a group of similar or nearly similar genes for meeting requirement of time and tissue specific products, e.g., globin gene family (e, 5, (3, y on chromosome 11, oc and 8 on chromosome.

6. Repeated Genes: The genes occur in multiple copies because their products are required in larger quantity, e.g., histone genes, tRN A genes, rRN A genes, actin genes.

7. Single Copy Genes: The genes are present in single copies (occasionally 2-3 times), e.g., protein coding genes. They form 60-70% of the functional genes. Duplications, mutations and exon reshuffling can form new genes.

8. Pseudogenes: They are genes which have homology to functional genes but are unable to produce functional products due to intervening nonsense codons, insertions, deletions and inactivation of promoter regions, e.g., several of snRNA genes.

9. Processed gene: They are eukaryotic genes which lack introns. Processed genes have been formed probably due to reverse transcription or retroviruses. Processed genes are generally nonfunctional as they lack promoters.

10. Split Genes: They were discovered in 1977 by many workers but credit is given to Sharp and Roberts (1977). Split genes are those genes which possess extra or nonessential regions interspersed with essential or coding parts. The nonessential parts are called introns, spacer DNA or intervening sequences (IVS). Essential or coding parts are called exons. Transcribed intronic regions are removed before RN A passes out into cytoplasm. Split genes are characteristic of eukaryotes. However, certain eukaryotic genes are completely exonic or non-split e.g., histone genes, interferon genes. Split genes have also been recorded in prokaryotes, thymidylate synthase gene and ribonucleotide reductase gene in T4. A gene that produces calcitonin in thyroid forms a neuropeptide in hypothalamus by removing an exon. Adenovirus has also a mechanism to produce 1 5220 different proteins from a single transcriptional unit by differential splicing

11. Transposons (Jumping Genes; Hedges and Jacob, 1974): They are segments of DNA that can jump or move from one place in the genome to another. Transposons were first discovered by Me Clintock (1951) in case of Maize when she found that a segment of DNA moved into gene coding for pigmented kernels and produced light coloured kernels. Transposons possess repetitive DNA, either similar or inverted, at their ends, some 5, 7 or 9-nucleotide long. Enzyme transposase separates the segment from its original by cleaving the repetitive sequences at its ends. There are many types of transposons. In human beings the most common types of transposons belong to A lu family (having a site for cutting by restriction enzyme A lu I). The number of nucleotides per transposon is about 300 with about 300,000 copies in the genome. Passage of transposons from one place to another brings about reshuffling of nucleotide sequences in genes. Reshuffling in introns often changes expression of genes, e.g., proto-oncogenes i oncogenes. New genes may develop by exon shuffling. Other changes caused by transposons are mutatio ns, through insertio ns, deletions and translocatio ns.

12. Overlapping Genes: Overlapping genes are defined as a pair of adjacent genes whose coding regions are partially overlapping. In other words, a single stretch of DNA codes for portions of two separate proteins. For two genes to overlap, the signal to begin transcription for one must reside inside the second gene, whose transcriptional start site is further "upstream". Some of the benefits of overlapping genes are that they enable the production of more proteins from a given region of DNA than is possible if the genes were arranged sequentially. In the bacteriophage PhiX174, overlapping of genes is necessary. The amount of DNA present in the circular, single-stranded DNA genome of this virus is not sufficient to encode the eleven bacteriophage proteins if transcription occurs in a linear fashion, one gene after another

13. Structural Genes: Structural genes are those genes which have encoded information for the synthesis of chemical substances required for cellular machinery.

The chemical substances may be:

(a) Polypeptides for the formation of structural proteins (e.g., colloidal complex of protoplasm, cell membranes, elastin of ligaments, collagen of tendons or cartilage, actin of muscles, tubulin of microtubules, etc.).

(b) Polypeptides for the synthesis of enzymes,

(c) Transport proteins like haemoglobin of erythrocytes, lipid transporting proteins, carrier proteins of cell membranes, *etc*.

(d) Proteinaceous hormones, e.g., insulin, growth hormone, parathyroid hormone,

(e) Antibodies, antigens, certain toxins, blood coagulation factors, *etc*,

(f) Non-translated RNAs like tRNAs, rRNA. Broadly speaking, structural genes either produce mRNAs for synthesis of polypeptides/proteins/enzymes or noncoding RN As.

14. Regulatory Genes (Regulatory Sequences): Regulatory genes do not transcribe RNAs for controlling structure and functioning of the cells. Instead, they control the functions of structural genes. The important regulatory genes are promoters, terminators, operators and repressor producing or regulator genes. Repressor does not take part in cellular activity. Instead, it regulates the activity of other genes. Therefore, repressor producing gene is of intermediate nature.

15. Tissue Specific Genes: They are genes which are expressed only in certain specific tissues and not in others.

16. Junk Genes: A DNA sequence that is part of a genome and is not known to code for proteus or to regulate the expression of genes. Junk DNA may constitute up to 95 percent of the human genome and is postulated to be involved in the evolution of new genes and possibly the repair of genes.

07. GENE FUNCTIONS

i. Genes are components of genetic material and are thus units of inheritance,

ii. They control the morphology or phenotype of individuals,

iii. Replication of genes is essential for cell division, (iv) Genes carry the hereditary information from one generation to the next,

iv They control the structure and metabolism of the body,

v. Reshuffling of genes at the time of sexual reproduction produces variations,

vi. Different linkages are produced due to crossing over,

vii. Genes undergo mutations and change their expression,

viii. New genes and consequently new traits develop due to reshuffling of exons and introns (x)Genes change their expression due to position effect and transposons

ix. Differentiation or formation of different types of cells, tissues and organs in various parts of the body is controlled by expression of certain genes and non-expression of others.

x. Development or production of different stages in the life history is controlled by genes

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ENVIRONMENTAL DNA: A GAME-CHANGER IN AQUATIC MONITORING

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Abstract

Aquatic ecosystems harbour immense biodiversity, yet monitoring these systems remains challenging due to the limitations of traditional survey methods. Environmental DNA (eDNA) has emerged as a cutting-edge, non-invasive tool for detecting organisms by analysing genetic material released into water bodies. This method makes biodiversity assessment quicker, more effective, and less disruptive by enabling researchers to identify species without direct observation or capture. eDNA has proven highly effective in detecting rare and endangered species, monitoring invasive organisms, and assessing ecosystem health. Its applications extend to fisheries management, conservation planning, and environmental monitoring. Despite certain limitations such as DNA degradation and the need for comprehensive reference databases, advancements in molecular techniques continue to enhance its accuracy and reliability. This article discusses the principles, applications, advantages, and future potential of eDNA as a transformative tool in aquatic biodiversity monitoring and ecosystem management.

Keywords: Environmental DNA, Aquatic biodiversity, Ecosystem monitoring, Molecular techniques

Introduction

Aquatic ecosystems such as rivers, lakes, wetlands, and oceans play a vital role in maintaining ecological balance and supporting biodiversity. Conservation and sustainable

management depend on monitoring these habitats. However, conventional techniques such as netting, trapping, and visual observation are frequently labour-intensive, time-consuming, and sometimes detrimental to organisms.

In recent years, environmental DNA (eDNA) has emerged as an innovative molecular approach that is transforming biodiversity monitoring. Organisms continuously release DNA into their environment through skin cells, mucus, faeces, and decomposition. This DNA can be collected from environmental samples and analyzed to identify species present in a particular habitat. As a result, eDNA offers a rapid, sensitive, and non-invasive method for assessing aquatic biodiversity.

Environmental DNA (eDNA) and Its Concept

Environmental DNA refers to genetic material obtained directly from environmental samples such as water, soil, or sediment without isolating the target organism. In aquatic systems, organisms shed DNA into the surrounding water, where it persists for a limited time before degrading. This DNA serves as a biological signature, enabling scientists to determine the presence of species within an ecosystem.

The concept of eDNA is based on the principle that all organisms leave traces of their genetic material in their environment, making it possible to detect them without direct observation. This approach has gained significant importance due to its ability to identify species that are rare, elusive, or difficult to capture using conventional techniques.

Source: National Park Service

Methodology of eDNA Analysis

The process of eDNA analysis involves a series of steps beginning with the collection of water samples from aquatic environments such as rivers, lakes, reservoirs, or coastal regions.

These samples are then filtered to capture DNA fragments suspended in the water. Following filtration, DNA is extracted using chemical and molecular methods.

The extracted DNA is subsequently amplified using techniques such as Polymerase Chain Reaction (PCR), quantitative PCR (qPCR), or metabarcoding to increase the detectable quantity of genetic material. Finally, the amplified DNA sequences are compared with reference databases to identify the species present in the ecosystem. This systematic approach allows for accurate and efficient biodiversity assessment.

Applications of eDNA in Aquatic Ecosystems

Environmental DNA has wide-ranging applications in aquatic biodiversity monitoring and ecosystem management. It is particularly useful in detecting rare and endangered species that are often missed by traditional survey methods. The technique also plays a crucial role in the early detection of invasive species, allowing for timely management interventions to prevent ecological damage. Additionally, eDNA is widely used to assess fish diversity and monitor aquatic communities in both freshwater and marine ecosystems. By providing detailed information on species composition, eDNA contributes significantly to evaluating ecosystem health and understanding ecological changes.

Factors Affecting eDNA Detection in Aquatic Systems

The efficiency of environmental DNA detection is influenced by several physical, chemical, and biological factors present in aquatic environments. Temperature plays a significant role, as higher temperatures can accelerate DNA degradation, reducing detection probability. Similarly, ultraviolet (UV) radiation from sunlight can break down DNA molecules, especially in shallow water bodies.

Water chemistry, including pH and salinity, also affects DNA stability, with extreme conditions leading to faster degradation. Hydrodynamic factors such as water flow, mixing, and turbulence influence the distribution and dilution of eDNA, making it challenging to determine the exact location of species. Additionally, microbial activity contributes to DNA degradation, as microorganisms break down genetic material present in the environment. Understanding these factors is crucial for improving sampling strategies and ensuring accurate biodiversity assessment.

Comparison with Traditional Monitoring Methods

Traditional methods of aquatic biodiversity monitoring, such as net sampling,

electrofishing, and visual surveys, have been widely used for decades. However, these methods are often labour-intensive, time-consuming, and may cause stress or harm to organisms. In contrast, eDNA offers a non-invasive alternative that requires minimal disturbance to the ecosystem. While traditional methods provide information on species abundance, size, and health, eDNA primarily indicates species presence or absence. Despite this limitation, eDNA is highly sensitive and can detect species at very low densities, which are often missed by conventional techniques. Therefore, integrating eDNA with traditional methods can provide a more comprehensive understanding of aquatic ecosystems.

Technological Advancements in eDNA Analysis

Recent advancements in molecular biology and sequencing technologies have significantly improved the efficiency and accuracy of eDNA analysis. High-throughput sequencing techniques, such as next-generation sequencing (NGS), allow simultaneous detection of multiple species from a single sample. Metabarcoding approaches enable comprehensive biodiversity assessment by analyzing mixed DNA samples.

Additionally, improvements in bioinformatics tools have enhanced the ability to process and interpret large datasets. Portable field-based DNA analysis tools are also being developed, which can provide rapid results without the need for complex laboratory facilities. These technological innovations are expanding the scope and applicability of eDNA in environmental monitoring.

Advantages and Limitations of eDNA

One of the major advantages of eDNA technology is that it is non-invasive and does not disturb organisms or their habitats. It is highly sensitive, capable of detecting species even at low population densities, and is more time-efficient and cost-effective compared to traditional methods. Furthermore, it is suitable for large-scale monitoring and can be applied in remote or inaccessible areas.

However, eDNA also has certain limitations. DNA degrades rapidly in aquatic environments, which may affect detection accuracy. There is also a risk of contamination during sample collection and analysis. Additionally, estimating population size using eDNA remains challenging, and the accuracy of species identification depends on the availability of comprehensive genetic reference databases.

Role in Ecosystem Management and Future Perspectives

Environmental DNA has become an essential tool in modern aquatic ecosystem management. It supports biodiversity conservation, fisheries management, and environmental monitoring by providing reliable and rapid data. In countries like India, where aquatic biodiversity is extensive, eDNA can significantly enhance monitoring efficiency and conservation efforts. Looking ahead, advancements in sequencing technologies, bioinformatics, and data analysis are expected to further improve the accuracy and applicability of eDNA. The integration of eDNA with other technologies such as remote sensing and artificial intelligence, may revolutionize ecosystem monitoring and management in the future.

Conclusion

Environmental DNA has emerged as a transformative tool in aquatic biodiversity monitoring and ecosystem management, offering unprecedented opportunities for non-invasive and efficient species detection. Its ability to reveal hidden biodiversity and detect ecological changes makes it invaluable in the face of growing environmental challenges such as climate change, habitat degradation, and biological invasions. While certain limitations exist, ongoing technological advancements and methodological improvements are steadily overcoming these challenges. The integration of eDNA with traditional monitoring methods and modern technologies will further enhance its effectiveness. As research continues to evolve, eDNA is expected to play a central role in shaping the future of aquatic conservation and sustainable resource management.

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ILLUMINATING THE PRESSURE: IMPACTS OF LIGHT FISHING ON MARINE FISHERIES

Article ID: AG-VO6-I04-48

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Introduction

The growing demand for fish has placed increasing pressure on marine resources, leading fishermen to adopt new and more efficient technologies. One such innovation is the use of LED lights in fishing, a method that attracts fish by taking advantage of their natural response to light. Widely used in regions like Goa and Karnataka, LED fishing allows fishermen to catch large quantities of fish quickly and at lower operational costs, particularly by reducing fuel use and labour. However, this efficiency comes with important concerns. Artificial lights attract not only adult fish but also juveniles and non-target species, increasing the risk of overfishing and affecting future fish populations. The light also alters natural marine behaviour, drawing plankton, small fish, and larger predators into a concentrated area, which can disrupt the balance of marine ecosystems. In addition, the growing number of illuminated fishing vessels may contribute to environmental issues such as pollution and increased fishing pressure. The ban on LED fishing in places like Cutbona Jetty in Goa reflects the ongoing debate between economic benefits and environmental sustainability. While many fishermen support LED fishing for its profitability, others worry about its long-term impacts on fish stocks and livelihoods. This highlights the urgent need for balanced and uniform policies that ensure both the conservation of marine resources and the well-being of fishing communities.

Keywords: LED fishing, Light fishing, Fish stocks, Marine ecology, Sustainability

LED Fishing Ban and Its Implications: Insights from Cutbona Jetty, Goa

Light plays a critical role in marine ecosystems by supporting photosynthesis and

influencing the behavior of marine organisms. Many fish species exhibit phototactic behavior, meaning they respond to light by either avoiding it or moving toward it. This biological response has been utilized in fisheries through the practice of light fishing, where artificial lights are used to attract fish. LED (light-emitting diode) fishing is a recent technological advancement in this field. The method uses LED lights to attract fish, enabling fishermen to capture large quantities efficiently. In India, LED fishing has primarily been practiced in the states of Karnataka and Goa. However, the technology has sparked significant debate within fishing communities due to concerns over its ecological impact and its potential effect on traditional fishing practices. As a result, there has been considerable agitation regarding the ban on LED fishing (Colaco, 2019).

LED Fishing and the Risk of Overfishing

One of the major concerns raised regarding the use of LED lights in fishing is their potential to contribute to overfishing. The use of LED lights may lead to excessive fishing pressure because these lights attract large aggregations of fish. The mechanism behind this phenomenon is largely related to the ecological interactions triggered by artificial light in the marine environment. LED lights used in fishing are commonly white or green in colour, wavelengths that are highly attractive to plankton. Plankton form the base of the marine food chain and serve as a primary food source for many small fish species. When plankton congregate around the illuminated area in the water column, small plankton-feeding fish are attracted to the site to feed. This aggregation of smaller fish subsequently attracts larger predatory fish, which move into the area to prey on them. In turn, even larger fish species may arrive in search of prey, thereby creating a cascading food-chain attraction effect around the light source. This chain reaction results in the formation of large schools of fish around the illuminated area, making it easier for fishermen to capture a significant quantity of fish in a short period. While this method increases fishing efficiency, it also raises concerns about unsustainable harvesting and the depletion of fish stocks, thereby contributing to the risk of overfishing (Colaco, 2019).

LED Fishing and Its Impact on Fish Breeding

Another major concern associated with the use of LED lights in fishing is the potential reduction in fish breeding. Artificial LED lights not only attract adult fish but also juvenile and immature fish. Since juvenile fish are drawn toward the illuminated area, they become vulnerable to capture before reaching reproductive maturity. When immature fish are harvested prematurely, they are unable to contribute to the spawning population. The continuous removal

of juvenile fish from the ecosystem can therefore reduce the number of individuals that reach maturity and participate in reproduction. Over time, this process may lead to declining breeding populations and reduced recruitment of young fish into the stock. Consequently, the capture of juvenile fish through LED fishing may contribute to long-term depletion of fish stocks and negatively affect the sustainability of marine fisheries (Colaco, 2019).

Positive Impacts of LED Fishing

The use of LED lights in fishing has gained support among several stakeholders due to its perceived economic, operational, and management advantages. A number of fishermen highlighted the positive impacts of LED fishing, particularly in terms of reduced operational costs, improved efficiency, and perceived ecological benefits.

Reduced Fuel Consumption

One of the major advantages is the reduction in diesel consumption. Fuel and engine oil expenses constitute a significant portion of the operational costs incurred by trawler owners. With the use of LED lights, fishermen do not need to travel long distances in search of fish. Instead, when LED lights are immersed in the water, fish are naturally attracted to the illuminated area. As a result, fish tend to move towards the vessel, thereby reducing the need for extensive navigation and lowering fuel costs.

Perceived Lower Ecological Impact

Some fishermen believed that LED fishing causes relatively less ecological harm compared to other fishing practices. LED lights mainly attract mature fish, while juvenile fish may escape through the nets. Based on this perception, they argued that LED fishing does not significantly affect juvenile fish populations and may therefore have a comparatively lower impact on marine ecosystems.

Reduced Labour Requirement

Another advantage highlighted by the fishermen is the reduction in labour requirements during fishing operations. The use of LED lights reduces the amount of work involved in fishing activities. Since fish are attracted directly to the light source, the fishing process becomes more efficient, which in turn reduces the need for a larger workforce on board.

Need for Uniform Policy Implementation

Some fishermen also emphasized the importance of uniform policy implementation regarding LED fishing. The regulations or bans related to LED fishing should be implemented

uniformly across the country. They believed that it would be unfair to prohibit LED fishing in certain regions while allowing it in others, such as in Kerala and Karnataka. A consistent policy framework would ensure fairness and clarity in fisheries management. In addition, fishermen highlighted the economic advantages of LED fishing; the mean profit from fishing operations using LED lights was estimated at Rs. 20,00,000, whereas operations without LED lights recorded a mean profit of Rs. 15,00,000. Overall, it suggests that fishermen perceive LED fishing as a cost-effective and efficient fishing method, although its long-term ecological implications remain a subject of ongoing debate in fisheries management (Colaco, 2019).

Role of Artificial Light in Pelagic Longline Fisheries and Its Ecological Consequences

Influence of Artificial Light on Fish Behavior and Catch Rates

Artificial light has long been used in marine fisheries to enhance catch efficiency by attracting or concentrating fish around fishing gear. In pelagic longline fisheries targeting species such as Swordfish and Bigeye tuna, chemical lightsticks or artificial illumination devices are often attached near hooks to increase visibility and attract prey organisms. These light sources may either directly attract target species or indirectly attract smaller prey such as squid and fish, which subsequently lure larger predators. Research conducted in the longline fishery of Réunion Island regarding the influence of artificial light on fish behaviour and catch rates. Artificial lights may interact with natural illumination conditions to influence feeding behavior and vulnerability to fishing gear (Poisson et al. 2010).

Ecological Impacts of Light-Based Fishing

Although artificial light can improve fishing efficiency, it may also have ecological consequences. One of the major concerns associated with light fishing is its potential to alter the natural behavior and vertical migration patterns of marine organisms. Many pelagic species, including prey organisms inhabiting the deep scattering layer, perform diel vertical migrations influenced by natural light cycles. Artificial illumination can disrupt these natural patterns by attracting organisms toward the fishing gear. Another important ecological concern is the potential increase in bycatch. Light devices attached to fishing gear may attract non-target species such as sharks, sea turtles, and other pelagic organisms. For example, blue sharks (Blue shark) frequently occur as bycatch in pelagic longline fisheries and may be attracted by illuminated bait or by signals produced by captured prey. Similarly, some studies have suggested that light sources can increase the interaction of longline gear with sea turtles, thereby increasing

the risk of incidental capture. Artificial lights may therefore influence the species composition of catches and potentially increase mortality of non-target organisms, which raises concerns for biodiversity conservation and sustainable fisheries management (Poisson et al. 2010).

Environmental Pollution from Light Devices

Apart from ecological impacts, the physical disposal of chemical lightsticks presents an additional environmental issue. In many fisheries, thousands of used lightsticks are discarded at sea during fishing operations (Fig. 1). These devices contain chemical substances that may pose toxic risks to marine organisms when released into the marine environment. Studies have shown that exposure to lightstick chemicals can cause irritation and physiological damage in experimental organisms, indicating potential environmental hazards. Because most chemical lightsticks are single-use products with limited operational lifespan, their widespread use contributes to marine pollution. Consequently, several fisheries management bodies have considered regulating or banning their use. For example, fisheries authorities in the Mediterranean region have proposed restrictions on the use of chemical light sources in pelagic longline fisheries to reduce environmental impacts (Poisson et al. 2010).

Fig. 1 Discarded lightsticks: The invisible footprint of the longline industry.

Implications for Fisheries Management

Understanding the ecological and operational effects of artificial light in fisheries is essential for developing sustainable fishing practices. Evidence suggests that the benefits of light devices in improving catch rates may be relatively small compared with other operational factors such as bait type, soak time, and fishing depth. As a result, fisheries managers and fishing

communities may consider reducing reliance on artificial light sources without significantly affecting catch efficiency. Alternative strategies, such as optimizing fishing operations according to natural lunar cycles, adjusting gear deployment times, or reducing soak time, may provide more sustainable approaches to improving fishing performance. In addition, minimizing the use of disposable light devices can reduce marine pollution and the risk of attracting non-target species.

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NANOBUBBLES: TINY TECHNOLOGY TRANSFORMING SOIL FERTILITY

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Introduction

Soil is the backbone of agriculture, supporting crop growth, nutrient cycling and water retention and it plays a crucial role in sustaining plant life and ecosystem balance. However, modern agricultural practices such as excessive fertilizer use, continuous cropping and soil compaction have significantly degraded soil health over time. These practices disturb the natural balance of soil and reduce its ability to function effectively. As a result, soil organic carbon levels decline, leading to poor soil fertility and reduced productivity. In addition, soil structure becomes weak, affecting aeration, water movement and root development. Beneficial microbial communities, which are essential for nutrient transformation and soil biological activity, are also disrupted. This imbalance negatively impacts nutrient availability and overall soil performance. Consequently, crop productivity and long-term agricultural sustainability are increasingly at risk. To overcome these challenges, there is a growing need for innovative and eco-friendly solutions that can restore soil health. One such promising advancement is nanobubble technology, which offers a new pathway to improve soil conditions and enhance agricultural productivity.

Nanobubbles: What They Are and What Makes Them Unique

Nanobubbles are extremely small gas-filled bubbles, typically measuring less than 200 nanometers in diameter, and are uniformly dispersed in water. Due to their nanoscale size, they exhibit unique physical and chemical properties that distinguish them from larger, ordinary

bubbles. Unlike conventional bubbles, which quickly rise to the surface and burst, nanobubbles remain suspended in water for extended periods. This remarkable stability is mainly attributed to their small size, high internal pressure, and negatively charged surface, which prevents them from coalescing and collapsing. As a result, nanobubbles can persist in liquid systems much longer than expected. These bubbles can be generated using different gases such as oxygen, carbon dioxide or nitrogen, depending on their specific application and purpose. Their exceptionally large surface area relative to their volume enhances their ability to interact with surrounding water molecules and dissolved substances. This property significantly improves gas transfer efficiency and creates unique physicochemical conditions in the system. In soil environments, nanobubbles play a crucial role in increasing dissolved oxygen levels, which supports better root respiration. They also influence nutrient availability by enhancing solubility and mobility of essential elements. Furthermore, nanobubbles stimulate beneficial microbial activity, leading to improved soil health and fertility. Because of these combined effects, nanobubbles are considered highly promising for sustainable agricultural applications.

How Nanobubbles Improve Soil Health

Nanobubble technology plays a vital role in enhancing the physical, chemical and biological properties of soil. When applied through irrigation systems, nanobubbles significantly increase the level of dissolved oxygen present in the soil solution. This improvement in oxygen availability enhances soil aeration and supports better root respiration in plants. As a result, plant roots function more efficiently, leading to improved growth and development. The increased oxygen levels also create a favorable environment for beneficial soil microorganisms, which play a key role in nutrient cycling and soil health.

In addition to biological benefits, nanobubbles improve soil physical properties by increasing porosity, aggregation and water retention capacity. Improved soil structure allows roots to penetrate more easily and access water and nutrients effectively. This also helps in reducing soil compaction and improving overall soil stability. Furthermore, nanobubbles influence soil chemical properties by altering redox conditions, which are important in regulating nutrient availability. These changes can help reduce the mobility and toxicity of harmful elements in the soil. Overall, the combined effects of nanobubbles enhance soil functionality, promote healthier crop growth and contribute to more sustainable and efficient farming systems.

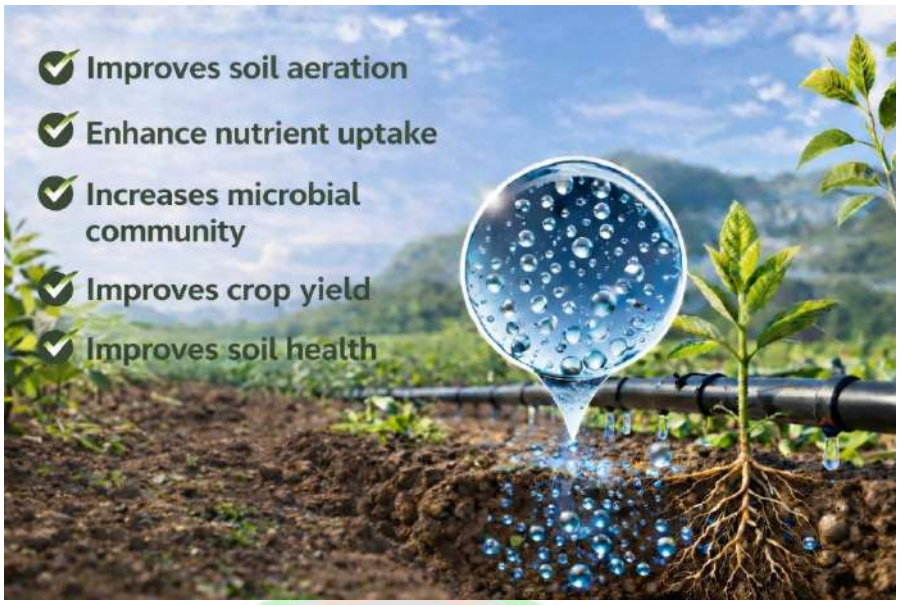

Fig.1 Role of Nanobubbles in Enhancing Soil Health and Crop Productivity

Boosting Nutrient Efficiency and Crop Productivity

One of the most important advantages of nanobubbles is their ability to enhance nutrient use efficiency in soil-plant systems. By improving soil aeration and increasing the availability of dissolved oxygen, nanobubbles create favorable conditions for both plant roots and soil microorganisms. This enhanced environment stimulates microbial activity, which plays a key role in decomposing organic matter present in the soil. As the decomposition process accelerates, nutrient mineralization is also increased, converting nutrients into forms that are readily available for plant uptake. Consequently, essential nutrients such as nitrogen, phosphorus and potassium become more accessible to crops.

Research studies have demonstrated that irrigation with nanobubble-enriched water can significantly improve plant growth and overall crop performance. Enhanced root development allows plants to explore a larger soil volume for nutrients and water. In addition, increased chlorophyll content leads to improved photosynthetic efficiency, which contributes to higher biomass production. As a result, crop yields are often increased when compared to conventional irrigation practices. In some cases, similar or even higher yields have been achieved with reduced fertilizer inputs, making nanobubble technology both cost-effective and environmentally sustainable.

Furthermore, nanobubbles promote the growth and activity of beneficial microbial communities in the rhizosphere. These microorganisms are essential for nutrient cycling, organic

matter decomposition and maintaining soil fertility. Their activity also helps suppress harmful pathogens and improve overall soil health. The combined effects of enhanced nutrient availability, improved microbial activity, and better plant growth make nanobubbles a highly effective tool for increasing agricultural productivity and sustainability.

Future Potential and Practical Challenges

Nanobubble technology holds significant promise for advancing sustainable agriculture and improving soil health. It has potential applications in degraded soil reclamation, salinity management and even in reducing the impact of heavy metal contamination. By enhancing soil conditions, this technology can help convert unproductive or marginal lands into more fertile and productive soils. In addition, nanobubbles improve oxygen availability and root function, which increases crop resilience to environmental stresses such as drought and poor soil aeration. These benefits make it a valuable tool for supporting sustainable crop production under challenging conditions.

Despite its considerable potential, nanobubble technology is still at an early stage of field-level application. Much of the existing research has been conducted under controlled laboratory or greenhouse conditions rather than in large-scale farming systems. Therefore, more extensive field studies are required to fully understand its long-term effects on soil properties, crop productivity and environmental sustainability. Such studies will also help determine its consistency and effectiveness across different soil types and climatic conditions.

Another important factor to consider is the cost and scalability of nanobubble systems for practical agricultural use. The initial installation cost can be relatively high, especially for small and marginal farmers. Although the technology can be integrated into existing drip irrigation systems, affordability and accessibility remain key challenges. With continued research, technological improvements and cost optimization, nanobubble technology has the potential to become an essential component of climate-smart and sustainable farming practices in the future. Overall, nanobubble technology emerges as a highly promising approach for soil health revival, offering the potential to restore degraded soils, enhance productivity and support long-term agricultural sustainability.

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SAME FODDER EVERY DAY: AN UNSEEN THREAT TO LIVESTOCK

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Introduction

Farmers and dairy entrepreneurs should rethink the common practice of feeding a single type of fodder continuously, assuming it provides all the required nutrients to livestock. No single fodder can meet the complete nutritional needs of animals. Instead, farmers should include a combination of fodders in the daily ration. One or two cereal fodders such as jowar, bajra, maize, guinea grass, or para grass can be used as the base. Along with this, it is essential to include at least one legume fodder crop like hedge lucerne, stylo, cowpea, lucerne, or berseem to improve protein content. In addition, nutrient-rich fodders such as moringa, mulberry, or sweet potato leaves can be incorporated. However, care must be taken to maintain proper balance—legume and nutrient-rich fodders together should not exceed 20–30% of the total ration to avoid nutritional imbalance and anti-nutritional effects.

In many parts of South India, especially in dairy farms, Napier–Bajra hybrid grass has become the main fodder. It is high yielding, easy to grow and available throughout the year. Because of this, many farmers are feeding the same fodder continuously to their animals without any change. At first, everything looks fine—good green fodder, animals eating well and milk production seems normal. But slowly, unseen problems start appearing. Animals, just like

humans, need a balanced diet. Feeding only one type of fodder means some nutrients are in excess, Some are deficient and some are harmful compounds slowly affect the body. This imbalance is not immediately visible but affects animals over time. Farmers should remember that diversified feeding is the key to healthy livestock. By mixing different types of fodder and following balanced feeding, the hidden effects of anti-nutritional factors can be avoided.

Continous feeding of Napier Bajra Hybrids

Feeding a single fodder like Napier continuously can lead to the accumulation of certain anti-nutritional factors, especially oxalates. Oxalates bind with calcium in the animal's body and make it unavailable. Over time, this leads to Weak bones, reduced milk yield, reproductive problems.

Paddy straw feeding in summer season

Paddy straw is very low in nutrients, especially protein, energy, vitamins, minerals and less digestive. When animals are fed on paddy straw only and affects the animals not get enough nutrition, Body weight gradually decreases, Milk yield drops significantly, Animals become weak and dull and also major issue that is mineral deficiency, particularly calcium and phosphorus.

Farmers can easily avoid these problems by following a few practical steps:

- ✓ Do not depend on a single fodder
- ✓ Mix legume fodders (like lucerne, cowpea etc..) with grasses, nutrient rich grasses like mulberry, moringa, sweet potato, fodder tree leaves etc…
- ✓ Provide dry fodder along with green fodder
- ✓ Use mineral mixture regularly
- ✓ Treat paddy straw (like urea treatment) to improve its quality
- ✓ Harvest fodder at the right stage (not too young or too mature)

Above simple change in feeding practice can improve the Animal health, Milk production and Farm income.

Conclusion

Feeding livestock with the same fodder continuously—whether it is Napier grass, paddy straw, or even a combination with concentrates—may appear sufficient, but it cannot meet the complete nutritional needs of animals. Such practices can lead to hidden problems like mineral deficiencies, low milk yield, poor growth, and reproductive issues.

A balanced ration with variety in fodder is essential for maintaining animal health and productivity. Inclusion of legumes, nutrient-rich fodders, and mineral mixtures along with proper proportion of green and dry fodder can prevent these issues.

"Filling the stomach is not enough—balanced feeding is the key to profitable dairy farming."

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AGRIVOLTAICS: DUAL-USE LAND FARMING FOR A SUSTAINABLE FUTURE

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Abstract

Agrivoltaics, also known as dual-use solar farming, is a cutting-edge method that combines solar photovoltaic (PV) energy generation and agricultural output on the same plot of land. This approach mitigates land-use disputes while addressing the growing global demand for electricity and food. Agrivoltaics increases land productivity, increases water-use efficiency, and helps climate-resilient farming systems by permitting simultaneous cultivation and energy production. Additionally, it helps lower greenhouse gas emissions and gives farmers a variety of revenue options. Widespread adoption is hampered by obstacles like pricey initial investment, crop compatibility problems, and legislative restrictions, despite its many advantages. With an emphasis on its applicability in India, this article examines the idea, workings, advantages, difficulties, and potential applications of agrivoltaics. The study highlights agrivoltaics as a transformative pathway toward sustainable agriculture and renewable energy integration.

Keywords: Agrivoltaics, Dual-use farming, Solar energy, Sustainable agriculture

Introduction

As the globe moves toward sustainable energy systems, it must simultaneously ensure food security for an expanding population. Global projections indicate that although renewable

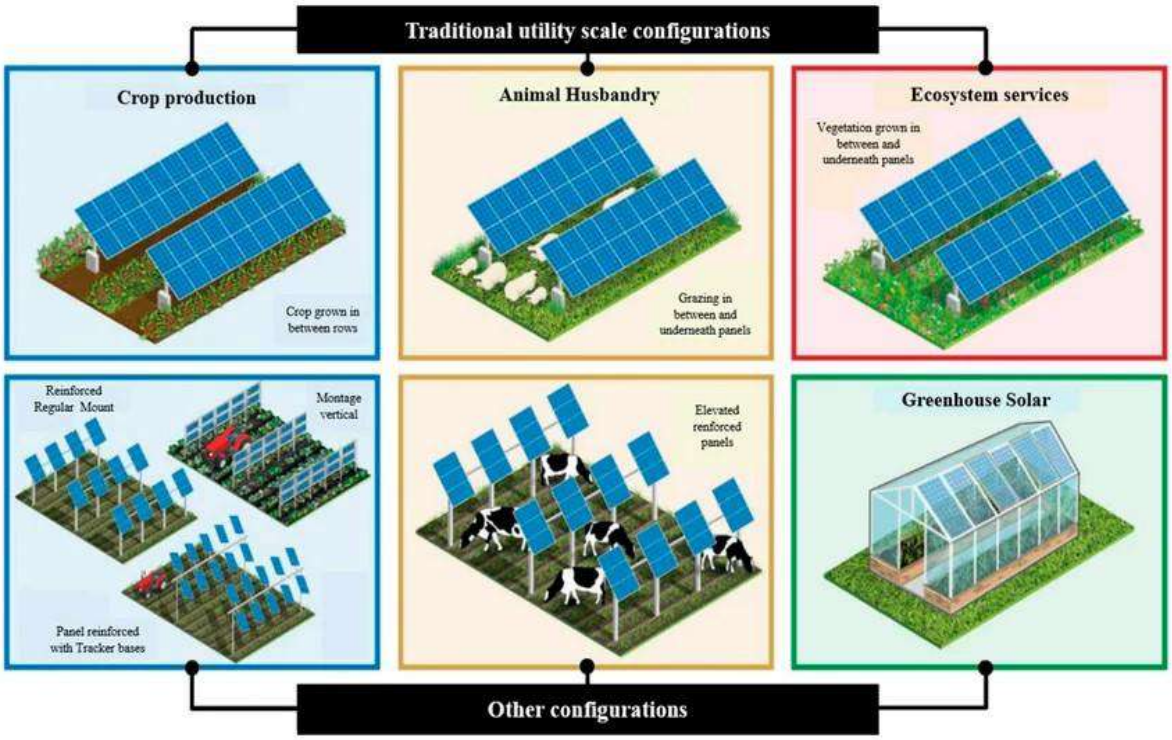
energy capacity needs to grow in order to counteract climate change, agricultural productivity needs to rise dramatically in order to fulfill future food demand (Widmer, 2024). However, there is a critical need for creative land-use solutions because solar energy systems and agricultural both compete for land resources.

By combining solar energy production with agricultural operations on the same property, agrivoltaics has become a viable solution to this problem (Dupraz et al., 2011). This idea maximizes land productivity without sacrificing either function by enabling farmers to raise livestock or grow crops under or in between solar panels.

The concept is gaining global attention due to its potential to enhance resource-use efficiency, improve farm incomes, and contribute to environmental sustainability (Jamil, 2026). In countries like India, where land scarcity and energy demand are critical issues, agrivoltaics offers a practical pathway to achieve both agricultural and energy goals simultaneously.

Concept and Working of Agrivoltaics

The goal of agrivoltaic systems is to maximize sunshine sharing between solar panels and crops. In order to provide enough sunshine penetration for crop development, solar panels are typically positioned at an elevated height or spaced enough apart (Dupraz et al., 2011).



Here are the main types of agrivoltaic systems utilized in India:

Various agrivoltaic system setups consist of:

- Inter-row systems, in which panels are positioned in between rows of crops
- Greenhouse-integrated systems that combine protected cultivation with solar power
- Systems based on pasture that allow animals to graze under solar panels
- Elevated panel systems, in which panels are positioned above crops

Temperature, humidity, and soil moisture are among the microclimatic parameters that are altered by the panels' partially shadowed environment (Barron-Gafford et al., 2019). In dry and semi-arid areas in particular, this microclimate can lessen heat stress and water loss.

By maximizing the utilization of solar radiation for both photosynthesis and power generation, research suggests that agrivoltaic systems can increase total land productivity (Dupraz et al., 2011).

1. Overhead Stilted/Elevated Structures

This is one of the most popular types in India, where solar panels are elevated on high poles (usually 2–3.5 meters high) to allow agricultural activity to take place underneath.

- **Features:** Provides partial shade to crops, which reduces transpiration and improves water use efficiency.
- **Examples:** Experiments with cultivating crops like turmeric, lady finger, bottle gourd, and coriander under raised panels.
- **Application:** Ideal for crops that benefit from low-light conditions or need protection from harsh summer sun.

2. Inter-row Spacing (Conventional Ground-Mounted)

In this layout, solar panels are installed in rows with significant space between them to allow for farming activity.

- **Features:** Crops are grown in the wide gaps between the rows of panels.
- **Examples:** The 4 MW agrivoltaic plant at Cochin International Airport and various pilots in Gujarat, where crops are grown between solar rows.
- **Application:** Allows for the use of small-scale agricultural machinery in the wide gaps.

3. Vertical/Bifacial Agrivoltaics

This system involves installing vertical solar panels on the edges of the farmland, acting like a fence or barrier.

- **Features:** Panels are often bifacial (can produce energy from both sides). They generate peak power in the morning and evening rather than noon, which is beneficial for the grid.
- **Examples:** Piloted by the National Institute of Solar Energy (NISE) in Gurugram, Haryana.
- **Application:** Ideal for crops that need maximum sun exposure, as the vertical panels do not provide heavy shading.

4. Floating Agrivoltaics (Agri-Floating PV)

Floating panels are deployed over water bodies, such as irrigation ponds or reservoirs, connecting aquaculture with energy production.

- **Features:** Reduces water evaporation by up to 60% and increases solar panel efficiency due to the cooling effect of the water.

Key Locations & Models in India

- **Parbhani, Maharashtra:** A notable project with high-elevation structures (3.75m) designed for tractor movement.
- **CAZRI, Jodhpur:** Features elevated panels designed to improve crop growth in arid regions.
- **Sardoi, Gujarat:** A model where water used to clean the panels is repurposed to irrigate the crops in the interspace.

These models are being actively promoted under projects like **PM-KUSUM** to provide additional income and electricity to farmers.

Benefits of Agrivoltaics

1. **Improved Efficiency of Land Use**

   By providing dual outputs, food and energy from the same land area, agrivoltaics dramatically boosts land productivity. When compared to separate agricultural and solar systems, combined systems can boost land-use efficiency by as much as 60–70%, according to studies (Widmer, 2024).

2. **Enhanced Water Efficiency and Crop Yield**

   Water-use efficiency is increased when solar panels provide partial shade, which lowers evapotranspiration and soil moisture loss (Barron-Gafford et al., 2019). Under agrivoltaic conditions, some crops, such lettuce, spinach, and tomatoes, have demonstrated steady or even increased yields.

This is especially helpful in areas where water is scarce because less irrigation is needed, which can drastically cut production costs.

3. **Adaptation and Mitigation of Climate Change**

By producing renewable energy and lowering dependency on fossil fuels, agrivoltaics helps mitigate climate change (Jamil, 2026). By shielding crops from harsh weather events like heatwaves and droughts, it also improves climate resilience.

Additionally, the system encourages sustainable land management techniques and lessens soil degradation.

4. **Financial Gains for Farmers**

Income diversification is one of the biggest benefits of agrivoltaics. Both agricultural production and solar energy generation can bring in money for farmers (Widmer, 2024). This lowers the financial risks brought on by market swings and crop failures.

Farmers' revenue can also be increased by leasing land for solar arrays or taking part in energy-sharing programs.

5. **Ecosystem Services and Biodiversity**

By providing habitats for beneficial creatures and pollinators, agrivoltaic systems can promote biodiversity (Barron-Gafford et al., 2019). Reduced land use intensity also contributes to the preservation of ecological balance and soil health.

The Indian Context of Agrivoltaics

India's large agricultural acreage and strong solar potential make it a unique place to implement agrivoltaics. Through programs like the PM-KUSUM plan, which promotes farmers to install solar pumps and grid-connected solar systems, the nation is actively encouraging renewable energy.

Agrivoltaics is a good fit for India's objectives of reaching renewable energy targets and increasing farmer income. In areas like Rajasthan, Gujarat, and Tamil Nadu, where solar radiation is plentiful and water scarcity is a serious issue, it is especially pertinent.

Pilot projects in India have demonstrated that agrivoltaic systems can enhance farm productivity while generating additional income (Islam, 2025). However, large-scale adoption requires policy support, financial incentives, and awareness among farmers.

Challenges and Limitations

Agrivoltaics has several advantages, but it also has some drawbacks.

1. Expensive initial outlay

   Small and marginal farmers may find it difficult to construct agrivoltaic systems due to the high capital costs involved (Jamil, 2026).

2. Problems with Crop Compatibility

   Not every crop can be grown in shadowed areas. To guarantee maximum productivity, crop selection and system design must be carefully considered.

3. Complexity of Technology

   Technical know-how is needed for the design and upkeep of agrivoltaic systems, and it might not be easily accessible in rural locations.

4. Regulatory and Policy Restraints

   Adoption of agrivoltaics may be hampered by unclear rules and regulations. Scaling up these systems requires supportive structures.

5. Acceptance by Society

   Due to perceived hazards and ignorance, farmers may be reluctant to embrace new technologies.

Prospects for the Future

Agrivoltaics has a bright future thanks to developments in solar technology and growing awareness of environmental practices. It is anticipated that innovations like adjustable mounting solutions and semi-transparent solar panels would increase crop compatibility and efficiency.

Agrivoltaic system performance can also be improved by connection with smart irrigation and digital agriculture. Adoption is also likely to be accelerated by investments from the public and commercial sectors.

The Sustainable Development Goals (SDGs) might be greatly aided by agrivoltaics, especially in areas like climate action, affordable and clean energy, and zero hunger.

Conclusion

Agrivoltaics, which combines the production of renewable energy with agriculture, is a revolutionary method to land-use management. It improves farmer livelihoods and environmental resilience while providing a sustainable answer to the conflicting demands for food and energy. The advantages of agrivoltaics greatly exceed its drawbacks, despite persistent

issues including high costs, technological complexity, and policy gaps. Agrivoltaics may significantly contribute to the development of a resilient and sustainable agricultural future with the right kind of policy support, technological advancement, and farmer knowledge.

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BEYOND CONVENTIONAL HORMONES: ADVANCED NANO-DELIVERY SYSTEMS FOR TARGETED SEX MANIPULATION IN GLOBAL FISHERIES

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Abstract

To meet escalating global food demand, aquaculture increasingly relies on monosex population cultivation to maximize growth rates and market value. Traditional sex-reversal methods, while established, are often limited by inconsistent conversion rates, high hormonal dosages, and environmental persistence. The article highlights nanotechnology as a transformative intervention, utilizing biocompatible nanocarriers like PLGA, chitosan, and nanostructured lipid carriers to optimize hormone delivery. Experimental data reveal that nano-encapsulated agents, such as fadrozole-loaded PLGA and MT-loaded lipid carriers, achieve superior masculinization (98.5% to 100%) at significantly lower concentrations than conventional methods. By enhancing bioavailability and facilitating controlled, site-specific release, nanotechnology provides a high-precision framework for sex manipulation. Ultimately, these nano-scale systems offer a more efficient, cost-effective, and sustainable approach to producing dominant commercial phenotypes in both food and ornamental fish species.

Keywords: Sex reversal, Nanotechnology, Synthetic steroids, Botanical extracts, Monosex

Introduction

Driven by rising global food demand, the aquaculture industry is increasingly adopting monosex population cultivation to optimize productivity and nutritional quality. In many teleost species, one sex possesses superior commercial traits, such as the accelerated growth rates in food fish or the vibrant coloration in ornamental species, which significantly enhances market value (Pandian and Sheela, 1995). To leverage these biological advantages, various sex-reversal

techniques are employed to shift phenotypic production toward the more economically viable sex. The efficacy of these interventions depends on the precise calibration of physiological and environmental variables, including hormone concentration, exposure duration, and ambient water temperature (Hoga et al., 2018).

Nanotechnology is increasingly recognized as a pivotal solution to the inherent limitations of conventional aquaculture, providing innovative frameworks to optimize both productivity and environmental sustainability. The versatility of nanomaterials allows for significant advancements across the industry, ranging from high-sensitivity disease diagnostics and targeted therapeutic delivery to the refined administration of nutrients and hormones. Furthermore, these materials play a critical role in enhancing water quality through advanced purification and the mitigation of pathogenic biofilms (Bhat and Hussna, 2022).

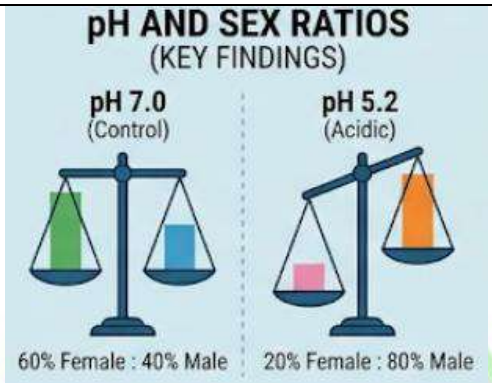
Among the most prominent delivery vehicles, organic NPs such as chitosan and poly (lactic-co-glycolic acid) (PLGA) are distinguished by their superior stability and biocompatibility (Bhat et al., 2018). Chitosan NPs provide a non-toxic, highly stable matrix for biological applications, while PLGA is widely utilized for the reliable, controlled release of pharmacological agents within aquatic organisms (Joshi et al., 2015). The strategic deployment of ZnO, chitosan, and PLGA NPs significantly augments disease management and growth performance, thereby elevating global production standards (Thangapandiyan and Monika, 2020). Of particular importance is the recent application of these nano-scale systems for the delivery of sex-reversal agents. By facilitating a more efficient and reliable targeted-delivery mechanism for hormones and bioactive extracts, nanotechnology ensures the production of monosex populations with the commercially dominant traits required to meet international food security demands (Joshi et al., 2015; Yostawonkul et al., 2023).

Targeted sex manipulation in fish

Sex reversal research is a critical pillar of aquaculture, offering insights into the complex biological mechanisms of sex determination while providing a pathway to enhanced productivity. By manipulating sex ratios to produce monosex populations, producers can capitalize on the superior growth rates and higher market values often associated with a specific gender (Baroiller and D'cotta, 2016). Key species of economic and scientific interest include Nile tilapia, Guppies, Siamese fighting fish, and various Salmonids, chosen for their well-characterized genetic and environmental sex determination systems (Abaho et al., 2022).

Environmental manipulations: Environmental interventions, such as thermal manipulation (Karayücel et al., 2006), pH adjustment (Petrescu Mag et al., 2007) (Figure 1), and stocking density modification (Budd et al., 2015), can trigger phenotypic shifts. For instance, thermal fluctuations in Nile tilapia and medaka induce female-to-male reversal through epigenetic modifications, such as DNA methylation (Sun et al., 2016).

Figure 1: Influence of pH on the sex of a fish.



Hormonal Interventions: The most prevalent artificial method involves the administration of estrogens (e.g., estradiol-17β) or androgens (e.g., 17α-methyltestosterone). The use of sex hormones and biochemical inhibitors remains a cornerstone of these protocols, involving agents such as synthetic steroids like 17α-methyltestosterone (MT), 17α-ethynyltestosterone, and 17α-ethynylestradiol, as well as aromatase inhibitors and estrogen receptor antagonists like tamoxifen, fadrozole, anastrozole, and letrozole (Angus et al., 2005). These steroids are typically delivered via cost-effective oral or immersion protocols to achieve masculinization or feminization (Pandian and Kirankumar, 2003).

Botanical Alternatives: To address the ecological concerns associated with synthetic steroids, botanical extracts are emerging as sustainable, eco-friendly alternatives for monosex fish production. These extracts utilize bioactive compounds, such as isoflavonoids, saponins, and tannins, which act as natural aromatase inhibitors to suppress estrogen biosynthesis and stimulate testosterone secretion (Mukherjee et al., 2018). Research has validated several plant-based sources for enhancing male ratios, including seeds (*Tribulus terrestris, Mucuna pruriens*), roots (*Asparagus racemosus, Withania somnifera*), and leaves or flowers (*Mangifera indica, Hibiscus* spp.). While these phytochemicals offer a superior safety profile, their efficacy remains dose-dependent and generally lower than synthetic counterparts, necessitating further optimization (De and Chakraborty, 2016). Consequently, focusing on optimizing delivery and dosage to

maximize sex-reversal efficiency while minimizing potential physiological drawbacks is the need of the hour.

Nanotechnology interventions in sex reversal of fish

The integration of nanotechnology is fundamentally transforming hormone and drug delivery within the aquaculture sector. By leveraging the unique physicochemical properties of NPs, specifically their high surface-area-to-volume ratio and ultra-small dimensions, researchers can now achieve superior cellular uptake and seamless translocation across critical biological barriers, such as epithelial and endothelial membranes (Rather et al., 2013; Joshi et al., 2015). This technological shift allows for a controlled, sustained, and site-specific release of bioactive agents, significantly enhancing the therapeutic index and bioavailability of encapsulated compounds. Consequently, the industry can achieve desired physiological outcomes with reduced dosages, minimizing both systemic side effects and environmental contamination (Table 1).

Table 1: Comparison of Nano-Delivery vs. Conventional Methods.

Feature	**Conventional Delivery**	**NP-Mediated Delivery**
Typical Dosage	High	Low
Release Profile	Immediate/Unregulated	Controlled and sustained
Bioavailability	Limited by biological barriers	Enhanced via membrane translocation
Conversion Rate	High, but variable	98–100% (Stable and Uniform)
Production Cost	Standard	Reduced (up to ~33% lower)
Environmental Risk	Higher residue/leaching	Minimized due to lower required concentrations

In the specialized field of sex control and manipulation, vital for both high-value ornamental markets and food fish production, nanotechnology-based delivery systems offer unprecedented precision and safety. Recent studies have demonstrated the clear advantages of nano-formulations in enhancing the phenotype with dominant characteristics (Table 2):

Table 2: Summary of NP-Mediated Delivery Systems in Teleost Sex Reversal and Reproductive Modulation.

NP	Delivered agent	Suggested dose	Mode of administration	Fish species	Outcome	Reference
poly(lactic-co-glycolic acid) (PLGA)	Letrozole	50 and 100 ppm kg^{-1}	Oral	*P. reticulata*	Testicular development	Joshi et al., 2015
Chitosan	Letrozole	100mg kg^{-1} of feed	Oral	*Clarias magur*	Testicular development	Wisdom et al., 2018
Chitosan	17α-methyltestosterone	0.5 µg g^{-1}	Injections	*Clarias batrachus*	Testicular development	Saha et al., 2018
Chitosan	GnRHa	100 µg kg^{-1}	Oral	*Carassius auratus*	Ovaries developed	Kookaram et al., 2021
Chitosan	Letrozole	1.5 mg kg^{-1}	Oral	*Oncorhynchus mykiss*	Testicular development	Alijani et al., 2022
Nanostructured lipid carrier (NLC)	17α-methyltestosterone	-	Immersion	Red tilapia	Testicular development	Yostawonkul et al., 2024
Nanoemulsion	Testosterone propionate	90 mg kg^{-1}	Oral	*Oreochromis niloticus*	Testicular development	Magnabosco et al., 2022
Nanoemulsion	17α-methyltestosterone	30 mg kg^{-1}	Oral	*Oreochromis niloticus*	Testicular development	Melo et al., 2025

- **Aromatase Inhibitors:** Research by Joshi et al. (2015) revealed that letrozole-loaded NPs could induce up to 96.67% masculinization in guppies. Also, poly(lactic-co-glycolic acid) (PLGA) NPs loaded with fadrozole achieved a remarkable 100% masculinization

within 30 days of treatment. These results highlight a more stable and uniform outcome over a shorter treatment duration compared to traditional methods.

- **Synthetic Steroids:** The delivery of 17α-methyltestosterone (MT) via chitosan NPs in *Clarias batrachus* has shown dose-dependent enhancements in spermatogenesis and elevated 11-ketotestosterone levels at significantly lower hormone concentrations (Saha et al., 2018). Similarly, in red tilapia, nanostructured lipid carriers (MT-APG-NLC) achieved 98.5% masculinization using only 30 ppm of MT, half the traditional dosage, while reducing production costs by approximately 32.9% (Yostawonkul et al., 2023).
- **Botanical and Targeted Modulation:** While some nano-conjugated botanical extracts, such as eurycomanone, have shown suppressive effects on ovarian development, these findings further refine the understanding of site-specific modulation, suggesting that certain nano-botanicals are better suited for male reproductive enhancement rather than female development (Bhat et al., 2018).

Conclusion

Integrating nanotechnology into aquaculture addresses the core limitations of traditional sex-reversal methodologies. By utilizing biocompatible nanocarriers like PLGA and chitosan, the industry achieves high-precision delivery of both synthetic hormones and sustainable botanical extracts. These systems ensure superior bioavailability and controlled release, facilitating near-total monosex conversion while significantly reducing required dosages and production costs. Ultimately, NP-mediated delivery enhances operational efficiency and environmental sustainability, providing a robust framework to meet escalating global food security demands.

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DIGITAL TRANSFORMATION IN AGRICULTURE: ENSURING INCLUSIVITY FOR SMALLHOLDER FARMERS

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Abstract

The agricultural sector is undergoing rapid digital transformation through the adoption of advanced technologies such as Artificial Intelligence (AI), Internet of Things (IoT), satellite imaging, blockchain, and precision farming tools. While these innovations promise improved productivity, sustainability, and profitability, unequal access to digital infrastructure and skills has created a significant digital divide among farmers. Smallholders, rural communities, and marginalized groups often lack connectivity, digital literacy, and financial resources to adopt modern technologies. This paper examines the concept of the digital divide in agriculture, its causes and implications, and the emerging technological trends shaping the future of the sector. The study emphasises the need for inclusive digital policies, infrastructure development, and capacity-building initiatives to ensure equitable agricultural growth.

Keywords: Digital Divide, Smart Agriculture, Precision Farming, Artificial Intelligence, IoT, Digital Inclusion

Introduction

Agriculture continues to serve as the backbone of rural economies and plays a crucial role in ensuring food security, employment generation, and sustainable development worldwide. In many developing countries, including India, a substantial proportion of the population depends directly or indirectly on agriculture for livelihood. However, the sector faces multiple challenges such as climate change, declining soil fertility, fragmented landholdings, price volatility, and increasing input costs. In response to these challenges, digital transformation has emerged as a powerful driver of modernization in agriculture.The advent of advanced digital technologies—

such as Artificial Intelligence (AI), Internet of Things (IoT), remote sensing, Geographic Information Systems (GIS), blockchain, big data analytics, and precision farming tools—has reshaped traditional agricultural practices. These technologies enable farmers to monitor crop health in real time, optimize water and fertilizer use, predict pest outbreaks, access market information instantly, and improve supply chain transparency.

Despite the transformative potential of digital technologies, access to these innovations remains uneven. Particularly small and marginal farmers—continues to face barriers in adopting digital tools. This inequality in access, usage, and benefits of digital technologies is referred to as the digital divide. In the agricultural context, the digital divide reflects disparities between large commercial farms and smallholders, urban and rural regions, technologically advanced and less-developed areas, and digitally literate and digitally excluded farmers.The digital divide in agriculture is multidimensional. First, it involves infrastructural disparities, including inadequate broadband connectivity and unreliable electricity supply in rural regions. Second, economic barriers limit farmers ’ability to invest in smartphones, sensors, drones, or subscription-based advisory platforms. Third, low levels of digital literacy hinder effective utilization of available technologies. Fourth, socio-cultural factors such as age, education level, gender inequality, and language barriers further restrict digital adoption. Data from the International Telecommunication Union indicate that rural internet penetration globally remains significantly lower than urban access, reinforcing structural inequalities in agricultural communities.

In this context, bridging the digital divide is not merely a technological challenge but a socio-economic imperative. Inclusive digital policies, investment in rural digital infrastructure, targeted capacity-building programs, and public–private partnerships are essential to ensure equitable access to digital agricultural innovations. Therefore, this paper examines the dimensions and causes of the digital divide in agriculture, analyzes the role of emerging technologies, discusses future trends, and proposes policy recommendations aimed at fostering inclusive and sustainable digital transformation in the agricultural sector.

Conceptual Framework: Digital Divide in Agriculture

The digital divide in agriculture refers to disparities in access to digital tools, knowledge, and infrastructure among different categories of farmers — especially between smallholder and commercial farmers, urban and rural regions, and across socio-economic strata. Research shows

significant variability in connectivity, digital literacy, and technology adoption at the global and regional levels.

Causes of the Digital Divide in Agriculture

- **Infrastructure Gaps**

Limited broadband and mobile network reach in rural areas reduces digital access among farming communities, inhibiting access to digital advisory services and market platforms.

- **Cost and Economic Barriers**

High upfront costs of IoT devices, AI solutions, and connectivity deter smallholders. This reduces adoption rates even where technology is available.

- **Digital Literacy and Skills**

Only a fraction of smallholder farmers are comfortable using smartphones or mobile apps.

- **Institutional and Cultural Factors**

Limited local language content, lack of training programs, and absence of supportive extension services exacerbate the divide.

Real-World Case Studies

✅Case Study 1 — Digital Agro Advisory Services in Jharkhand

□ Source:

Sustainable Agriculture Research – MDPI

https://www.mdpi.com/2077-0472/12/1/112?utm_source=chatgpt.com

Overview-

This study examines the use of digital farm advisory systems such as e-Sagu, IFFCO Kisan, and digital weather & market advisory apps by smallholder farmers in Jharkhand, India. It highlights how digital solutions changed decision-making for soil, irrigation, crop choice, and fertilizer application.

The increase in productivity ranged from 8% to 15% for farmers using mobile apps versus non-users.

Lack of connectivity and digital literacy were the largest adoption barriers.

□ Cited In-Text:

(Prasad & Chandra, 2020)

Case Study 2 — mKRISHI: Vodafone & ICRISAT Digital Extension

 Source:

International Crops Research Institute for the Semi-Arid Tropics

https://www.icrisat.org/wp-content/uploads/2020/11/ICRISAT-mKRISHI-Mobile.pdf

Overview:

mKRISHI, a joint initiative by Vodafone India & ICRISAT, provides personalized crop advisories via SMS and voice in local languages. The platform targets farmers with limited smartphone use and internet access.

- Reached more than 150,000 smallholder farmers in Telangana and Andhra Pradesh.
- Farmers received real-time alerts on weather, pest warnings, and market price information.
- Average input cost savings of 12–18% and yield improvements of 10–14%.

 Cited In-Text:

(ICRISAT & Vodafone, 2019)Emerging Digital Technologies in agriculture)

Case Study 3 — eNAM (Electronic National Agriculture Market)

 Official Website:

https://enam.gov.in/web/

Overview:

eNAM is an Indian government initiative to integrate agricultural markets through a digital platform providing real-time price discovery and transparent trade. It aims to reduce inefficiencies and empower smallholder farmers.

- Connected more than 1,000 mandis across 18 states.
- Increased price realization for farmers by eliminating middlemen inefficiencies.
- Enabled farmers to access buyers from other states digitally.

 Cited In-Text:

(Ministry of Agriculture & Farmers Welfare, Government of India, 2024)

Case Study 4 — Digital Soil Health Cards (DSHC)

 Source:

National Informatics Centre (Government of India)

https://soilhealth.dac.gov.in/

Overview:

Under the Soil Health Card Scheme, farmers receive digital soil analysis results on mobile phones with precise nutrient recommendations. Alerts and reminders are also sent via SMS app

- Better nutrient management decreased input cost by up to 10%.
- Increase in per hectare yields of 5–12% in trial districts.
- However, adoption still skewed toward farmers with smartphones.

 Cited In-Text:

(DAC & Farmers Welfare, 2023)

Emerging Digital Technologies in Agriculture

Technology	Primary Use	Impact
AI & ML	Crop disease detection	Improved yield prediction
IoT Sensors	Soil & water monitoring	Resource optimization
Blockchain	Supply chain traceability	Transparency & trust
Precision Farming	GPS & drone use	Reduced input waste

AI, IoT & Digital Twins

Digital twin technology creates virtual models of farms for real-time monitoring and prediction.

Unlocking Big Data and Cloud Analytics

Big data platforms integrate weather, soil, and market data to support farmer decision-making and input allocation.

Quantitative Evidence: Adoption & Outcomes

IoT and AI Impact on Indian Agribusiness

Empirical research indicates:

- Wheat (Punjab): 18% yield increase with digital tech
- Rice (Tamil Nadu): 15% yield improvement via IoT irrigation
- Cotton (Maharashtra): 20% yield gain via AI pest management
- Water savings: Up to 30% via automated irrigation systems
- Profit increase: Approx. 80% profit growth with IoT & digital integration

Future Trends and Bridging Digital Divide in Agriculture

The future of agriculture is increasingly shaped by digital innovation, data-driven decision-making, and technology-enabled sustainability. As global food demand rises and climate variability intensifies, emerging technologies are expected to play a transformative role in

strengthening agricultural productivity, resilience, and profitability. However, the extent to which these benefits are realized depends largely on the ability to bridge the digital divide and ensure inclusive access to innovation. The following subsections outline major future trends and associated opportunities in digital agriculture.

Artificial Intelligence–Driven Predictive Agriculture

Artificial Intelligence (AI) and machine learning are expected to become central to farm management systems. AI-powered platforms can analyze historical weather patterns, soil data,

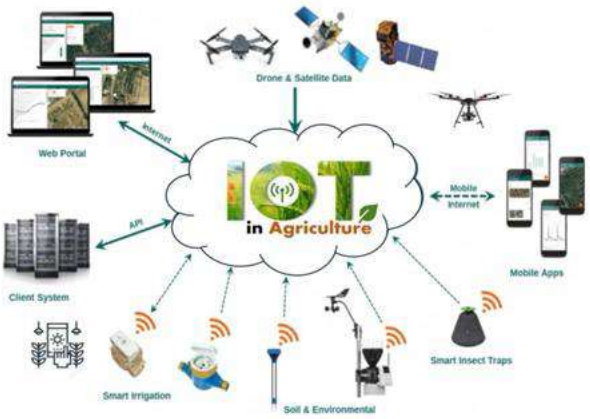
satellite imagery, and pest incidence records to generate predictive insights for farmers. In the future, AI systems will increasingly support:

- Early detection of crop diseases
- Yield forecasting and risk assessment
- Precision input recommendations
- Automated decision-support systems

The Food and Agriculture Organization highlights that AI-based advisory services can significantly improve climate resilience and resource efficiency. The opportunity lies in developing low-cost, mobile-based AI tools tailored to smallholder farmers, thereby enhancing inclusivity.

Expansion of IoT-Enabled Smart Farming Systems

The Internet of Things (IoT) is transforming agriculture by enabling real-time monitoring of soil moisture, temperature, humidity, and crop health. Future farms are expected to integrate networks of sensors connected to cloud-based platforms for automated irrigation, fertilization, and crop monitoring.



Key opportunities include:

- Reduction in water usage through smart irrigation
- Improved fertilizer efficiency
- Lower production costs
- Enhanced sustainability

According to the World Bank, digital technologies such as IoT can increase productivity while reducing environmental impact. As sensor costs decline, IoT adoption is likely to expand even

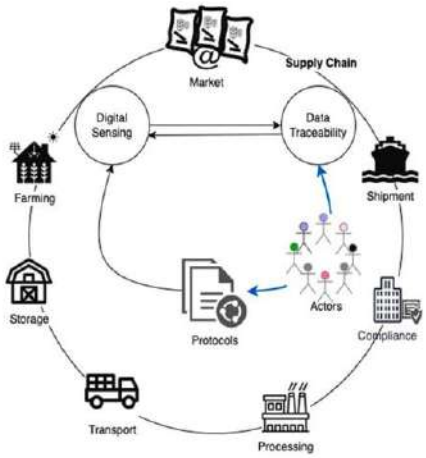
among medium and small-scale farmers.

- **Integration of Drones and Remote Sensing Technologies**

Drone technology and satellite imagery are becoming integral to precision agriculture. In the future, drones will be widely used for:

- Crop surveillance and health monitoring
- Targeted pesticide spraying
- Soil analysis
- Yield estimation

Remote sensing combined with AI analytics will enable farmers to detect crop stress at early stages. This integration will improve farm efficiency and reduce chemical overuse. However, supportive policies and training programs are essential to ensure equitable access.

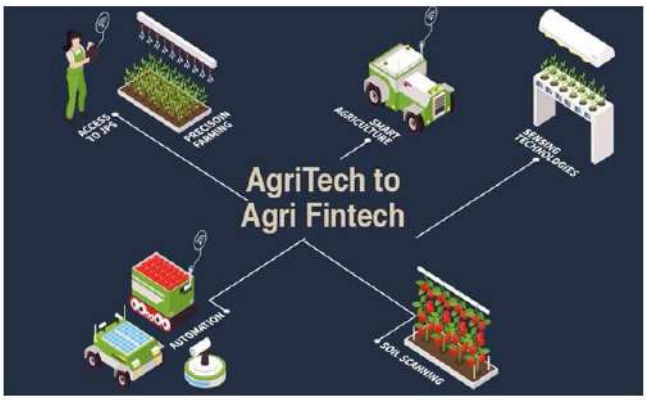


Blockchain and Digital Traceability Systems

Blockchain technology offers significant opportunities for improving transparency and trust in agricultural supply chains. It enables secure recording of transactions and product traceability from farm to consumer.

Future opportunities include:

- Strengthening export competitiveness
- Enhancing food safety standards
- Reducing fraud and middlemen inefficiencies
- Building consumer trust in organic and specialty products



Digital traceability systems can particularly benefit smallholder farmers by providing direct market access and premium pricing opportunities.

Growth of Agri-FinTech and Digital Financial Inclusion

Digital financial platforms are expected to revolutionize agricultural credit, insurance, and payment systems. Mobile-based digital wallets, AI-driven credit scoring, and blockchain-based crop insurance can enhance financial inclusion.

Reports from the International Telecommunication Union emphasize the importance of digital connectivity in enabling access to financial services. Future opportunities include:

- Faster and transparent loan disbursement
- Weather-indexed crop insurance
- Digital subsidies and direct benefit transfers
- Reduction in transaction costs

This trend can significantly empower small and marginal farmers.

Climate-Smart Digital Advisory Systems

Climate change presents increasing risks to agricultural productivity. Future agricultural systems will rely heavily on digital climate advisory services providing:

- Real-time weather forecasts
- Drought and flood alerts
- Pest outbreak warnings
- Adaptive cropping recommendations

Integration of satellite data with mobile-based advisory platforms will help farmers make timely and informed decisions, improving resilience.

Big Data and Cloud-Based Agricultural Platforms

The use of big data analytics is expected to expand significantly. Agricultural data from multiple sources—satellites, sensors, market databases, and weather stations—will be integrated into cloud platforms for comprehensive farm management.

Opportunities include:

- Data-driven policy planning
- Improved supply chain coordination
- Efficient resource allocation
- Predictive market intelligence

Big data can also assist governments in monitoring crop patterns and ensuring food security planning.

Public–Private Partnerships and Digital Ecosystems

The future of digital agriculture will increasingly depend on collaboration between governments, agribusiness firms, start-ups, financial institutions, and research organizations. Public–private partnerships can:

- Expand rural broadband infrastructure
- Promote affordable agri-tech solutions
- Provide farmer training and digital literacy programs
- Support innovation hubs and agri-startups

Developing inclusive digital ecosystems will ensure that technological growth does not widen existing inequalities.

Opportunities for Smallholder Farmers

Bridging the digital divide presents immense opportunities for smallholder farmers, including:

- Increased productivity and profitability
- Better market access and price transparency
- Reduced input costs
- Enhanced climate resilience
- Improved bargaining power in value chains

Ensuring affordable and user-friendly digital tools can transform small-scale agriculture into a more competitive and sustainable enterprise.

Toward Sustainable and Inclusive Digital Agriculture

The future of agriculture lies in integrating technological innovation with sustainability and inclusiveness. While emerging technologies promise higher efficiency and profitability, equitable access must remain a policy priority. Digital transformation should aim not only at increasing production but also at promoting environmental conservation, social equity, and rural development.

Policy Recommendations

To close the digital divide:

1. Expand rural broadband and low-cost connectivity options
2. Subsidize digital devices and data plans for smallholders
3. Launch multilingual digital literacy initiatives
4. Foster public–private collaborations in agri-technology deployment

Conclusion

Digital agriculture offers transformative potential for food systems — yet the digital divide remains a critical barrier. With targeted policy interventions, capacity building, and inclusive

technology design, the benefits of digital innovation can be equitably shared, driving sustainable and profitable agriculture for all.

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ECO-BOTANICAL SOLUTIONS FOR AGRICULTURAL PEST MANAGEMENT

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Abstract

Endless use of synthetic insecticides in agriculture has led to serious problems, including harmful effects on non-target organisms such as natural enemies, pollinators, animals, fish and humans, also development of pest resistance and resurgence. Raising awareness of these issues has created an urgent need for sustainable alternatives. Botanical insecticides have appeared as an eco-friendly solution, derived from plant parts like leaves, bark, seeds and essential oils, and rich in bioactive compounds such as alkaloids, phenolics and flavonoids. These compounds exhibit insecticidal, repellent, antifeedant and growth-regulating properties. Examples such as neem, custard apple, lantana, tobacco, garlic and turmeric as a effective pest management with minimum environmental impact. Botanical extracts are biodegradable, residue-free and compatible with sustainable farming system, making them a hopeful alternative for environmentally safe and socially acceptable crop protection strategies.

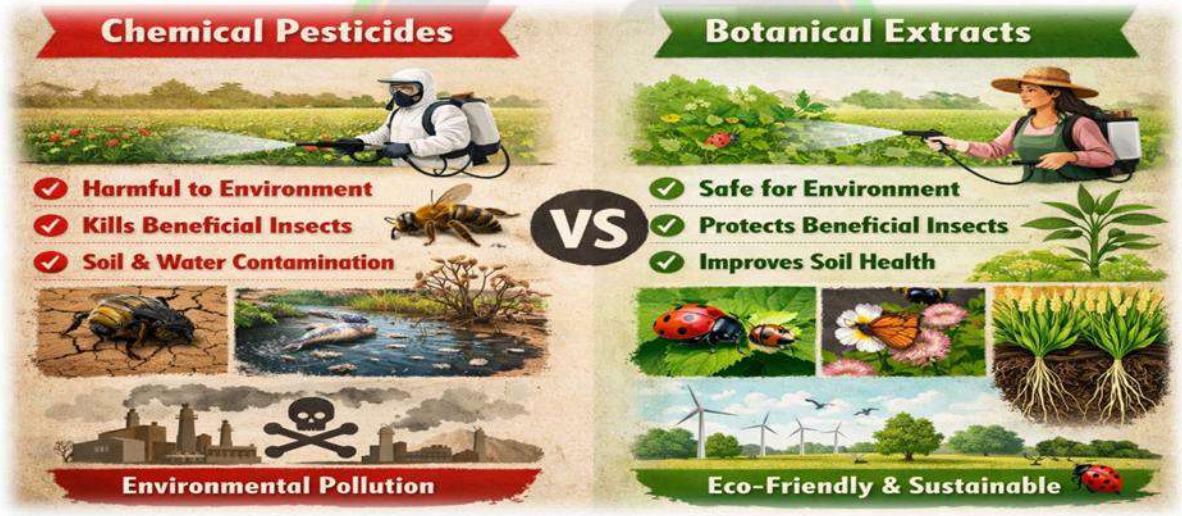
Keywords: Botanical insecticides, Eco-friendly pest control, Plant extracts, Sustainable agriculture, Vriksha Ayurveda

Introduction

Synthetic insecticides have been widely used to decrease the pest problems and indiscriminately, resulting in number of problems like; Negative effects on non-target organisms such as natural enemies of insect pests, honeybees and other pollinators, domestic animals, fish and humans. endless application of synthetic insecticides promotes the pest resistance and pest resurgence in agricultural eco-systems. With greater awareness of these drawbacks of synthetic

insecticides, there is an urgent need to look for alternatives that are environmentally safe, ecologically and socially acceptable. Now a days botanicals have become more attractive and considered to provide an eco-friendly alternative. botanical extracts resulting from plant parts like leaves, bark, flowers, seeds and essential oils, botanical insecticides comprise bioactive secondary metabolites with alkaloids, terpenoids, phenolics and flavonoids that exhibit insecticidal, antifeedant, repellent and growth-regulating properties. Like pyrethrum acquired from *Chrysanthemum cinerariifolium* and azadirachtin from *Azadirachta indica* (neem), while essential oils such as eucalyptus, citronella and clove have also important in pest control.

The science and the method for using botanicals in plant pest control are described in Vriksha Ayurveda. an ancient text on plant health and protection Like Ayurveda, which is the ancient wisdom and science of human medicine, around 2000 years ago, Surpala compiled the data from the ancient scripts and knowledge for the plant science and documented it in the form of a grantha called "Vriksha Ayurveda, the science of Plant Life.



KEY EXAMPLES OF BOTANICAL EXTRACT AND USE OF THEM

Custard apple (*Annona squamosa*)

The natural insecticide resulting from custard apple seed oil is effective, economical and safe to use. A 0.75% biopesticide formulated from custard apple seed oil is sufficient to control white mealybugs on guava leaves within two days. This biopesticide is eco-friendly and does not involve in to water or air pollution. It degrades naturally in the environment, helps maintain soil fertility and does not harm earthworms.

Fortification of cow urine with leaf extracts of *Annona squamosa* and *Ipomoea fistulosa* has been observed to increase insecticidal property against castor leaf hoppers (*Empoasca flavescens*), whitefly (*Trialeurobus ricini*) and thrips (*Scirtothrips dorsalis*) (Shukla et al., 2003), mustard aphids (*Lipaphis erysimi*) (Patel et al., 2003) and sucking pests, viz., aphid, thrips and leaf hoppers in cotton (Patel et. al., 2003b) after 3 and 7 days of application as compared with control. Plant Extracts (Botanical Insecticides) To control their natural enemies, some plants have developed the ability to synthesize products that are derived from their secondary metabolism with specific properties against insects (Isman, 2006).

Neem (*A. indica*)

Geetanjaly and Tiwari (2014) studied antifeedant and growth regulatory effects of cow urine, neem leaf extracts prepared in water and cow urine @ 5% and 10% against different stages of *Spilarctia obliqua*. The cent percent mortality of neonate larvae of *S. obliqua* was observed with less mean leaf area consumed by 4th instar larvae at higher concentration @ 10%. Plant extracts mixed with indigenous cow (Hariana) urine, *A. indica* (neem) kernel and Jatropha kernel were the most effective in controlling white grubs. These treatments showed almost zero tuber damage in both 2007 and 2008 seasons. Neem and Jatropha kernel extracts in cow urine gave the greatest protection. (Puja Rani et al.)

Lantana Camara

Eco-friendly control of stored-grain pests has been widely researched. Major stored-grain pests such as *Sitophilus oryzae*, *Callosobruchus chinensis* and *Tribolium castaneum* were effectively controlled by methanolic leaf extracts of *Lantana camara*. Both contact and fumigant toxicity assays demonstrated severe toxic effects. All three species exhibited 90-100% mortality following seven days of exposure to treated grains at a dosage of 500 ppm, with *C. chinensis* showing the greatest susceptibility. These findings suggest that *L. camara* may serve as a viable botanical alternative to synthetic fumigants in grain storage (Rajashekar et al., 2014).

The leaf extract of *L. camara*, *C. odorata* and cow urine has anti-insecticidal activity against plant damaging insects like Brown Citrus Aphid (*Toxoptera citricida*). Cow urine, when combined with extracts of L. camara and C. odorata, can be an helpful natural solution for pest control. The eco-friendly, cost effective and residue-free nature of the cow-urine-based leaf extract can be easily incorporated into the natural farming system. The treatment of combined

mixture of L. camara, C. odorata and Cow Urine was the highly effective in controlling the Brown Citrus Aphid, *T. citricida* in Assam lemon.

Mahua (*Madhuca longifolia*)

Aqueous extracts of Mahua oil cake indicating strong larvicidal and ovicidal activity against root knot nematodes, *Meloidogyne incognita*. The extract decreased egg hatching and inhibited larval development. Mahua cake is therefore considered a potential botanical nematicide in organic farming. (Verma et al., 2014; Lanjewar and Shukla, 1986)

Moringa (*Moringa oleifera*)

Protection for stored grains *Moringa oleifera* leaf extracts exhibit strong repellent and contact toxicity against *Sitophilus oryzae* and *Tribolium castaneum*. It has great repelling activity because of phenolic chemicals, antioxidant qualities that maintain grain quality and is totally safe for grain storage (Bachrouch et al., 2025)

Tobacco (*Nicotiana tabacum*)

Nicotiana tabacum is well known for its high nicotine and alkaloid content, which has a potent insecticidal effect by acting on the neurological system of insects, paralyzing and killing them in a within hours (Phambala et al., 2020). In contact toxicity tests, the highest larval mortality was obtained from *Nicotiana tabacum* (66%).

In a screenhouse condition by Ranjith and Arivudainambi (2020), reduction of 60.9% in mustard aphid *Lipaphis erysimi* was observed a week after spraying of tobacco leaf extract (10%) in urine.

Garlic (*Allium sativum*)

Garlic (*Allium sativum*) containing allicin, an organosulfur compound with powerful antifungal activity. It interferes with thiol-containing enzymes in pathogens and promote oxidative stress (Nwankwo and David, 2025). Methanolic garlic extracts have been reported to completely inhibit *Botrytis cinerea* mycelial growth at 2% concentration.

Clove (*Syzygium aromaticum*)

The essential oil of *Syzygium aromaticum*, rich in eugenol, changes membrane permeability and denatures fungal proteins. It has been reported to demonstrate >90% inhibition of *Alternaria alternata* and *Fusarium* spp. mycelial growth at a 0.3% concentration.

Ginger (*Zingiber officinale*)

Ginger rhizome extracts are rich in gingerol and shogaol, which disrupt bacterial

membranes and inhibit quorum sensing. Ethanol extracts at 10 mg/mL decreased *Xanthomonas campestris* growth by over 75%.

Turmeric (*Curcuma longa*)

Turmeric contains curcumin, a polyphenolic compound known for its antimicrobial and anti-inflammatory properties (Razavi et al., 2021). It interrupts bacterial signal transduction and cell wall synthesis. Turmeric extracts have indicate 68% inhibition of *Pseudomonas syringae*.

Aloe vera

The insecticidal effect against *Raphidopalpa foveicollis* was evaluated. Within a single day, the undiluted (100%) Aloe vera extract resulted in 71.23% larval mortality, demonstrating instant insecticidal activity. Its dose-dependent toxicity was evidenced by progressively reduced effects at lower concentrations (Patel, 2017).

Nirgundi (*Vitex negundo*)

The Nirgundi leaf extract showed effective antifeedant activity. According to the Experiment, Nirgundi leaf solvent extracts with 1.0 mg/ml concentrations of effective antifeedant properties. While studying all aspects of *Spodoptera litura* life cycle, the chloroform extract of Nirgundi leaf indicating the maximum impact.

Ocimum (*Ocimum tenuiflorum* L.)

The bean weevil, *Acanthoscelides obtectus* causes serious post-harvest losses in the common bean, *Phaseolus vulgaris* L. Control of this insect remains ineffective and largely relies on the use of conventional insecticides. The essential oil of *Ocimum basilicum* was most effective at a dose of 120 µL, resulting in approximately 75% mortality after 15 days of use (Rodríguez-González et al.).

Marigold (*Tagetes erecta* L.)

Research indicates that marigold decreases egg laying (oviposition) in pests such as *Bemisia tabaci* and increases adult mortality in both *Lygus hesperus* and *B. tabaci*. Aqueous (water) leaf extracts exhibit clear dose-dependent toxicity, indicating that higher concentrations result in greater pest control efficacy. Methanolic extracts may also act as feeding deterrents due to the presence of methanol-soluble bioactive compounds.

Conclusion

Botanical extracts recommend a sustainable and eco-friendly alternative to chemical pesticides in recent agriculture. Their bioactive compounds provide effective pest control

through multiple mechanisms such as toxicity, repellency and growth regulation. Due to their biodegradability and lower environmental persistence, botanicals reduce ecological risks and chemical residues in food systems. Their compatibility with Integrated Pest Management (IPM) further helps sustainable crop protection. Therefore, botanical pesticides play an important role in promoting residue-free and naturally safe farming practices.

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FISH AS A NUTRITIONAL POWERHOUSE IN ADDRESSING MALNUTRITION

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Abstract

Malnutrition remains a significant public health challenge in many developing countries, particularly affecting children, pregnant women, and economically vulnerable populations. Fish is recognized as one of the most nutrient-dense foods and plays an important role in improving nutritional security. It provides high-quality protein, essential amino acids, micronutrients such as iron, iodine, zinc, calcium, and vitamins, along with beneficial omega-3 fatty acids that support brain development and overall health. Small indigenous fish species are especially valuable because they are often consumed whole, providing higher concentrations of minerals and vitamins. In India, where a substantial proportion of children suffer from undernutrition, increasing fish consumption can serve as an effective strategy to address protein and micronutrient deficiencies. Promoting sustainable fisheries, improving fish availability, and encouraging the consumption of nutrient-rich small fish species can significantly contribute to combating malnutrition and improving public health outcomes.

Keywords: Fish nutrition; Malnutrition; Small indigenous fish species; Nutritional security;

Introduction

Malnutrition continues to be a major challenge in developing countries and remains one of the leading causes of poor health and reduced productivity. It results from deficiencies of essential nutrients required for normal growth, development, and body functions. Children under five years of age and pregnant women are particularly vulnerable to the effects of inadequate nutrition.

According to the National Family Health Survey (NFHS-5, 2019–2021), approximately 35.5% of children under five years in India are stunted, while nearly 32% are underweight, reflecting widespread chronic undernutrition. Addressing these nutritional deficiencies requires increasing the availability and consumption of nutrient-dense foods.

Fish is considered one of the most important animal-source foods due to its high nutritional value and digestibility. It is an excellent source of high-quality protein containing all essential amino acids required for human health. In addition to protein, fish provides vital micronutrients such as iron, zinc, iodine, calcium, selenium, and vitamins A, D, and B-complex.

India is among the largest fish-producing countries in the world. According to the Department of Fisheries, fish production has exceeded 17 million tonnes annually. Globally, the Food and Agriculture Organization reports that fish contributes nearly 20% of the animal protein intake for more than three billion people worldwide. These facts highlight the importance of fish as a key food source in combating malnutrition.

Fish as a Rich Source of High-Quality Protein

Fish provides highly digestible protein that supports growth, tissue repair, and overall body functioning. Unlike many plant protein sources, fish contains all essential amino acids required by the human body.

Regular fish consumption can help prevent protein-energy malnutrition, especially among children and pregnant women. Due to its soft texture and digestibility, fish is also suitable for elderly individuals and young children.

Source of Essential Micronutrients

Fish contains several essential micronutrients including iron, iodine, zinc, calcium, selenium, and vitamins A, D, and B-complex.

- Iron helps prevent anemia
- Iodine supports thyroid function and brain development
- Calcium strengthens bones and teeth
- Zinc improves immunity and growth

These nutrients are often deficient in cereal-based diets commonly consumed in many developing regions.

Omega-3 Fatty Acids and Brain Development

Fish is one of the richest natural sources of omega-3 fatty acids such as EPA and DHA.

These fatty acids play an important role in brain development, cognitive function, and vision. Adequate intake of omega-3 fatty acids during pregnancy and early childhood supports neurological development in children and reduces the risk of cardiovascular diseases later in life.

Role of Small Indigenous Fish Species

Small indigenous fish species are particularly important in combating micronutrient deficiencies. Since they are often eaten whole, including bones and internal organs, they provide higher concentrations of minerals and vitamins.

Examples include:

- *Amblypharyngodon mola* – rich in vitamin A and calcium
- *Puntius sophore* – good source of protein and minerals
- *Esomus danricus* – contains important micronutrients
- *Gudusia chapra* – rich in protein and omega-3 fatty acids
- *Chanda nama* – good source of calcium and phosphorus
- *Mystus tengara* – provides high-quality protein

Promoting the cultivation and consumption of these species can significantly improve dietary diversity and nutrition in rural communities.

Nutritional Composition of Fish (Approximate)

Nutrient	Amount per 100 g fish
Protein	18–22 g
Fat	1–12 g
Calcium	20–200 mg
Iron	1–3 mg
Vitamin D	200–400 IU
Omega-3 fatty acids	0.5–2 g

This nutrient richness makes fish one of the most effective foods for addressing both protein deficiency and micronutrient malnutrition.

Indian Case Examples of Fish in Reducing Malnutrition

1. Small Fish Consumption in Eastern India

In several rural areas of eastern India, small fish such as Amblypharyngodon mola are commonly included in daily diets. Studies have shown that these fish provide high levels of vitamin A and calcium, helping improve child nutrition.

2. Fish Powder Supplementation Programs

Some nutrition intervention programs have introduced fish powder made from dried small fish into complementary foods for children. These programs have shown improvements in protein intake and micronutrient levels among children.

3. Integrated Fish Farming Systems

Integrated rice-fish farming systems practiced in several parts of India provide both food and income for rural families. Such systems improve household nutrition by increasing the availability of fresh fish for consumption.

Promoting Fish Consumption

To effectively combat malnutrition, awareness about the nutritional benefits of fish should be increased through nutrition education, extension programs, and government initiatives.

School feeding programs, community nutrition campaigns, and the development of value-added fish products such as dried fish, fish powder, and ready-to-cook fish items can further improve accessibility and consumption.

Conclusion

Fish plays a vital role in combating malnutrition by providing high-quality protein, essential micronutrients, and beneficial omega-3 fatty acids. Small indigenous fish species are particularly important due to their rich nutrient content and affordability. Strengthening fisheries production, promoting fish consumption, and supporting sustainable fish farming practices can significantly improve food and nutritional security. Therefore, integrating fish into regular diets can serve as an effective strategy to reduce malnutrition and improve public health.

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LANDRACES OF YARDLONG BEAN (*VIGNA UNGUICULATA* SUBSP. *SESOUIPEDALIS*)

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01. Introduction

Yardlong bean (*Vigna unguiculata* subsp. *sesquipedalis*), commonly known as asparagus bean, snake bean or Chinese long bean, is an important vegetable legume widely cultivated in tropical and subtropical regions. It belongs to the family Fabaceae and is believed to have originated from cowpea types domesticated in Africa and subsequently diversified in Asia. The crop is characterized by its long, slender pods that may reach 30–90 cm in length, making it highly preferred as a fresh vegetable.

In India, yardlong bean is extensively grown in southern states such as Kerala, Tamil Nadu, Karnataka and Andhra Pradesh, where several traditional landraces have evolved over time through farmer selection. These landraces possess unique pod characteristics, adaptability to local agro-climatic conditions and tolerance to certain stresses. Farmers often maintain these landraces because of their taste, cooking quality, yield stability and suitability for local markets.

Landraces represent an important genetic resource for crop improvement, as they contain valuable traits such as pest and disease tolerance, abiotic stress adaptation and superior culinary quality. Documentation and conservation of these landraces are essential for sustaining genetic diversity and supporting future breeding programs.

02. IMPORTANCE OF YARDLONG BEAN

Yardlong bean plays an important role in nutrition, income generation and soil health in smallholder farming systems.

1. Nutritional importance: Pods are rich in essential nutrients and serve as a low-cost source of protein and vitamins.

2. Economic importance: The crop has high market demand due to its tender pods, making it a profitable vegetable for farmers.

3. Short duration crop: It can be harvested within 45–55 DAS, providing quick returns.

4. Nitrogen fixation: Being a legume, yardlong bean forms symbiotic association with Rhizobium bacteria, helping in biological nitrogen fixation and soil fertility improvement.

5. Adaptability: Landraces show excellent adaptability to local climatic conditions, including tolerance to high humidity and moderate salinity in coastal regions.

03. NUTRITIONAL COMPOSITION OF YARDLONG BEAN

Yardlong bean (*Vigna unguiculata* subsp. *sesquipedalis*) is a highly nutritious vegetable legume widely consumed for its tender green pods and mature seeds. The pods are rich in proteins, vitamins, minerals and dietary fiber, while the seeds contain higher concentrations of protein and carbohydrates, making them an important source of plant-based nutrition. Due to its low-fat content and high micronutrient levels, yardlong bean is considered an excellent component of a balanced diet. Tender pods contain high moisture and moderate protein levels, making them a nutritious vegetable suitable for regular consumption. The presence of vitamin C, carotenoids and minerals such as calcium and iron contributes to their nutritional value. The mature seeds are nutritionally rich and contain high protein levels comparable to other pulses, along with essential amino acids such as lysine and tryptophan, which are important for human nutrition.

Table 1. Nutritional Composition of Tender Pods and dry seed (per 100 g edible portion) of Yardlong bean

Nutrient	Tender pods	Dry seeds
Energy	37–47 kcal	330–350 kcal
Moisture	88–90 g	11.80 g
Protein	28–33 g	23–27 g
Carbohydrates	6.2–8.4 g	55–60 g
Fat	0.1–0.4 g	1.0–2.0 g
Dietary fiber	1.2–1.8 g	5–7 g
Calcium	42–64 mg	70–90 mg
Phosphorus	54–59 mg	300–400 mg
Iron	0.8–1.3 mg	6–8 mg
Magnesium	40–46 mg	180–200 mg

Potassium	230–246 mg	900–1100 mg
Vitamin C	18–28 mg	-
Vitamin A	167–869 IU	-
Thiamine (B1)	0.07–0.11 mg	0.7 mg
Riboflavin (B2)	0.09–0.11 mg	0.2 mg
Niacin (B3)	0.40–0.42 mg	2–3 mg
Folate	~60 µg	350–450 µg

04. HEALTH BENEFITS OF YARDLONG BEAN

1. Improves digestion: High dietary fiber helps in maintaining digestive health and preventing constipation.

2. Regulates blood sugar: Low glycaemic index helps in managing blood glucose levels, beneficial for diabetic patients.

3. Supports heart health: Presence of potassium and antioxidants helps in maintaining cardiovascular health.

4. Boosts immunity: Vitamin C and other antioxidants strengthen immune function.

5. Prevents anaemia: Iron content contributes to haemoglobin formation, helping prevent anaemia.

05. CHARACTERISTICS OF IMPORTANT LANDRACES OF YARDLONG BEAN

1. Kanjikuzhi Payar Local

This landrace is known for its long, tender pods and excellent culinary quality. It is a vigorous climbing type with indeterminate growth habit with dense foliage with medium sized trifoliate leaves. The pods are 50–65 cm long, slender, light green with red stripes. Tender pods are excellent in taste and low in fibre. It produces 35–40 pods per plant under normal cultivation. It has good adaptability to humid tropical climate. It is preferred in the local markets due to its excellent taste and tenderness.

Kanjikuzhi payar local

2. Kilichundan Payar Local

Kilichundan Payar is a popular traditional landrace of Kerala, particularly valued for its distinct pod shape and good yield potential. It is a strong climbing vine with profuse branching and with indeterminate growth habit. The pods are 45-60 cm long and are slightly curved and medium green in colour with soft texture with moderate thickness. It produces 42–45 pods per plant. It has good consumer preference and performs well under rainfed conditions.

Kilichundan Payar Local

3. Palakkad Local

This is well adapted to warm and humid environments. It is a vigorous climber with spreading growth with moderate branching. The pods are 55-70 cm long that are dark green in colour and cylindrical. Tender pods have good shelf life. It produces around 48–50 pods per plant. This tolerant to high temperature and humidity and suitable for continuous harvesting.

Palakkad local

4. Mannuthi Local

This is popular among farmers due to its stable yield. It is a strong climbing vine with vigorous vegetative growth. The pod length is 50-60 cm, light green in colour and slightly curved. The tender pods have good cooking quality. It produces 36-40 pods per plant. It is well adapted to humid tropical climate

Mannuthi Local

5. Kollam Local

This landrace is cultivated in the coastal region of Kollam district, showing adaptation to high humidity and coastal conditions. It is a vigorous climbing vine with dense foliage cover. The pod length is 45–55 cm and are light green and smooth. The tender pods are with mild flavour. It produces around 45–48 pods per plant. It is well adapted to coastal climatic conditions and has good market demand.

Kollam Local

6. Kerala Local

Kerala local represents a traditional farmer-maintained population widely cultivated across different parts of Kerala. It is a vigorous climbing vine with profuse branching. The pod is 50–65 cm long, green, cylindrical and smooth. Tender pods with good texture. It produces 48–50 pods per plant. It has high adaptability to diverse agro-ecological conditions. It is preferred for home gardens and local markets.

Kerala local

7. Salem Local

Salem local is a traditional landrace cultivated in Salem district of Tamil Nadu and is adapted to semi-arid tropical climate. It is a vigorous climbing habit with moderate branching. The pod is 40–55 cm long, red, slightly thick and fleshy. The tender pods are suitable for cooking.

Salem local

It produces 44-47 pods per plant. It is tolerant to relatively dry conditions and performs well in Tamil Nadu agro-climatic conditions.

Conclusion

Landraces of yardlong bean represent a valuable reservoir of genetic diversity developed through long-term farmer selection and adaptation to specific local environments. These landraces possess unique traits such as pod length, tenderness, flavor, adaptability and stress tolerance, which are important for both cultivation and breeding programs. Conservation and characterization of these traditional varieties are essential for sustaining crop diversity and improving future yardlong bean cultivars.

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NEMATODE PEST OF FLOWER CROPS

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Introduction

Flower crops are also known as floriculture crops, and they are more significant in agriculture, horticulture, economy, and daily life. India is the second largest producer of flower crops in the world. In India key producing states are Tamil Nadu, Madhya Pradesh followed by Karnataka while major exports include roses and marigold to the USA, Netherlands and UAE. Flower crops help to earn a high income when compared to many food crops. Flowers are widely used for aesthetic purposes, religious ceremonies, weddings, festivals, and decorations. In flower crops are mostly affected by pest, diseases and nematodes, particularly root-knot nematode (*Meloidogyne* spp.) and foliar nematode (*Aphelenchoides* spp.) types, cause severe damage to flower crops by reducing their yield, impairing quality and inducing root galls or leaf necrosis. Key symptoms include stunting, wilting, chlorosis, distorted flower buds and deformed roots, especially in crops such as Tuberose, Rose, Chrysanthemum, Vedchi and Jasmine.

Vedchi flower

1.Above-ground symptoms

- Stunted growth (plant looks weak and undersized)
- Yellowing of leaves (chlorosis)
- Wilting even when soil has enough moisture
- Reduced flowering or poor bloom quality

- Leaves may drop prematurely

2. Below-ground symptoms (most diagnostic)

- **Root galls (knots/swelling)** – small to large lumps on roots
- Reduced root system (few feeder roots)
- Roots may rot in severe cases due to secondary infections

Management

- Apply **neem cake** regularly
- Use bio-agents: Paecilomyces lilacinus
- Grow **marigold** as intercrop
- Remove heavily infected plants
- Ensure good drainage
- Chemical control: phorate

JASMINE

Above-ground symptoms

- Stunted plant growth
- Yellowing of leaves (nutrient deficiency-like symptoms)
- Reduced flowering (fewer buds, poor fragrance)
- Wilting during hot hours even with sufficient water
- Overall weak, unhealthy appearance

Below-ground symptoms (key diagnostic sign)

- **Root galls (knots/swelling)** on roots
- Roots become thick, deformed, and irregular
- Reduced feeder roots
- In severe cases, root rot due to secondary infections

Management

- Apply **neem cake** regularly
- Use bio-agent: Paecilomyces lilacinus
- Remove severely infected plants
- Use well-drained, healthy soil
- Grow in sterilized potting mix (for pots)

TUBEROSE

Meloidogyne incognita

Symptoms

- Stunted patches of plants with unthrifty growth
- Leaves turn pale yellow
- Reduction of no. of flowers
- Moderate to severe galling in the roots.

Management

- Apply carbofuran 3G @ 1.0 kg a.i/ha
- Neem cake at 500 kg /ha
- FYM @ 10 tons/ha.

CROSSANDRA

Pratylenchus delattrei

Symptoms

- Stunted parches in field
- Leaves turn pale yellow with puckering symptoms
- Internodal length reduced to give a rosette appearance
- Lesions on the secondary and tertiary roots.

Management

- Apply carbofuran 3G 1.0 kg a. i /ha
- Apply FYM @ 10 ton/ha
- Apply neem cake@500 kg/ha
- *Helicotylenchus dihystera*

CHRYSANTHEMUM

Aphelenchoides ritzemabosi

Symptoms

- Carbofuran (restricted in many places—check local regulations)
- Phorate granules (use carefully under expert guidance)
- Safer newer nematicides may be recommended by local Agri officers
- The first stem appears to be dwarfed. The plant is forced to produce other basal stems, thus acquiring a bushy appearance. Early nematode feeding in the buds and growing points causes growth retardation, resulting in distorted and deformed leaves.
- The growing points may be so severely damaged that they blacken and eventually die. Nematode injury induces the growth of side shoots, which also become infected.

- Later, infection of the leaves causes the formation of yellow spots or blotches, which are first noticeable on the lower leaf surfaces. The often wedge - shaped discolored areas gradually expand, turn yellowish-brown, and finally blacken.
- Developing leaves become distorted and crinkled. The entire leaf soon becomes infected, shrivels, dies and hangs downward or falls to the ground. The destruction of the leaves usually progresses upward as the stems elongate.
- The nematodes may eventually infect the terminal flower buds, producing deformed and undersized flowers.

Management

- All infected plants and fallen leaves should be carefully removed from the garden or greenhouse and burned.
- Soil in affected nursery plantings should be fumigated.
- Floors, benches and storage areas should be thoroughly cleaned of plant debris. Containers and tools should be steamed or fumigated.
- Pots, potting soil and tools must be baked in an oven or steamed at 180-200°F (82- 93°C) for 30 minutes.
- Foliar nematode diseases can be minimized with good cultural practices.
- Only carefully selection of nematode -free plants or plant parts should be used for propagation.
- Excessive humidity, splashing water on stems and leaves and contact between plants should be avoided.
- Moisture should not be allowed to stand on the foliage for over a few minutes.
- The use of a dry surface mulch or a ring of petroleum jelly around the base of stems helps to prevent the nematodes from migrating up the plant stems

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SEAWEEDS AND CARBON SEQUESTRATION: OCEAN GARDENS

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Abstract

Climate change is one of the greatest environmental challenges facing the world today, primarily driven by the continuous increase in atmospheric carbon dioxide (CO_2). In recent years, marine ecosystems have gained significant attention for their role in capturing and storing carbon, commonly known as *blue carbon*. Among these ecosystems, seaweeds have emerged as an important natural resource with immense potential for carbon sequestration. Seaweed farming not only contributes to food security, livelihoods, and the coastal economy but also offers an eco-friendly strategy to reduce atmospheric CO_2 levels. Through rapid growth and efficient photosynthesis, seaweeds absorb large quantities of carbon and can store it in biomass and marine sediments. This article explores the importance of seaweed cultivation, its role in carbon capture, mechanisms of carbon sequestration, ecological benefits, challenges, and future prospects as a climate mitigation strategy.

1. Introduction

The increasing concentration of greenhouse gases in the atmosphere, especially carbon dioxide, has accelerated global warming and climate change. Rising temperatures, sea level rise, ocean acidification, and extreme weather events are some of the visible consequences affecting ecosystems and human society. While terrestrial forests are widely recognized as carbon sinks, the role of marine vegetation in climate regulation is equally important. Coastal ecosystems such as mangroves, seagrasses, salt marshes, and seaweeds act as significant reservoirs of carbon. Among these, seaweeds are increasingly being recognized for their remarkable capacity to

absorb atmospheric CO_2. Seaweed farming has expanded rapidly across the globe, particularly in Asian countries such as India, China, Indonesia, Japan, and South Korea. Beyond its commercial value in food, pharmaceuticals, fertilizers, and cosmetics, seaweed farming now holds promise as a nature-based climate solution.

2. Understanding Carbon Sequestration

Carbon sequestration refers to the process of capturing and storing atmospheric carbon dioxide for long periods, thereby preventing its release into the atmosphere.

There are two major forms:-

Biological carbon sequestration - This involves the absorption of CO_2 by living organisms through photosynthesis and its storage in biomass.

Geological or long-term storage - This includes storage in deep ocean sediments, soils, and other stable reservoirs for decades to centuries.

Seaweeds contribute mainly through **biological sequestration**, but a fraction of the captured carbon can also enter long-term marine storage.

3. How seaweeds capture carbon?

Seaweeds (macroalgae) live in sunlit coastal waters and, like land plants, they photosynthesize. They pull carbon dioxide from the water (and indirectly the air) to grow. On a sunny day, a seaweed plant might look like a *green lawn under the sea*, brushing up nutrients. Brown kelps and other large algae can reach lengths of several meters in a season. Globally, all marine vegetation (including seaweeds) is very productive: one estimate is that wild seaweed populations fix about 173 teragrams of carbon per year (1 Tg = 10^12 grams) on roughly 3.5 million km² of ocean. (As a comparison, all coastal "blue carbon" ecosystems like mangroves and seagrass bury on the order of 0.08–0.20 Pg CO_2 per year.) In a seaweed "farm", carbon follows two main pathways (see Figure 1 below). First, some of the carbon enters fast-moving cycles: the plant biomass is harvested and ends up as food, fertilizer, bioplastics or biofuel. Most of this carbon eventually returns to the atmosphere or nearby waters within months to years (through decomposition, combustion or digestion). This is like planting a crop of vegetables: you eat it or burn it, and that CO_2 is back in the air by next year. NOAA highlights that such uses are not considered true sequestration because the carbon is quickly "spent".

Second, some carbon can take a slow path into long-term storage. When seaweed leaves fall off or waste sinks to the seafloor, a fraction can get buried in sediments. If that carbon stays

locked in mud for decades to centuries, it effectively removes CO_2 from the atmosphere for a long time – similar to how dead trees become coal or oil over geological time. Research suggests that this fraction is relatively small: wild and farmed seaweeds export some dissolved organic carbon (DOC) and particulate carbon downward. Estimates vary, but one review notes that perhaps only a few tens of percent of seaweed carbon becomes refractory DOC or deep sediment, while the rest is recycled. Capturing this "slow" carbon is the key to true sequestration.

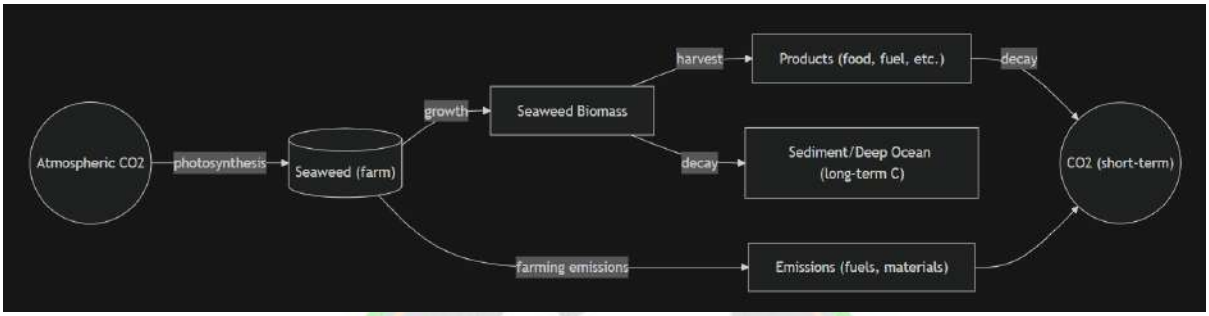

Figure 1: Schematic of carbon flows in seaweed farming. Seaweeds take up CO_2 and build biomass. Harvested biomass can be used for products (green arrow) whose carbon is usually respired back as CO_2 (dashed return). Some biomass or dissolved carbon can sink and enter long-term ocean sediment (blue arrow). At the same time, farming activities (e.g. boats, fertilizers) emit CO_2 (red arrow), which adds to the total.

4. Seaweed Farming Today: Scale and Yield

So far, seaweed farming is mostly a small-sector aquaculture. Worldwide, farms occupy only about 1,600 km² of ocean (0.01% of the whole ocean surface). By comparison, wild seaweed beds cover over 3.5 million km², and only ~0.004% of that wild area is cultivated. The industry is highly concentrated in Asia: China alone produces roughly half of global seaweed by weight. Farms tend to be in sheltered coastal bays with ropes or nets (Figure 1); in these settings, most organic matter falls into the underlying sediment, which could favor burial. Seaweed yields are high: fast-growing species like kelp or nori can produce on the order of 10–40 tons of wet seaweed per hectare per year (varying by location). In a lifecycle analysis of kelp farms in China, Lian *et al.* found that each square meter of kelp farm sequestered about 97.7 grams of carbon per year (full cycle). That translates to roughly 3.5 metric tons of CO_2 per hectare per year (photosynthetically captured). By itself, this is promising – it's comparable to mid-range forest sequestration rates. However, one must subtract emissions from the farm's operations. In the

same study, the 97.7 gC/m² figure already accounts for farm inputs and processing into biochar (a stable product). It shows that under *ideal conditions*, a temperate kelp farm could be a net carbon sink. Other places and species may do better or worse.

To get a sense of aggregate impact: pessimistically or realistically, if all ~1,600 km² of farms operated at this rate, that would be ~0.00016 Pg C/yr (0.58 Tg CO_2/yr), still tiny globally. On the optimistic side, if farming expanded greatly, rough estimates by Krause-Jensen & Duarte suggest a potential of ~0.173 PgC/yr (~0.635 PgCO_2/yr) sequestration if all suitable areas were used. The truth is likely somewhere in between, and depends on farm design, species, and carbon fate.

5. Carbon Accounting: Benefits vs. Footnotes

Even with good growth rates, many factors limit the climate payoff. An analogy often used is that seaweed farming is like **planting a garden vs. a forest**. You can grow vegetables (fast carbon uptake) but if you eat or burn them, little is left for the long term. By contrast, planting a tree locks much of the carbon away in the wood. Many seaweed products (biofuels, packaging, etc.) eventually oxidize to CO_2 quickly, so they don't count as sequestration. Additionally, there's the issue of supply-chain emissions – energy, materials, and chemicals used to run farms. In other words, the "carbon profit" per farm hectare is currently negative. This is a critical insight: **decarbonizing the farm's operations** is as important as growing more seaweed. Otherwise, it is like harvesting energy from a treadmill – you only get out what you put in.

In practice, then, seaweed farms today are **modestly beneficial or neutral** for climate, but not a silver bullet. To realize any real carbon "gain," plans often rely on novel steps. For instance, one idea is to harvest and sink seaweed intentionally to very deep waters (sometimes called "carbon-negative seaweed wrack" schemes). Another is to convert biomass to biochar (charcoal) or stable materials that don't decompose for centuries. A recent model by Fakhraee & Planavsky (2026) even highlights a surprising mechanism: seaweed decay can increase sediment alkalinity, turning CO_2 into dissolved bicarbonate that stays out of the atmosphere. They estimate this could remove about **0.1–2 tonnes CO_2 per hectare-year** on average. In other words, a well-designed seaweed farm might draw down roughly **1 tonne of CO_2 per year from each cultivated hectare** via chemical processes – if all goes well. This points to a still-emerging understanding of how seaweed ecosystems alter ocean chemistry.

6. Challenges and Considerations

Several practical challenges loom. First, scaling up from small coastal farms to global impact means using a lot more ocean space. Cantasano (2024) notes that only 0.01% of the ocean is currently farmed; even if millions more square kilometers were suitable, we must learn how to farm in open, rough seas without harming ecosystems. Second, environmental effects are uncertain: adding biomass or nutrients can alter local food webs and oxygen levels. Third, **monitoring and verification** is hard. On the positive side, seaweed farming has co-benefits. It can clean coastal waters by using excess nitrogen and phosphorus, and it provides jobs and biomass that substitutes for more carbon-intensive products. These benefits make seaweed appealing, even if the climate story is complex. Many experts now suggest framing seaweed primarily as a **blue bioeconomy solution** rather than a pure carbon offset. For instance, one viewpoint argues we should let the quest for carbon removal drive technical precautions (like careful accounting), but invest in seaweed growth mainly for its direct uses (food, materials, pollution control). If we increase seaweed production for fertilizer or food, any carbon co-benefit is a bonus.

Throughout, it's crucial to keep an open mind and fill in data gaps. For example, the actual amount of carbon buried under farms is poorly known – studies often use proxies or local measurements. We recommend consulting **satellite data or farm records** (where available) for more accurate area and yield statistics, and *national fishery or aquaculture agencies* for production numbers. Reliable inventories (e.g. from FAO or UNESCO) of farmed seaweed area and biomass would greatly improve global estimates.

Conclusion

Seaweed farming is an exciting frontier in marine resource use, with real potential benefits for communities and ecosystems. In terms of climate impact, however, the verdict is still out. We have learned that simply expanding farms is not enough to guarantee carbon removal. According to recent reviews, most carbon fixed by seaweeds today ends up in short-lived pools, and the farming process itself often emits CO_2, leading to a net neutral or negative outcome. Long-term sequestration requires additional steps: transporting biomass to deep sinks, transforming it into stable materials, or harnessing chemical changes (like alkalinity) that lock away carbon.

For educated readers, the takeaway is: Seaweed farming alone is not a magic bullet for climate. It must be paired with careful carbon accounting and low-carbon practices. That said,

the research is rapidly evolving. New field experiments and monitoring methods (using tracers, isotopes or satellite tracking) will clarify exactly how much carbon can be buried safely. In the meantime, seaweed's role in the "blue bioeconomy" – replacing plastic, feeding people, cleaning water – should not be overlooked. Its climate co-benefit might be modest now, but with smart design and rigorous science it could grow.

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THE GUT MICROBIOTA: SMALL ORGANISMS, BIG IMPACT ON HEALTH

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Introduction

We often hear the phrase, "You are what you eat." But modern science suggests something even more intriguing – you are also what your gut microbes do with what you eat.

Deep within our digestive system lives a vast and complex community of microorganisms known as the gut microbiota. These microscopic residents are not just passive inhabitants; they actively influence how our body processes food and maintains health. Among the many dietary components, they interact with, plant-derived compounds called polyphenols have gained significant attention in recent years.

What are Polyphenols?

Polyphenols are a diverse group of natural compounds found in plants. They contribute to the color, taste, and defense mechanisms of plant foods, and they are an important part of a healthy diet. Common sources include berries, grapes, green tea, cocoa, nuts, whole grains, fruits vegetables and many plant-based foods. While they are often praised for their health benefits, their true potential is not fully realized until they are transformed by the gut microbiota. This hidden interaction between diet and microbes plays a crucial role in shaping human health.

These compounds are widely recognized for their antioxidant properties, which help protect the body from oxidative stress and cellular damage. However, despite their importance, most polyphenols are not easily absorbed in their original form. A large portion passes through

the upper digestive tract without being fully utilized. This limited absorption highlights the importance of what happens next – when these compounds reach the large intestine and encounter the gut microbiota.

The Gut Microbiota: Hidden Partners in Digestion

The human gut is home to trillions of microorganisms, including bacteria, fungi, and other microbes. Together, they form a dynamic ecosystem that plays a central role in digestion, metabolism, and immune function. When polyphenols reach the colon, gut microbes begin to act on them through a series of biochemical processes. This interaction is not random; different microbial species carry out specific reactions that gradually transform complex compounds into simpler forms.

The efficiency of this process depends on the composition of an individual's gut microbiota. Since each person's microbial community is unique, the way polyphenols are processed can vary from one individual to another. This explains why the same food may have different health effects in different people.

Biotransformation: Unlocking Hidden Potential

Polyphenols in their natural form are often too large or complex to be readily absorbed by the body. Through microbial action, these compounds undergo a process known as biotransformation, where they are broken down into smaller, more accessible molecules.This transformation involves several types of reactions, including the removal of sugar groups, structural rearrangements, and the breakdown of complex rings. As these changes occur, polyphenols are converted into simpler compounds such as phenolic acids and other metabolites.

In simple terms, gut microbes act as biological processors, unlocking the hidden potential of polyphenols and making them more useful to the body. Without this transformation, many of the health benefits associated with polyphenol-rich foods would remain inaccessible.

Microbial Metabolites: Small Molecules with Big Effects

The compounds produced during biotransformation, known as microbial metabolites, often have greater biological activity than the original polyphenols. These smaller molecules can be more easily absorbed into the bloodstream and can interact with various systems in the body.

They contribute to a range of beneficial effects, including reducing inflammation, protecting against oxidative stress, and supporting cardiovascular health. Some metabolites also

influence important cellular pathways, affecting how the body responds to stress, regulates metabolism, and maintains overall balance.

What makes this process especially fascinating is that its outcome depends on the gut microbiota itself. The diversity and composition of microbial communities determine which metabolites are produced and in what quantities, further emphasizing the personalized nature of nutrition and health.

Health Implications: A Dynamic Relationship

The interaction between polyphenols and gut microbiota represents a two-way relationship. While microbes transform polyphenols into beneficial compounds, polyphenols in turn influence the composition of the gut microbiota.

Regular consumption of polyphenol-rich foods has been shown to promote the growth of beneficial bacteria while inhibiting harmful ones. This creates a more balanced and resilient microbial community, which supports better digestion, improved immunity, and overall health.

At the same time, the enhanced microbial activity leads to more efficient nutrient cycling and better utilization of dietary components. This dynamic interaction highlights how closely diet, microbes, and human health are connected.

Future Perspectives

As research in this field advances, scientists are beginning to explore how knowledge of the gut microbiota can be used to improve dietary strategies. The idea of personalized nutrition is gaining importance, where diets can be tailored based on an individual's microbial composition. There is also growing interest in developing functional foods that combine polyphenols with beneficial microbes. Since bioactive compounds depend on microbial transformation, combining them with the right microbial partners could enhance their effectiveness.

In addition, this research opens new possibilities for managing health conditions through diet. By understanding how gut microbes interact with food components, it may become possible to design targeted nutritional approaches that support long-term health and disease prevention.

Conclusion

The journey of food does not end with digestion – it continues through a complex and fascinating interaction with the gut microbiota. These tiny organisms play a powerful role in transforming dietary compounds into forms that the body can use effectively. Polyphenols, though abundant in plant-based foods, rely heavily on microbial transformation to deliver their

full benefits. This invisible process highlights the importance of maintaining a healthy and diverse gut microbiota.

To conclude, it is not just what we eat, but how our body's microscopic partners process it, that shapes our health. By understanding and supporting this hidden world within us, we can unlock new pathways to better nutrition and well-being.

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FARMING WITHOUT SOIL: HYDROPONICS AND SOILLESS CULTIVATION

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Introduction

The twenty-first century confronts global agriculture with multiple crises. According to the Food and Agriculture Organization of the United Nations (FAO), approximately 1.5 billion hectares just 11% of the Earth's total land areacurrently serve as cultivated agricultural area. Simultaneously, the United Nations projects that the world population will reach 9.8 billion by 2050, demanding a 70% increase in food production. Theshrinking land and rising demandare further amplified by accelerating climate instability, soil degradation, and freshwater scarcity.

Against this backdrop, hydroponics and soilless cultivation technologies have emerged not merely as experimental novelties but as scientifically mature, commercially scalable solutions. The term 'hydroponics' derives from the Greek words hydro (water) and ponos (labour), and the technique involves delivering dissolved nutrients directly to plant root zones, entirely bypassing the need for soil as a growth medium. Plants grown this way can access oxygen, water, and a precisely calibrated suite of macronutrients and micronutrients under controlled environmental conditions, enabling higher growth rates and yield which is impossible to achieve in open-field agriculture.

The global hydroponics market was valued at approximately USD 14.73 billion in 2024 and is projected to exceed USD 33 billion by 2033, expanding at a compound annual growth rate (CAGR) of 9.3–13.1% depending on the analytical framework employed.

Physiological Basis: How Plants Thrive Without Soil

Soil, in conventional agriculture, serves two primary functions: mechanical anchorage of roots and a reservoir of dissolved mineral nutrients. Hydroponics achieves both through

engineered substitutes. Inert growing mediaincluding rockwool (a mineral fibre derived from basalt), coconut coir, perlite, vermiculite, peat moss, and expanded clay aggregates, provide physical root support. Whereas, the nutrient solution used in hydroponics depending on the crop supplies all the essential mineral nutrients required for plant growthand it is typically maintained at a pH of 5.5–6.5 and an electrical conductivity (EC) of 1.5–3.5 dS/m. Thus, the advantage of hydroponics lies in the direct and unimpeded delivery of nutrients to the root zone. In soil systems, nutrient availability is mediated by soil pH, microbial activity, ion exchange capacity, and root exudate chemistry all of which are variable and inefficient. Whereas, in hydroponics, nutrients are dissolved in bioavailable ionic form and given at optimal concentration continuously, allowing the plant to allocate less metabolic energy to root development and more to aboveground biomass and reproductive structures.

Dissolved oxygen (DO) in the root zone is a critical parameter often overlooked. Roots require aerobic respiration to actively transport ions against concentration gradients. Hydroponic designs such as Nutrient Film Technique (NFT) and DeepWater Culture (DWC) are specifically engineered to maintain DO levels above 5–8 mg/L, preventing the hypoxic conditions that cause root rot in poorly managed stagnant systems. As articulated in the Canadian Journal of Plant Science (2023): "The nutrient solution is a substantial factor in hydroponics; thus, proper nutrient solution management is essential to improve nutrient use efficiency (NUE) and water use efficiency (WUE) in hydroponic cultivation systems".

Major Hydroponic System Types

Modern soilless cultivation encompasses a spectrum of system architectures, each optimised for different crops, scales, and economic contexts. The primary configurations are summarised in Table 1 below.

System Type	Mechanism	Best Crops	Key Advantage
Nutrient Film Technique (NFT)	Thin film of nutrient solution flows continuously over bare roots in sloped channels	Lettuce, herbs, spinach	High O_2 to roots; water efficient
Deep Water	Roots suspended in	Lettuce, tomatoes,	Simple design; excellent for

Culture (DWC)	oxygenated nutrient solution reservoirs	cucumbers	leafy greens
Drip Irrigation (Substrate)	Nutrient solution dripped onto rockwool or coir substrate around roots	Tomatoes, peppers, strawberries	Highly scalable for large commercial farms
Ebb and Flow	Growing trays periodically flooded with nutrient solution then drained	Herbs, flowers, seedlings	Versatile; compatible with many media types
Aeroponics	Roots suspended in air; misted with fine nutrient droplets at intervals	High-value crops, microgreens	Highest water efficiency; rapid growth rates
Aquaponics	Integrates fish culture; fish waste provides plant nutrients biologically	Leafy greens, herbs, fish	Circular bioeconomy; potential organic certification

Table 1. Hydroponic system types, mechanisms, and crop suitability

Comparing NFT, DWC, aeroponic, and drip systems, aeroponics achieved high water use efficiency compared to NFT counterparts, and that water usage could be reduced by more than 90% and fertilizer consumption by up to 60% depending on system type and crop variety.

Resource Use Efficiency: Water, Land, and Nutrients

Water Conservation: Hydroponic systems achieve dramatic reductions in water consumption through closed-loop recirculation, in which unused nutrient solution is captured, re-mineralised, and reapplied to the crop. Multiple independent studies converge on a reduction of 80–95% in water consumption relative to open-field agriculture.Water use efficiency (WUE), defined as fresh fruit mass produced per litre of transpired water, was higher in soilless systems (DWC and drip-irrigated rockwool) compared to soil-grown tomatoes.Additionally, hydroponically grown

tomatoes exhibited significantly higher lycopene and β-carotene concentrations, indicating enhanced nutritional quality.

Land Use and Vertical Integration: Hydroponic installations particularly vertical farms using stacked growing tiers decouple food production from land area constraints. Commercial hydroponic operations can produce crops on approximately one-fifth of the land area required for equivalent yields in conventional agriculture. Vertical farming systems have demonstrated up to 10 -11-fold higher crop output per square metre compared to field agriculture. A landmark example was the Eden Green Technology facility in Texas (USA), which produces approximately 340,000 plants annually on just 62,000 square feet a productivity density unachievable in conventional horticulture.

Soilless systems substantially outperform traditional methods in land and water use efficiency, while enabling year-round, climate-independent production. Use of hydroponics can buffer crop yield against increasingly erratic precipitation and temperature patterns associated with anthropogenic climate change.

Nutrient Use Efficiency: In conventional soil agriculture, significant proportions of applied fertiliser are lost through leaching, runoff, volatilisation, and microbial immobilisation. The USDA estimates that only 30 - 50% of applied nitrogen in field crops reaches the harvested product. In recirculating hydroponic systems, nutrient uptake efficiency exceeds 95%.

Yield and Crop Quality

Yield superiority in hydroponic systems is well-documented across multiple crop species. According to a United Nations analysis, plants grown in hydroponic systems achieve 20–25% higher yield than traditional agriculture on average, with productivity 2–5 times greater under optimised conditions. Deep Water Culture and NFT systems in particular have been shown to boost leafy-green yields by 30–50% compared to aggregate-based substrate counterparts.

In addition, hydroponically grown tomatoes showed significantly higher lycopene and beta-carotene content than soil-grown tomatoes under identical conditions, while maintaining comparable sugar (Brix) levels. Additionally, barley seedlings grown in electrically conductive "eSoil" exhibited 50% faster growth within 15 days, demonstrating the potential of emerging hydroponic innovations.

Technological Frontiers: ***IoT, AI, and Precision Sensing***

The convergence of hydroponics with digital agriculture technologies has produced a

new generation of smart soilless systems capable of autonomous monitoring and adaptive management. Internet of Things (IoT) sensor networks now continuously track pH, electrical conductivity (EC), dissolved oxygen (DO), water temperature, air humidity, and CO_2 concentration in real time, transmitting data to cloud-based management platforms. Such systems apply machine learning algorithms trained on thousands of crop-growth datasets to pre-emptively correct nutrient imbalances before physiological symptoms.

Challenges and Limitations

- **High capital investment:** Establishing hydroponic systems requires substantial upfront costs, ranging from ~USD 110,000 for a 500 sq. ft. unit to USD 500,000–800,000 for larger automated setups, limiting accessibility for smallholder farmers.
- **Pathogen risks in closed systems:** Waterborne pathogens such as *Pythium* spp. and *Fusarium oxysporum* can spread rapidly in recirculating nutrient solutions, necessitating strict monitoring and periodic sterilisation due to the absence of natural soil microbial suppression.
- **High energy demand:** Controlled-environment hydroponic systems, particularly indoor vertical farms, can consume 10–20 times more energy per kg of produce than conventional field agriculture, highlighting the need for renewable energy integration.
- **Regulatory and certification challenges:** Differences in organic certification standards permitted in hydroponics in the United States but restricted in the European Union create policy inconsistencies, market barriers, and consumer confusion.

Conclusion

Hydroponics and soilless systems are scientifically validated and commercially proven, offering superior water (80–95% savings), land (2–11× productivity), and nutrient use efficiency (>95%), along with year-round production. Feeding a projected 10 billion people will require integrating these systems with conventional agriculture, where the future of food security lies beyond soil-bound cultivation.

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MICROPLASTIC POLLUTION IN AQUATIC SYSTEMS: CONSEQUENCES FOR FISH HEALTH

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Abstract

The microplastics, which are defined as particles of plastic <5 mm, have been reported as a major pollutant in aquatic ecosystems due to increased levels of plastic waste and degradation. Microplastics are known to enter the environment through sources such as industrial waste, domestic waste, and degradation of larger plastics. The fish are also highly vulnerable to microplastics, which can enter their system through ingestion, food chain, and gill uptake, resulting in bioaccumulation in different parts of their body. The microplastics are known to affect fish health in many ways, including digestive blockage, reduced food intake, and growth. At the cellular level, microplastics can cause oxidative stress, metabolic disorders, immune system suppression, and behavioral responses. Microplastics can also act as a vehicle for toxic compounds, including heavy metals and pesticides, which can increase their adverse effects. The bioaccumulation of microplastics in fish can also affect human health, as it can enter the human body through food consumption, causing inflammation and toxicity. Therefore, it is important to understand the effects of microplastics, which can be helpful for protecting aquatic ecosystems.

Keywords: Microplastics, Fish health, Aquatic pollution, Oxidative stress, Bioaccumulation, Food safety

Introduction

Plastic pollution is a significant environmental issue, with large amounts of plastic entering aquatic environments, leading to the formation of microplastic pollutants, which are defined as plastic particles less than 5mm in size (Wootton et al., 2026).Microplastic pollutants

are formed from degraded plastic waste, industrial waste, and synthetic fibers, which are now found in water, sediments, and aquatic life (Chen et al., 2021).

Fish are highly susceptible to the impacts of microplastic pollutants, which are ingested, leading to the accumulation of these pollutants in the bodies of fish (Wootton et al., 2021). According to research, a large proportion of fish in the world are found to have microplastic pollutants, which is a significant ecological risk (Wootton et al., 2021).

The presence of microplastic pollutants in fish not only impacts the health of the fish but also poses a risk to humans who consume fish, making it important to understand the impact of these pollutants.

Sources and Entry into Fish :

Microplastics are introduced into aquatic ecosystems mainly through the degradation of larger plastic debris, as well as domestic and industrial waste. Microplastics have become widespread in aquatic ecosystems as a result of their persistence and continuous input (Piyawardhana et al., 2022).Fish are mainly exposed to microplastics through ingestion. This is because microplastics are ingested by fish, which mistake them for food. In addition, microplastics can be introduced into the bodies of fish through the food chain.

This is because microplastics are ingested by prey species, and as a result, they bioaccumulate in higher trophic species (Wootton et al., 2021).Another mode of microplastic exposure to fish is through gill uptake. In this case, microplastics present in the water are ingested by the fish during respiration. Once ingested, microplastics accumulate in organs such as the digestive tract, liver, and gills. This exposes the fish to health hazards (Chen et al., 2021).

Effects on Fish Health :

Microplastics have adverse effects on the health of fish, which include physical, physiological, and cellular effects. One of the adverse effects of microplastics on the health of fish is physical harm, which is caused by the accumulation of microplastics in the digestive system, thereby causing blockage, reduced feeding, and a false feeling of being full, which eventually affects nutrition (Piyawardhana et al., 2022).

Another adverse effect of microplastics on the health of fish is physiological harm, which is caused by the reduction of growth rate and disruption of normal physiological functions, particularly in the liver and gills. It is also known that microplastics induce oxidative stress, which is caused by the generation of reactive oxygen species (ROS), thereby damaging the

components of the cell, which include DNA, proteins, and lipids (Subaramaniyam et al., 2023).

Another adverse effect of microplastics on the health of fish is that they cause metabolic disorders and suppression of the immune system, which increases the susceptibility of fish to diseases. It is also known that microplastics induce behavioral disorders, which include alterations in the normal swimming and feeding behaviors of fish. In some cases, microplastics induce reproductive problems, which include reduced fertility (Chen et al., 2021).

Microplastics as Toxic Carriers:

Microplastics not only cause damage to the fish but also act as vectors of different types of toxic substances present in the aquatic ecosystem. The large surface area of the microplastic particles, along with their hydrophobic nature, makes it easy for these particles to adsorb different types of harmful substances present in the aquatic ecosystem, including heavy metals, pesticides, and different types of organic pollutants (Wootton et al., 2026).

When the fish ingest these types of microplastics, the different types of toxic substances present on the surface of the particles can be released inside the fish, thereby increasing the overall level of toxicity in the fish.

It has been observed that the overall effect of the presence of these types of particles, along with the overall effect of the toxic substances present on the surface of the particles, has been described as the “chemical cocktail effect,” which has the overall effect of increasing the impact of the presence of these types of particles on the health of the fish (Wootton et al., 2026).

Human Health Implications:

As a result, these microplastics can enter the human body through the consumption of contaminated fish, making them a potential food safety risk. This risk can be considered significant, given that fish are a source of protein for humans worldwide (Wootton et al., 2026).As a result of ingestion, these microplastics can react with the human digestive system, leading to adverse health effects. According to research, these microplastics can alter the human gut, cause inflammation, and affect the immune system (Piyawardhana et al., 2022).

In addition, these microplastics can accumulate toxic substances, which can be released in the human body upon consumption, thereby causing health hazards. Although the long-term effects are still under investigation, concerns are rising regarding the potential role of these microplastics in causing chronic diseases and toxicity in humans (Subaramaniyam et al., 2023).

Conclusion

Microplastic pollution has been identified as a major threat to aquatic ecosystems, especially concerning the health of fishes at different levels. These microplastics have a major impact on the health and survival of fishes, causing a decline in their health (Subaramaniyam et al., 2023).Moreover the capacity of microplastics to carry out toxic compounds also enhances the impact of microplastic pollution, which not only affects the health of aquatic species but also affects human health by consuming such species (Wootton et al., 2026).

Despite the increasing research on microplastic pollution, it is important to understand the long-term impact of microplastic pollution. It is important to control this emerging environmental issue through effective management, reduction of plastics, and awareness (Chen et al., 2021

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LITCHI: A SUBTROPICAL FRUIT FOR FUTURE

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Introduction

The Litchi (*Litchi chinensis Sonn*) an important sub-tropical evergreen fruit crop belonging to family *Sapindaceae*, is believed to have originated in China, where it has been grown in Southern Guangdong State for thousands of years. It is highly specific to climatic requirements and probably due to this reason its cultivation is restricted to few countries in the world. In India, Litchi was introduced in the 18th century through Burma, and from there, it spread to many countries. India and China account for 91 per cent of the world Litchi production but it is mainly marketed locally.

Climate and Soil

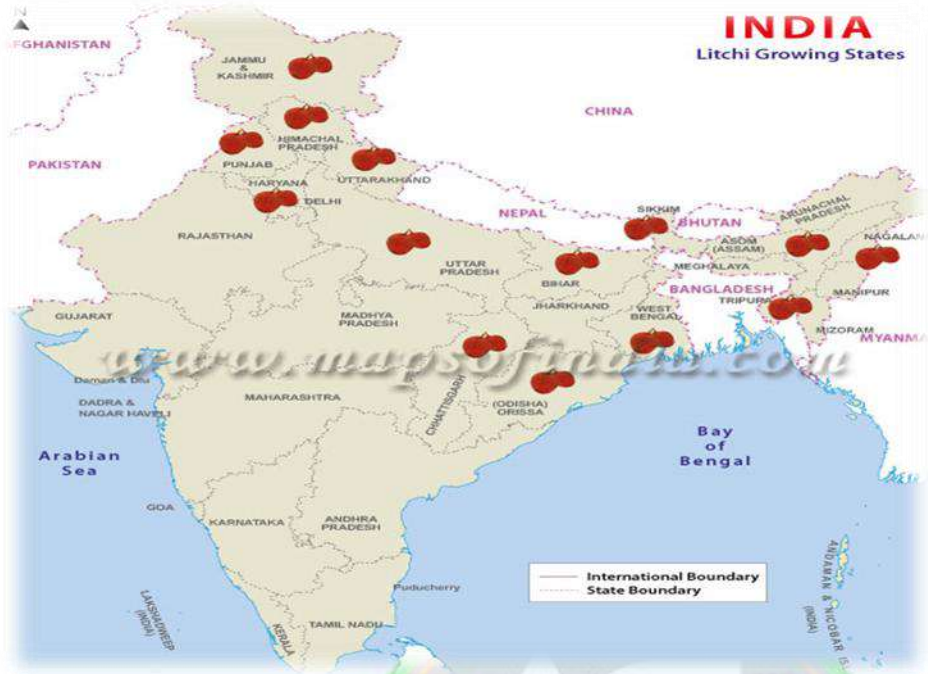
Since, flower bud differentiation, flowering, fruit set, fruit quality and flavour development in Litchi is influenced significantly by temperature and humidity, it has adapted well in the sub-tropics where summer months are hot and wet and winter months are dry and cool. Hot summers free from hot wind and winters free from frost are essential.

Litchi cultivation is highly successful in areas having minimum temperature of 10°C from December to February and 38°C from April to June. However, temperature of 32° C during these months is considered to be optimum. In Litchi growing areas in India the temperature

varies from 21° C to 37.8°C during flowering and fruiting.In India, Litchi is grown successfully on a wide range of soil types, which include sandy loams, laterite, alluvial sand, and calcareous soil, but the best Litchi orchards are seen in alluvial sandy loam soils with good drainage and access to the water table. The performance of orchards is very poor on clay soil with poor drainage. The pH of soils ranges from 6.0 to 7.5.

State-wise Area, Production & Productivity of Litchi

State	Area (Ha.)	Production (MT)	Productivity (MT/Ha.)
Bihar	27.7	221.7	8.0
West Bengal	5.9	61.4	10.5
Assam	4.1	18.7	4.6
Punjab	1.2	11.6	10.0
Orissa	3.5	10.2	2.9
Tripura	1.7	9.0	5.1
Jharkhand	1.5	7.5	5.0
Uttaranchal	7.8	7.5	1.0
Nagaland	0.8	4.0	5.1
Others	4.0	4.5	-
TOTAL	58.2	356.2	6.1



Commercial Cultivars

Shahi	**China**	**Rose Scented**
Mandraji	**Purbi**	**Bombai**

Dehradun	**Early seedless**	**Ajhauli**
Gandaki Smpada	**Gandaki Yogita**	**Gandaki Lalima**

Varietal Distributions of Litchi in Different States in India

States	Varieties
Bihar	Deshi, Purbi, China, Kasba, Bedana, Early Bedana, Late Bedana, Dehra Rose, Shahi, Manragi, Maclean, Longia, Kaselia and Swarna Rupa
Uttar Pradesh	Early Large Red, Early Bedana, Late Large Red, Rose Scented, Late Bedana, Calcuttia, Extra Early, Gulabi, Pickling, Khatti, Dehra Dun, Piyazi
West Bengal	Bombai, Ellaichi Early, China, Deshi, Purbi and Kasba
Haryana / Punjab	Early Seedless, Late Seedless, Seedless-1, Seedless-2

Propagation : Air-layering

Air-layering, known as 'marcottage' in China and 'goottee' in India, is commercially practiced for large scale multiplication. For preparation of the air-layer a healthy terminal branch receiving good sunshine with a thickness of about 1.2-1.5 cm is selected and a 2.5 cm ring is made by removal of bark about 45-50 cm below the apical growth. The cambium layer is rubbed

off and the woody portion is exposed. Rooting hormone (1000 ppm IBA) is used as paste or powder. A layer of moist sphagnum moss or coir pith is placed and wrapped with a piece (20 x 25 cm) of 400 gauge polythene sheet and tied properly at both ends to ensure supply of proper moisture which facilitates the development of roots. After about 50-60 days, the adequate root system develops from the upper end of the ring, which is visible through the polythene film. The layer is removed by making a sharp cut about 5 cm below the lower end of the ring, preferably in 2-3 stages. The detached layers are planted in partial shade. June is considered to be best time for air-layering. In order to enhance the success of the detached layer, defoliation of leaves up to 50 percent is advocated.

Planting

Pits 90 x 90 x 90 cm in dimension are dug at the spacing decided for the orchard. Pit opening is normally recommended in April-May to have a sterilization effect for about 3 days. Before the onset of monsoon pits are filled with topsoil mixed with about 40 kg decomposed compost, 2 kg neem/karanj cake, 1 kg bone meal/single super phosphate and 200-300 g muriate of potash. Incorporation of about 2 baskets of soil from the root zone of old Litchi trees encourages the mycorrhiza growth. Planting is done during June to July. At the time of planting a hole the size of ball of earth is made in the centre of the pit at the marked point where the plant is fixed and the soil is pressed to remove air. Watering is done immediately after planting for proper establishment. Subsequently the plant is regularly irrigated till it is properly established.

Square system at a distance of 9-10 m within and between the rows has been practiced. However, planting of Litchi in a double hedgerow system at a distance of 4.5 x 4.5 x 9 m accommodating 329 plants/ha has been found to be the best and gave higher yield of equally good quality fruits up to 16 years of plantation.

Manure and fertilizer

Among the several factors associated with production of Litchi, balanced nutrition is considered to be the most important which determines productivity and quality. FYM : 60 kg

Application of FYM : 60 kg, 600-800 g N, 200-300 g P_2O_5 and 400-600 g K_2O per plant is recommended for 12-15 year old trees. Nitrogen and Potassium should be applied in 2-3 splits and P_2O_5 in two splits. Excessive application of nitrogenous fertilizer before flowering should be avoided. Phosphorus application at the time of flower bud differentiation improves flowering and

fruiting. In acidic soil application of 10-15 kg lime/tree once in 3 years has been found to increase the yield.

Physiological disorders of litchi

s.R no	Disorder name	Causing by	management
1	Little leaf	Zn deficiency	Aplly ZnSo4
2	Fruit crack	Excess water with high temperature	Irrigate properly, NAA and 2,4,5-T (35-100ppm) are effective in checking fruit splitting and increasing fruit size.
3	Chicken tongue	Embryo abortion	Properly pollinate the plant
4	Sun burn	Direct exposure of sun light	Practice of sod culture

Pests of litchi

s.r no	Disease name	Causal organism	management
1	Fruit fly	*Bactocera dorsalis*	5 gm. trichloroform with 10 ltrs of water
2	Fruit borer	*Cryptophlebia illepida*	fenvolarate @ 0.01%
3	Eriophide mite	*Acaria litchi*	Pruning and apply spinosyn.
4	Bark eating caterpillar	*Inderbella tetragonis*	Plugging the hole with formalin
5	Red rust	algae	Sulphur spray 3 times in autumn and spring.

Harvesting

Depending on the tree age there are four growth phases in litchi plants

- **young non-bearing stage (1-3 years),**

- **young bearing stage (6-10 years),**
- **junior adult bearing stage (11-20 years)**
- **senior adult bearing stage (21 years and above).**
- Harvesting is usually done in **May and June**.

The fruits are harvested in bunches along with a portion of the branch and a few leaves

Yield

The yield of Litchi varies according to the age of the tree, agro-climatic condition and maintenance of the orchard. Usually about 80-150 kg fruit/tree is obtained from 14-16 year old trees. However, from a fully grown tree a yield of 160-200 kg/tree has also been recorded.

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BIOTECHNOLOGY INTERVENTIONS IN DISEASE DIAGNOSIS: ADVANCING PRECISION AND GLOBAL HEALTH

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Abstract

Accurate and timely disease diagnosis is fundamental to effective healthcare delivery and global disease control. Conventional diagnostic approaches, including microscopy and culture-based methods, are often limited by low sensitivity, long turnaround times, and inability to detect early or asymptomatic infections. The advent of biotechnology has revolutionized disease diagnostics by enabling detection at molecular, genetic, and proteomic levels. Advanced tools such as polymerase chain reaction (PCR), next-generation sequencing (NGS), CRISPR-based diagnostics, biosensors, and microarrays have significantly improved diagnostic accuracy, speed, and scalability. These technologies play a critical role in the diagnosis of infectious diseases, cancer, antimicrobial resistance (AMR), and genetic disorders. Furthermore, integration with bioinformatics and artificial intelligence (AI) enhances data interpretation and predictive capabilities. Despite challenges such as high costs, technical complexity, and ethical concerns, continuous advancements are making biotechnology-based diagnostics more accessible and efficient. This article explores the evolution, applications, challenges, and future prospects of biotechnology interventions in disease diagnosis, emphasizing their role in advancing precision medicine and global health.

Keywords

Biotechnology, Disease Diagnosis, PCR, Next-Generation Sequencing, CRISPR, Antimicrobial Resistance, Bioinformatics

1. Introduction

Disease diagnosis is the cornerstone of clinical medicine, influencing therapeutic decisions, patient prognosis, and public health strategies. Historically, diagnosis relied heavily on clinical symptoms and laboratory-based techniques such as microscopy, microbial culture, and serological assays. While these methods have significantly contributed to disease detection, they are inherently limited by low sensitivity, prolonged processing time, and dependence on viable organisms (Lazcka et al., 2007).

One of the major drawbacks of traditional diagnostics is their inability to detect diseases during early or asymptomatic stages. For instance, culture-based methods require viable organisms and may take days to weeks, delaying treatment. Similarly, serological tests often depend on host immune responses, which may not be detectable during early infection stages. These limitations can result in delayed diagnosis, inappropriate treatment, and increased disease transmission, particularly in the context of infectious diseases.

The emergence of biotechnology has transformed this landscape by shifting diagnostics from phenotypic to genotypic and molecular-level detection. Biotechnology encompasses the use of biological systems, living organisms, or their derivatives to develop technological applications. In disease diagnostics, it enables detection of specific biomarkers such as DNA, RNA, proteins, and metabolites, allowing unprecedented sensitivity and specificity.

The importance of biotechnology-based diagnostics has been underscored by global health challenges such as: Emerging and re-emerging infectious diseases (e.g., COVID-19, Zika, Ebola), rising burden of non-communicable diseases such as cancer, rapid spread of antimicrobial resistance (AMR). increasing prevalence of genetic and hereditary disorders. Modern diagnostic technologies allow: Early detection before symptom onset, real-time disease monitoring, personalized treatment strategies, epidemiological surveillance and outbreak tracking

For example, during the COVID-19 pandemic, molecular diagnostics such as RT-PCR enabled large-scale testing and real-time surveillance, significantly contributing to disease containment efforts. Similarly, in oncology, molecular diagnostics facilitate identification of specific genetic mutations, enabling targeted therapies under the framework of precision medicine (Tang et al., 2020; Kevadiya et al., 2021).

Another critical advancement is the integration of high-throughput technologies with computational tools, allowing analysis of vast biological datasets. This convergence of biotechnology with bioinformatics and artificial intelligence has ushered in a new era of data-driven diagnostics, where diseases can be predicted, monitored, and managed with unprecedented accuracy.

Despite these advancements, challenges such as cost, infrastructure requirements, technical expertise, and ethical concerns related to genetic data remain significant barriers, particularly in low-resource settings. Addressing these challenges is essential to ensure equitable access to advanced diagnostic technologies.

This article provides a comprehensive overview of biotechnology interventions in disease diagnosis, covering technological advancements, applications, challenges, and future directions, with a focus on their role in improving global health outcomes.

2. Evolution of Diagnostic Technologies

2.1 Conventional Methods vs Modern Biotechnology

Conventional diagnostic methods—including microbial culture, histopathology, and serology—have long been considered the gold standard in clinical microbiology. However, these approaches are often constrained by: Long incubation periods, limited sensitivity for low pathogen loads, inability to culture fastidious or unculturable organisms, reduced effectiveness in polymicrobial infections

Biotechnology-based diagnostics overcome these limitations by targeting biomolecular signatures such as DNA, RNA, proteins, and metabolites. These methods offer: High sensitivity and specificity, rapid turnaround time, quantitative analysis, early and pre-symptomatic detection, multiplexing capability. The shift from phenotype-based to genotype-based diagnostics represents a paradigm change in modern medicine (Ritchie et al., 2021)

3. Key Biotechnology Tools in Disease Diagnosis

3.1 Polymerase Chain Reaction (PCR)

The Polymerase Chain Reaction (PCR), developed by Mullis and Faloona (1987), remains a cornerstone of molecular diagnostics. It enables exponential amplification of specific DNA sequences, allowing detection of extremely low quantities of nucleic acids.

Recent advancements include:

- Real-time PCR (qPCR): Enables quantitative measurement of nucleic acids

- Reverse Transcription PCR (RT-PCR): Essential for RNA virus detection
- Digital droplet PCR (ddPCR): Provides absolute quantification with high precision
- PCR has been instrumental in diagnosing diseases such as tuberculosis, HIV and COVID-19. Its rapid adaptability makes it ideal for emerging pathogens (Corman et al., 2020).

3.2 Next-Generation Sequencing

Next-Generation Sequencing (NGS) technologies have revolutionized genomics by enabling massively parallel sequencing of DNA and RNA.

Key advantages:

- High throughput
- Comprehensive genome coverage
- Detection of novel and rare variants
- Simultaneous analysis of multiple pathogens

Applications:

- Whole genome sequencing (WGS) for pathogen characterization
- Metagenomics for detecting unculturable organisms
- Cancer genomics for mutation profiling
- AMR gene identification
- NGS plays a critical role in genomic epidemiology, enabling tracking of disease outbreaks and transmission pathways.

3.3 CRISPR-Based Diagnostics

CRISPR-based systems such as SHERLOCK (Specific High-sensitivity Enzymatic Reporter unlocking) and DETECTR (DNA Endonuclease-Targeted CRISPR Trans Reporter) have emerged as powerful diagnostic tools due to their ability to detect nucleic acids with exceptional specificity.

Mechanism:

- CRISPR-associated enzymes (Cas12, Cas13) recognize target sequences
- Collateral cleavage activity generates detectable signals

Advantages:

- Ultra-high specificity
- Rapid detection (within minutes)

- Minimal instrumentation
- Suitability for point-of-care testing
- CRISPR diagnostics have shown great promise in detecting viral infections, including SARS-CoV-2, dengue, and Zika (Broughton et al., 2020; Fozouni et al., 2021).

3.4 Biosensors and Nanotechnology

Biosensors integrate biological recognition elements (e.g., enzymes, antibodies, nucleic acids) with physicochemical transducers to detect analytes.

- Nanotechnology enhances biosensors by:
- Increasing surface area for binding
- Improving sensitivity and signal amplification
- Enabling miniaturization and portability

Examples:

- Glucose biosensors for diabetes management
- Gold nanoparticle-based pathogen detection
- Lab-on-a-chip systems for multiplex diagnostics
- Recent developments include electrochemical and optical nanosensors capable of real-time disease monitoring.

3.5 Microarrays

DNA microarrays allow simultaneous analysis of thousands of genes, providing a global view of gene expression and genetic variation.

Applications:

- Detection of mutations and SNPs
- Cancer classification and prognosis
- Identification of virulence and resistance genes
- Comparative genomics
- Although partially replaced by NGS, microarrays remain valuable for high-throughput screening and gene expression studies.

4. Applications in Disease Diagnosis

4.1 Infectious Diseases

Biotechnology has revolutionized infectious disease diagnostics by enabling rapid, accurate,

and early detection.

- PCR and RT-PCR: rapid pathogen identification
- NGS: detection of novel and emerging pathogens
- CRISPR: portable and rapid diagnostics
- These tools are critical for outbreak management, surveillance, and pandemic preparedness (Tang et al., 2020).

4.2 Cancer Diagnosis

Biotechnology has transformed oncology diagnostics through molecular profiling and biomarker detection.

Key advancements:

- Liquid biopsy for detecting circulating tumor DNA (ctDNA)
- NGS for identifying oncogenic mutations
- Microarrays for tumor classification
- These approaches support precision oncology, allowing personalized treatment strategies (Wan et al., 2017; Heitzer et al., 2019).

4.3 Antimicrobial Resistance (AMR)

AMR is a major global health threat requiring rapid and precise diagnostics.

Biotechnology enables:

- Detection of resistance genes (e.g., *bla, mecA, mcr*)
- Surveillance of resistant strains
- Phylogenetic tracking of transmission
- Whole genome sequencing (WGS) provides comprehensive insights into resistance mechanisms and evolution (Didelot et al., 2012; WHO, 2023).

4.4 Genetic Disorders

Molecular diagnostics allow early detection and management of inherited disorders.

Examples:

- Cystic fibrosis
- Thalassemia
- Sickle cell anemia

- Technologies such as PCR, NGS, and prenatal screening enable carrier detection, newborn screening, and genetic counseling (Rehm, 2017).

5. Point-of-Care Diagnostics

Point-of-care (POC) diagnostics bring testing closer to patients, improving accessibility and reducing turnaround time.

Advantages:

- Rapid results
- Minimal infrastructure
- User-friendly design
- Suitability for remote settings

Examples:

- Lateral flow assays
- Portable PCR devices
- Smartphone-integrated biosensors
- POC diagnostics are essential for resource-limited settings and outbreak control (Kozel et al., 2017).

6. Integration with Bioinformatics and Artificial Intelligence

Modern diagnostics generate large-scale data requiring computational analysis.

- Sequence alignment and genome assembly
- Variant detection
- Functional annotation
- Phylogenetic analysis
- Pattern recognition in imaging and genomics
- Disease prediction models
- Clinical decision support
- AI-driven diagnostics improve accuracy, reduce human error, and enable predictive medicine (Topol, 2019; Rajpurkar et al., 2022).

7. Challenges in Biotechnology-Based Diagnostics

✓ Advanced technologies such as NGS and CRISPR diagnostics remain expensive, limiting widespread adoption in low-resource settings.

- ✓ Highly skilled personnel are required for operation, data analysis, and interpretation.
- ✓ Genomic data raises issues related to data security, consent, and misuse.
- ✓ Lack of standardized protocols and regulatory frameworks can affect reproducibility and clinical implementation.

8. Future Perspectives

The future of biotechnology in diagnostics is driven by innovation and interdisciplinary integration.

- ✓ Development of low-cost, portable diagnostic devices
- ✓ Integration of AI and machine learning
- ✓ Use of wearable biosensors for continuous monitoring
- ✓ Expansion of personalized and precision medicine
- ✓ Rapid diagnostics for emerging pathogens
- ✓ Advances in synthetic biology and nanomedicine

Technologies such as single-cell sequencing, CRISPR-based point-of-care tools, and digital health platforms are expected to redefine disease diagnostics (Collins & Varmus, 2015; Hood & Flores, 2022).

Conclusion

Biotechnology has revolutionized disease diagnosis by enabling rapid, accurate, and early detection of diseases at the molecular level. Tools such as PCR, NGS, CRISPR, biosensors, and microarrays have significantly enhanced diagnostic capabilities across infectious diseases, cancer, genetic disorders, and antimicrobial resistance.

Despite challenges related to cost, expertise, and ethical concerns, ongoing advancements are making these technologies more accessible and efficient. The integration of biotechnology with bioinformatics and artificial intelligence is paving the way for precision medicine and improved global health outcomes.

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COMPARATIVE ANALYSIS OF WATER FOOTPRINT IN DRY DIRECT SEEDED RICE

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Abstract

Rice (*Oryza sativa L.*) is a primary staple food supporting more than half of the global population. However, its cultivation is highly water-intensive and increasingly constrained by declining water resources, labour shortages and climate change. This article presents a comparative analysis of the water footprint (WF) of rice under different establishment methods, with a special focus on Dry Direct Seeded Rice (DSR). The study highlights the potential of DSR in reducing blue water consumption, enhancing green water utilization and improving sustainability in rice production systems.

Keywords: Rice, Water Footprint, Direct Seeded Rice, Blue Water, Green Water, Sustainability, Climate Smart Agriculture.

1. Introduction

Rice is cultivated on approximately 47–50 million hectares in India, producing about 138 million tonnes annually. With projected demand expected to increase over 43% by 2050, enhancing resource-use efficiency is essential. Traditional puddled transplanted rice (PTR) systems are becoming unsustainable due to high water requirements, labour intensity and greenhouse gas emissions.

Alternative crop establishment methods such as Direct Seeded Rice (DSR), semi-dry rice and System of Rice Intensification (SRI) are gaining importance as climate-resilient technologies. These systems reduce water use, labour demand and methane emissions while ensuring timely crop establishment.

2. Water Requirement in Rice Cultivation

Rice cultivation is one of the most water-intensive agricultural practices, requiring between 800 and 5,000 liters of water per kilogram of grain, with an average of about 2,500 liters.

2.1 Seasonal Water Requirement

- Total water requirement: 1,000–2,000 mm per crop season
- Daily requirement: 6–10 mm
- Water use distribution:
    - 30% for land preparation
    - 40% for crop growth
    - Remaining losses through seepage, percolation and evaporation

2.2 Factors Influencing Water Requirement

- Soil texture (higher in sandy soils)
- Crop duration (100-day vs. 150-day varieties)
- Climatic conditions (temperature and evaporation)

3. Rice Establishment Methods and Water Use

Rice cultivation methods significantly influence water consumption:

3.1 Conventional Transplanted Rice (PTR)

- Requires continuous flooding
- Water requirement: 1,000–2,000 mm
- High percolation and evaporation losses

3.2 Dry Direct Seeded Rice (DSR)

- Seeds are sown directly in dry soil
- Eliminates puddling, saving 100–300 mm water
- Relies more on rainfall (green water)

3.3 Wet Direct Seeded Rice

- Pre-germinated seeds sown in puddled soil
- Moderate water requirement

3.4 System of Rice Intensification (SRI)

- Maintains moist soil instead of flooding
- Saves 40–50% water

4. Water Footprint Concept in Rice

The water footprint (WF) represents the total volume of freshwater used and polluted during crop production. It consists of three components:

- **Green Water Footprint:** Rainwater stored in soil and used by crops
- **Blue Water Footprint:** Surface and groundwater used for irrigation
- **Grey Water Footprint:** Water required to dilute pollutants

Globally, the average water footprint of rice is about 1325 m^3/ton, comprising 48% green, 44% blue and 8% grey water.

Methodology for Water Footprint Estimation

Water footprint estimation is based on the methodology proposed by Hoekstra *et al*. (2009):

WF (m^3/ton) = Total water use (m^3/ha) / Yield (ton/ha)

Tools like the CROPWAT model are used to estimate crop evapotranspiration (ETc) and effective rainfall. The distinction between green and blue water is made based on rainfall and irrigation contributions.

5. Comparative Water Footprint Analysis

5.1 Transplanted Rice (PTR)

- Total WF: ~1071–1673 m³/ton
- Blue water contribution: up to 68%
- Heavy dependence on irrigation
- Higher percolation losses

5.2 Dry Direct Seeded Rice (DSR)

- Total WF: ~953.8 m³/ton
- Blue water reduced to ~27%
- Green water increased to ~53%
- Saves 25–40% irrigation water

5.3 Key Observations

- DSR reduces groundwater dependency
- Enhances rainfall utilization
- Minimizes seepage and percolation losses

6. Water Management Strategies

6.1 Stage-wise Water Management

1. **Establishment Stage:** 2 cm water depth
2. **Vegetative Stage:** 5 cm or AWD practice
3. **Reproductive Stage:** Critical for yield
4. **Ripening Stage:** Irrigation stopped 15 days before harvest

6.2 Water-Saving Technologies

- **Alternate Wetting and Drying (AWD):** Saves ~30% water
- **Drip Irrigation:** Saves up to 60% water
- **Aerobic Rice Systems:** Minimal water requirement

7. Environmental and Sustainability Implications

7.1 Groundwater Depletion

Excessive irrigation in regions like Punjab has led to severe groundwater decline.

7.2 Climate Change Impact

- Temperature rise increases water demand by 0.6–3.7%
- Increased evapotranspiration

7.3 Methane Emissions

Flooded rice fields contribute nearly 12% of global methane emissions, whereas DSR significantly reduces emissions.

8. Role of DSR in Enhancing Water Productivity

Dry Direct Seeded Rice improves water productivity by:

- Eliminating puddling losses
- Increasing effective rainfall use
- Reducing irrigation demand
- Lowering production costs

It also supports climate-resilient agriculture by reducing greenhouse gas emissions and conserving water resources.

Conclusion

The comparative analysis clearly indicates that Dry Direct Seeded Rice (DSR) has a significantly lower water footprint than conventional transplanted rice systems. By reducing dependence on blue water and enhancing green water utilization, DSR emerges as a sustainable and climate-smart alternative for future rice production. Adoption of DSR, along with improved agronomic practices can substantially reduce water consumption, improve productivity, and ensure long-term sustainability of rice-based farming systems.

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FROM WASTE TO WORTH: UPCYCLING FOOD BY-PRODUCTS IN MODERN FOOD PROCESSING

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Introduction

Almost one-third of the food produced worldwide is lost or wasted each year, posing serious problems for the environment, the economy, and society. Food waste increases global food insecurity, wastes important natural resources, and makes a substantial contribution to greenhouse gas emissions. As a result, the food sector is adopting more creative methods to turn food waste into useful resources. Proteins, dietary fibre, and polyphenols are among the useful substances found in food waste that can be collected and used in functional food systems. Food upcycling, which is the act of turning food waste, surplus resources, or byproducts into useful ingredients that may be used in new food products, is one of the most promising strategies.

Food waste is produced at various phases, including domestic use, food service and hospitality, retail and distribution, food processing, and agricultural production. Food waste can now be transformed into biofuels, bioplastics, high-value nutraceuticals, fertilisers, animal feed, and bioactive chemicals thanks to technological advancements like precision fermentation and bioconversion technologies. Many of these materials were either thrown away or used as cheap animal feed in the past. However, studies have revealed that these by-products frequently include high concentrations of proteins, vitamins, minerals, antioxidants, dietary fibre, and bioactive substances. Recovering these elements can enhance food systems' sustainability and nutritional value.

Fruit and vegetable pomace, the residue left over after juice extraction, is one of the most popular examples of food upcycling. Pomace from apples, carrots, grapes, and tomatoes is high in fibre and polyphenols and can be added to baked goods, snacks, and drinks to increase their

nutritional value. Similarly, high-fiber flours, protein bars, and meat substitutes are increasingly using brewer's waste grain, a by-product of the brewing industry that is rich in protein and insoluble fibre. Okara, the soybean pulp produced during the manufacturing of soy milk and tofu, is another noteworthy example. Okara, which was once thought of as waste, is now used in baked goods, meat substitutes, and functional food formulations as a great source of fibre and protein. Likewise, whey, a by-product of cheese manufacturing, has evolved from a disposal challenge into a highly valued ingredient in sports nutrition, dairy beverages, and infant formula due to its high-quality protein content.

This change is being propelled by modern technologies that make it possible to effectively collect and stabilise nutrients from food waste. While fermentation can improve the flavour, digestibility, and bioavailability of minerals, processes like drying and milling turn by-products into powders that are shelf-stable. The potential to transform waste streams into novel food ingredients with desired functional qualities is increased by extraction techniques. In addition to assisting businesses in lowering raw material costs and increasing process efficiency, upcycled ingredients promote the creation of wholesome and sustainable foods. Additionally, they meet the growing demand from consumers for clean-label and ecologically friendly products. Food upcycling thus supports the more general idea of a circular economy, in which resources are constantly recycled rather being thrown away.

Food upcycling has a number of obstacles despite its potential. Widespread adoption may be hampered by variations in the mix of raw materials, worries about food safety and shelf life, legal issues, and customer attitudes. Industries must make investments in transparent labelling, standardised processing techniques, and consumer education to overcome these obstacles and increase consumer confidence in upcycled goods.

food waste streams and potential for valorization value-added applications

Sector	Types of Waste	Potential Valorization Products
Agricultural Production & Post-Harvest Handling	Unharvested crops, damaged produce, spoilage during storage & transport	Animal feed, compost, biochar, biogas, organic fertilizers
Cereal and Pulse Processing	Bran, germ, husks, spent grains	Functional fibers, prebiotics, protein concentrates, biopolymers,

		biodegradable packaging
Fruit and Vegetable Sector	Peels, pulp, spoiled produce	Natural antioxidants, polyphenols, dietary fiber, biofilms, food colorants, edible coatings.
Meat Industry	Meat Industry	Enzymatic hydrolysates, collagen, bioactive peptides, biofertilizers.
Dairy Sector	Spoiled milk, whey, yogurt whey, substandard milk	Whey proteins, lactose-derived bioactives, fermented beverages, peptides, lactic acid, ethanol
Aquatic & Seafood Industry	Heads, skins, bones, shells, off-cuts	Fish collagen, gelatin, bioactive peptides, chitosan/chitin, fish oil, protein hydrolysates
Fats and Oils Sector	Oilseed cakes, refining residues, gums, soap stocks	Protein isolates, bioplastics, functional lipids, antioxidant-rich extracts, animal feed, bio-lubricants.

Polyphenols are a diverse group of bioactive compounds abundantly present in various food waste materials, particularly those generated by the fruit and vegetable industries, such as peels, seeds, skins, and pomace. These compounds exhibit potent antioxidant, anti-inflammatory, and antimicrobial activities, making them attractive for applications in functional foods, nutraceuticals, and pharmaceuticals. Astaxanthin, a potent xantophyll carotenoid with robust antioxidant, anti-inflammatory, and immunomodulatory properties, is predominantly found in the exoskeletons and cephalothorax of crustacean processing waste such as shrimp, crab, and lobster shells.

There are some novel extraction techniques like Enzyme-assisted extraction, ultrasound probe extraction, high-pressure processing, microwave extraction, pulse electric field, supercritical fluid extraction, deep eutectic solvents (DES) extraction and cold pressing to extract the bio- active compounds from food waste such as protein, lipid, dietary fiber, vitamin, mineral, carbohydrate and polyphenols. A more targeted selection of extraction methods based on

compound-specific characteristics can significantly improve yield, quality, and bioactivity retention, thereby enhancing the industrial potential of these bio-waste-derived extracts.

Cold pressing is a non-thermal, mechanical extraction method primarily used to recover oils and other bioactive compounds from food waste matrices without applying external heat. This technique is widely applied in the valorization of oil-rich food by-products, such as mango kernels, jackfruit seeds, avocado peels, and olive pomace, producing nutrient-dense oils with minimal oxidative damage.

Adding ingredients made from food waste to baked goods is a creative way to boost functional qualities and nutritional worth.These substances add to the texture, flavour, and shelf life of baked goods in addition to enhancing their health advantages. In addition to supporting sustainability objectives, this makes it possible to create next-generation functional meals that can satisfy environmental and consumer health demands. Adding antioxidants high in polyphenols, especially those derived from food waste, has two benefits: it increases shelf life and fits in with clean-label and sustainable trends. In addition to satisfying customer desire for healthier delicious foods, this valorisation technique advances the objectives of the circular bioeconomy.

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APPLICATION OF eDNA IN FISH DISEASE DIAGNOSIS

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Abstract

Environmental DNA (eDNA) has emerged as a powerful, non-invasive tool for monitoring aquatic ecosystems and diagnosing fish diseases. This technique involves the detection of genetic material shed by organisms, including fish and their associated pathogens, into environmental matrices such as water, sediment, and biofilms. In aquaculture, where disease outbreaks caused by bacteria, viruses, fungi, and parasites can lead to significant economic losses, eDNA offers a rapid, sensitive, and efficient alternative to conventional diagnostic methods. Unlike traditional approaches that require handling or sacrificing fish, eDNA enables continuous surveillance with minimal stress to aquatic organisms.The standard eDNA workflow includes sample collection, filtration, DNA extraction, amplification using PCR-based methods, and sequencing for accurate identification. Advanced molecular techniques such as quantitative PCR (qPCR), droplet digital PCR (ddPCR), and metabarcoding further enhance detection sensitivity and allow simultaneous identification of multiple pathogens. eDNA has demonstrated its effectiveness in early disease detection, outbreak prediction, and monitoring of pathogen dynamics in aquaculture systems.Despite challenges such as DNA degradation, environmental influences, and potential contamination, eDNA remains a promising tool for sustainable aquaculture management. Its ability to provide early warning signals and comprehensive pathogen profiling highlights its growing importance in fish disease diagnosis and aquatic health monitoring.

Keywords: eDNA,Water samples, Quantitative PCR, droplet digital PCR, Fish diseases.

Introduction

Environmental DNA (eDNA) technology has gained significant attention in recent years due to advancements in molecular techniques for DNA recovery, amplification, and sequencing from environmental samples. It has emerged as a powerful tool in modern ecological and aquaculture studies, enabling researchers to detect species presence, estimate population size, and analyze spatial distribution without direct organism capture. Traditionally, such assessments were challenging using conventional survey methods.The foundation of eDNA applications was initially laid in fisheries and aquaculture research. Its non-invasive nature and ability to provide detailed insights into aquatic ecosystems have made it highly valuable. By analyzing genetic material shed by organisms into their surroundings, researchers can assess biodiversity, monitor ecosystem health, and detect the presence of various species, including fish, parasites, bacteria, and fungi.With the increasing global demand for fish and the need to ensure food security, the development of advanced pathogen detection methods has become essential.

Aquaculture systems are highly vulnerable to infections caused by bacteria, viruses, and fungi, making early diagnosis and continuous health monitoring crucial. Conventional diagnostic approaches are often time-consuming and labor-intensive, especially when large numbers of samples are involved. In contrast, eDNA-based techniques use target-specific primers to amplify pathogen DNA, which can then be identified through sequencing, offering rapid and sensitive detection.The integration of high-throughput sequencing technologies, particularly third-generation sequencing, has further enhanced the efficiency of eDNA as a bio-monitoring tool. eDNA refers to small fragments of DNA or RNA released by organisms into environmental matrices such as water, soil, sediment, and air. Among these, DNA is more stable than RNA, making it easier to detect under most environmental conditions. While DNA degradation may take thousands of years in frozen environments, it typically persists for only a few weeks in aquatic systems.The standard workflow of eDNA analysis includes sample collection, filtration, DNA extraction, purification, polymerase chain reaction (PCR) amplification, and sequencing. These methods allow accurate detection of both single species and entire communities, including rare, cryptic, or low-abundance organisms that are otherwise difficult to identify.eDNA technology also plays a critical role in detecting harmful organisms such as pathogens and toxic algae, which can impact aquaculture productivity and water quality. Additionally, it is

increasingly used to monitor antibiotic resistance genes (ARGs), which are of growing concern due to the extensive use of antibiotics in aquaculture practices.

Environmental factors such as temperature, pH, UV radiation, oxygen levels, and microbial activity influence the persistence and degradation of eDNA in aquatic environments. Smaller DNA fragments tend to persist longer, making fragment size an important consideration in eDNA studies. Regular monitoring using eDNA metabarcoding can help identify potentially harmful organisms early, thereby preventing disease outbreaks and reducing economic losses.Overall, eDNA technology represents a significant advancement in ecological monitoring and aquaculture management. Its ability to provide rapid, accurate, and non-invasive assessment of biodiversity and pathogen presence highlights its importance as a modern tool for sustainable aquaculture and environmental conservation.

eDNA:

- Environmental DNA (eDNA) refers to the genetic material (DNA/RNA) shed by fish, or by their pathogens (bacteria, viruses, fungi, parasites), into the aquatic environment—including water, sediments, and biofilm—without direct isolation of the host animal.
- In fish disease monitoring, eDNA is generally defined as the nucleic acids of pathogenic agents or host tissues extracted from environmental samples.

Benefits of eDNA methods for the detection of Aquatic Animal pathogenic agents:

eDNA detection is a promising tool that can be used to complement direct sampling of aquatic animals for surveillance. eDNA methods offer some benefits compared to direct sampling and testing of aquatic animals, including,

- eDNA methods do not require intrusive or lethal sampling of aquatic animal hosts. They may be particularly useful for rare or valuable aquatic animals, or difficult to collect wild animals.
- eDNA methods do not require handling of animals, avoiding the stress associated with obtaining non-destructive tissue samples.
- Sample collection and sample processing time and associated costs may be reduced substantially compared to collection and processing of individual animal samples.
- As environmental samples may contain analyte from the entire, or a large percentage of a target captive population, many fewer samples may be required to detect a pathogenic

agent (compared to individual animal samples), even when diagnostic sensitivity of the eDNA method is low.

Overview of eDNA Technology:

Environmental DNA (eDNA) technology involves a series of systematic steps, including sample collection, DNA extraction, amplification, and sequencing. These steps form the foundation for detecting and analyzing genetic material present in environmental samples.The process begins with the collection of samples from the environment, typically water or soil, depending on the study area. These samples contain DNA fragments released by organisms through processes such as excretion, secretion, or decomposition. Following collection, specialized laboratory procedures are used to extract and purify the DNA from the samples, ensuring that the environmental DNA is isolated effectively.

Once extracted, specific regions of the DNA that serve as genetic markers are amplified using Polymerase Chain Reaction (PCR). This step is crucial for increasing the quantity of target DNA, making it easier to detect and analyze. With the advancement of high-throughput and next-generation sequencing technologies, it is now possible to analyze multiple genetic markers simultaneously within a single sample. The obtained DNA sequences are then compared with reference databases to identify the species present in the sampled environment.

Additionally, quantitative analysis can provide insights into species abundance, helping to determine whether particular organisms are common or rare. Due to its high sensitivity, eDNA technology can detect elusive, rare, or cryptic species that are often missed by conventional survey methods. Moreover, it allows real-time monitoring of changes in species diversity due to its high temporal resolution. eDNA technology has wide applications in ecological research, including biodiversity assessment, conservation biology, and monitoring of aquatic ecosystems. It enables researchers to track endangered species, identify disease-causing organisms, and assess the impact of human activities on natural habitats. Furthermore, eDNA can be used in dietary and trophic studies through metabarcoding techniques, eliminating the need for direct observation or traditional stomach content analysis.

Despite its advantages, eDNA technology faces several challenges. Issues such as contamination, DNA degradation, and variability in DNA shedding rates among species can affect the accuracy of results. Environmental factors, including temperature, pH, microbial activity, and UV radiation, also influence the persistence and detectability of eDNA. In marine

ecosystems, the large volume of water can dilute and disperse eDNA, making detection more difficult compared to freshwater systems. The concentration of eDNA in aquatic environments depends on species diversity, organism abundance, and the rate of DNA degradation influenced by both biotic and abiotic factors. Therefore, further research is required to standardize methodologies, improve accuracy, and establish strict quality control measures. Overall, eDNA technology represents a powerful and innovative approach for studying ecosystems, offering significant potential for advancing biodiversity monitoring and sustainable environmental management.

eDNA detection of fish pathogens:

A key application of eDNA in aquaculture is the detection of fish pathogens. Fish farms are highly susceptible to disease outbreaks due to high stocking densities, environmental stress, and pollution. Pathogens such as bacteria, viruses, and parasites can cause severe economic losses. eDNA technology provides a rapid, sensitive, and non-invasive method for detecting these pathogens in water without the need to capture or sacrifice fish.

Bacteria release DNA into the environment through processes such as cell lysis or active secretion. Similarly, viral DNA and RNA can be detected using eDNA and environmental RNA (eRNA) techniques. Although fungal detection is comparatively less developed, eDNA still offers potential for identifying fungal pathogens present in aquatic systems. This method enables early detection of infections, allowing timely intervention and disease management.

Traditionally, disease diagnosis required the collection and examination of fish, which was time-consuming, invasive, and stressful to the organisms. In contrast, eDNA-based monitoring allows continuous surveillance of aquaculture systems with minimal disturbance. It provides a comprehensive overview of pathogen diversity and disease prevalence in a given water body.

Molecular methods used in eDNA-based fish disease diagnosis:

Two main molecular approaches dominate this field. The first is species-specific quantitative PCR (qPCR), where primers are designed to amplify DNA from a single target pathogen. This has been successfully applied to detect parasites like *Gyrodactylus salaris* in Norwegian rivers, the oomycete *Saprolegnia parasitica* in aquaculture environments, and the myxozoan *Ceratonova shasta* in California streams. A newer refinement is droplet digital PCR (ddPCR), which Rusch et al. (2018) showed outperforms qPCR in specificity for *G. salaris*

detection by eliminating cross-amplification of closely related species.

The second approach is eDNA metabarcoding, which uses universal primers and high-throughput sequencing to detect multiple species simultaneously. Sieber et al. (2023) demonstrated this by simultaneously monitoring four different aquatic pathogens — *Aphanomyces astaci*, *Batrachochytrium dendrobatidis*, *Saprolegnia parasitica*, and *Tetracapsuloides bryosalmonae* — across 280 sites in Switzerland from water samples alone. Peters et al. (2017) benchmarked Illumina and Ion Torrent sequencing platforms for eDNA-based pathogen detection in salmon aquaculture and found both equally effective at identifying parasite species like sea lice (*Lepeophtheirus salmonis*) and amoebic gill disease agent (*Paramoeba perurans*).

Case studies: eDNA in action for specific fish diseases:

Viral diseases: One of the most compelling field applications comes from Kawato et al. (2021), who monitored Red Sea Bream Iridovirus (RSIV) eDNA in a Japanese fish farm over three years. They detected viral eDNA in seawater at least 5 days before a disease outbreak occurred in juveniles, and viral loads in the water correlated closely with daily mortality rates, peaking at 10^6 copies per liter during outbreaks. Critically, they discovered that asymptomatic broodstock were shedding virus — the eDNA load near broodstock pens (10^5 copies/L) was actually higher than near juvenile pens (10^4 copies/L) just before the outbreak, identifying the broodstock as the infection source.

Parasitic diseases: Duan et al. (2025) used eDNA/eRNA extracted from tank water to track *Ichthyophthirius multifiliis* (white spot disease) in experimentally infected rainbow trout. The pathogen's eDNA signal peaked at the onset of mortality (10 days post-challenge), and a Ct value of 18–25 was identified as indicating a critical disease threat. For Proliferative Kidney Disease (PKD) caused by *Tetracapsuloides bryosalmonae*, Duval et al. (2021) developed a method detecting parasite DNA in fish urine, allowing them to map infection prevalence across 50 sites in the French Pyrenees without sacrificing fish.

Bacterial diseases: Henard et al. (2025) tracked *Yersinia ruckeri* eDNA during experimentally induced Enteric Redmouth Disease in rainbow trout. The eDNA signal was significantly elevated by 3 days post-infection, though notably clinical signs appeared even earlier (1 day post-infection), suggesting eDNA may not always outpace visual diagnosis for bacterial pathogens. They also found that when fish were immunocompromised by handling stress, mortality

increased without corresponding changes in the water eDNA profile — highlighting a limitation of relying on eDNA alone.

Microsporidian diseases: Schuster et al. (2022) validated an eDNA water assay for *Pseudoloma neurophilia* in zebrafish research facilities. The parasite was detectable in water immediately after exposure through week 4, became undetectable, then reappeared sporadically — likely reflecting the parasite's lifecycle. The assay was validated at the Zebrafish International Resource Center for routine surveillance.

Procedure for eDNA detection of fish pathogens:

1. Sample Collection:

- Water samples are collected from aquaculture systems such as ponds, lakes, rivers, or tanks.
- Typically 1–2 L of water is collected for analysis.
- Samples may be taken from different depths (surface, mid, bottom) depending on study design.
- Use sterile bottles; avoid contamination by using gloves and disinfected equipment.
- Samples are kept cold and transported to the laboratory quickly (within a few hours).

2. Filtration of Water Sample:

- Water samples are filtered to concentrate eDNA.
- Filtration is done using membrane filters (commonly 0.22–0.45 µm pore size).
- Filtration should be performed on the same day of sampling.
- The filter traps DNA fragments released by pathogens (from mucus, feces, tissues, etc.).

3. DNA Extraction:

- DNA is extracted from the filter using commercial extraction kits or standard protocols.
- Cell lysis is performed to release DNA from trapped material.
- Purification steps remove inhibitors and contaminants.
- Extracted DNA is collected as purified eDNA.

4. Amplification of Target DNA:

Specific pathogen DNA is amplified using molecular techniques:

- PCR (Polymerase Chain Reaction)
- qPCR (Quantitative PCR)
- ddPCR (Droplet digital PCR)

- Primers specific to fish pathogens (bacteria, viruses, parasites) are used.

5. Detection and Quantification:

- Amplified DNA is analyzed to confirm pathogen presence:
- Gel electrophoresis (for PCR products)
- Fluorescence detection (qPCR/ddPCR)
- Quantification helps estimate pathogen load in water.

6. Sequencing / Confirmation:

Positive samples may be confirmed by:

- DNA sequencing (e.g., Sanger sequencing)
- Metabarcoding (for multiple pathogens)

7. Data Interpretation:

- Presence/absence of pathogen is determined.
- Results help in: Disease surveillance, Early outbreak prediction, Aquaculture management decisions

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THE BERMUDA TRIANGLE: A SCIENTIFIC EVALUATION OF OCEANIC MYSTERIES

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Abstract

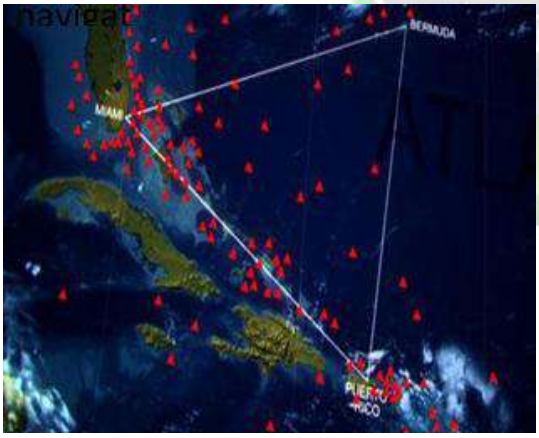
The Bermuda Triangle is a region in the western part of the North Atlantic Ocean that has gained global attention due to reports of mysterious disappearances of ships and aircraft. Bounded by Florida, Bermuda, and Puerto Rico, this area has been widely associated with myths, supernatural theories, and unexplained phenomena. This article examines the historical background of the Bermuda Triangle, including notable incidents such as the Flight 19 disappearance, and analyzes various explanations proposed over time. While popular theories include magnetic anomalies and the existence of lost civilizations like Atlantis, scientific evidence points to natural causes such as extreme weather conditions, strong ocean currents like the Gulf Stream, and human error. The study highlights that the frequency of accidents in this region is not significantly higher than in other busy oceanic zones. Overall, the Bermuda Triangle represents a compelling case where myth and science intersect, emphasizing the importance of scientific investigation in understanding oceanic phenomena.

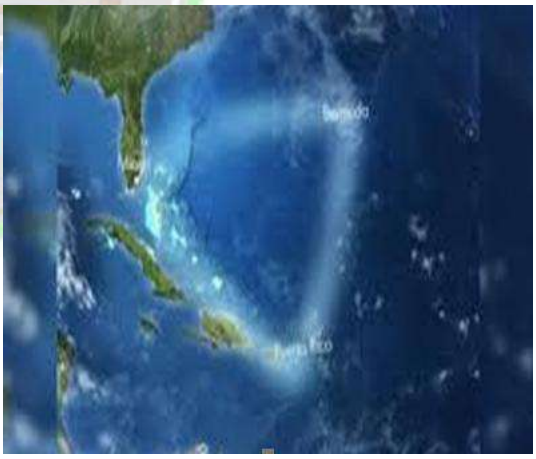
Keywords

Bermuda Triangle, Oceanography, Marine Environment, Ship Disappearances, Aircraft Accidents, Weather Extremes, Ocean Currents, Gulf Stream, Methane Hydrates, Magnetic Variations, Navigation Errors, Human Factors, Marine Safety

Introduction

The Bermuda Triangle is a widely discussed region of the North Atlantic Ocean, known for its association with the unexplained disappearance of ships and aircraft. Geographically, it forms a triangular area bounded by Florida, Bermuda, and Puerto Rico. Over the past century, numerous incidents reported within this region have attracted global attention, giving rise to a mixture of myths, speculation, and scientific inquiry. While early interpretations often attributed these disappearances to supernatural forces or unexplained phenomena, modern research emphasizes scientific explanations based on oceanographic and atmospheric processes. Factors such as rapidly changing weather conditions, strong ocean currents, magnetic variations, and human error are now recognized as key contributors to many of these incidents. Notable cases, including the Flight 19 disappearance, have been re-examined to better understand the interplay between environmental conditions and navigational challenges. This article aims to present a scientific overview of the Bermuda Triangle by analyzing the natural and human-induced factors responsible for reported events. By moving beyond myths and focusing on evidence-based explanations, it highlights the importance of marine science in understanding complex oceanic regions and ensuring safer





BERMUDA TRIANGLE

Geographical Setting of the Bermuda Triangle

The Bermuda Triangle is a loosely defined region in the western part of the North Atlantic Ocean, forming an imaginary triangle between Florida, Bermuda, and Puerto Rico. Although widely discussed in scientific and popular literature, it is important to note that this

area is not officially recognized by any international maritime organization as a distinct geographic boundary. This region covers a vast expanse of ocean characterized by deep waters, complex seabed topography, and dynamic environmental conditions. The seafloor in this area includes continental shelves, steep slopes, and deep ocean basins, which influence ocean circulation patterns. One of the most significant features of this region is the presence of the Gulf Stream, a strong and warm ocean current that flows rapidly from the Gulf of Mexico across the Atlantic Ocean. This current plays a crucial role in regulating climate but also contributes to swift movement of water masses, which can complicate navigation and recovery of debris.

The Bermuda Triangle is also one of the busiest routes for international shipping and aviation. Numerous commercial vessels and aircraft pass through this region daily, connecting North America, South America, and Europe. Due to this heavy traffic, the probability of accidents or incidents is naturally higher compared to less frequented areas. Additionally, the region is influenced by tropical and subtropical climatic conditions. It is prone to hurricanes, cyclones, and sudden weather disturbances, especially during certain seasons. These environmental factors, combined with its geographic location and oceanographic characteristics, make the Bermuda Triangle a region of significant scientific interest. Understanding its geographical setting is essential for interpreting the various natural phenomena associated with it and for ensuring safer navigation in this part of the ocean.

Historical Incidents and Case Studies

The mystery of the Bermuda Triangle gained widespread attention due to a series of unusual incidents reported during the 20th century. Among these, the most notable case is the Flight 19 disappearance. In December 1945, five U.S. Navy training aircraft departed from Florida for a routine navigation exercise. During the flight, the pilots reported compass malfunctions and disorientation. Communication became increasingly confused, and eventually, all five aircraft disappeared without a trace. A rescue plane sent shortly afterward also vanished, further deepening the mystery. Another frequently cited case is the disappearance of the USS Cyclops in 1918, a large naval cargo ship carrying over 300 crew members. The vessel was traveling from the Caribbean region toward the United States when it suddenly disappeared without sending any distress signal. Despite extensive search efforts, no wreckage was ever found, making it one of the largest non-combat losses in U.S. naval history. In addition to these major incidents, several smaller cases involving private aircraft and commercial ships have been reported over the years.

Many of these events initially appeared mysterious due to the lack of immediate evidence or communication. However, later investigations often pointed toward natural causes such as severe weather conditions, strong ocean currents, and navigational errors. It is important to consider that during earlier decades, technological limitations played a significant role in these incidents. Navigation systems were less advanced, weather forecasting was less accurate, and communication equipment was not as reliable as it is today. As a result, accidents that occurred in this region were more likely to remain unexplained at the time. Overall, while historical incidents contributed to the reputation of the Bermuda Triangle as a zone of mystery, modern scientific analysis suggests that most of these cases can be explained through a combination of environmental factors and human error rather than supernatural causes.

Oceanographic Factors Influencing the Region

a. The Bermuda Triangle is strongly influenced by various oceanographic processes that play a crucial role in shaping its environmental conditions. These factors not only affect marine ecosystems but also have significant implications for navigation and safety in the region. Strong Ocean Currents

One of the most dominant features of this region is the Gulf Stream, a powerful, warm, and fast-moving ocean current that originates in the Gulf of Mexico and flows through the Atlantic Ocean. This current can reach speeds of up to several kilometers per hour, rapidly transporting water masses across large distances. From a scientific perspective, the Gulf Stream has a major influence on climate regulation and heat distribution. However, in the context of the Bermuda Triangle, it can complicate search and rescue operations. If a ship or aircraft is lost, the current can quickly disperse debris over a wide area, making it extremely difficult to locate wreckage and determine the exact cause of an incident.

b. Methane Gas Hydrates

Another important oceanographic factor is the presence of methane gas hydrates beneath the seafloor. These are ice-like structures that trap methane gas under high pressure and low temperature conditions. Occasionally, disturbances in the seabed can cause sudden releases of methane gas into the water column. When large amounts of methane gas rise to the surface, they can significantly reduce the density of seawater. This reduction in buoyancy may cause ships to lose stability and potentially sink rapidly. Although such events are considered rare, they provide a scientifically plausible explanation for some unexplained maritime incidents in the region.

c. Seafloor Topography and Depth Variations

The seafloor of the Bermuda Triangle is highly irregular, consisting of continental shelves, steep slopes, and deep ocean basins. Sudden changes in depth can influence ocean currents and create turbulence in the water. These variations can also affect sonar readings and underwater navigation systems. Overall, the combination of strong currents, potential gas releases, and complex seabed structures makes the Bermuda Triangle a dynamic and sometimes challenging marine environment. These oceanographic factors highlight that many of the so-called mysteries can be better understood through scientific study of natural ocean processes.

Atmospheric and Weather Conditions

The Bermuda Triangle is located in a zone that experiences highly dynamic and sometimes extreme atmospheric conditions. These weather-related factors play a major role in many of the incidents reported in this region and are considered one of the most important scientific explanations for its reputation. One of the key features of this area is the frequent occurrence of **tropical storms and hurricanes**. The region lies along major storm tracks in the North Atlantic Ocean, especially during the hurricane season. These storms can develop rapidly, producing strong winds, high waves, and heavy rainfall, which can severely affect both ships and aircraft. Another important phenomenon is the presence of **sudden and localized weather changes**. The Bermuda Triangle is known for unpredictable weather patterns, where clear skies can quickly turn into stormy conditions. This rapid change can catch pilots and sailors off guard, especially in earlier times when weather forecasting systems were less advanced. **Waterspouts**, which are rotating columns of air and water, are also commonly observed in this region.

These can pose serious threats to small vessels and low-flying aircraft. In addition, **thunderstorms and microbursts** can create intense downdrafts and turbulence, making flying conditions extremely hazardous. The interaction between warm ocean waters—particularly due to the Gulf Stream—and the atmosphere further intensifies weather activity. Warm water provides energy for storm formation, increasing the frequency and intensity of atmospheric disturbances. In earlier decades, limited weather monitoring and forecasting technologies made it difficult to predict such conditions accurately. As a result, many ships and aircraft may have unknowingly entered dangerous weather systems, leading to accidents that were later labeled as mysterious. In conclusion, the atmospheric conditions in the Bermuda Triangle are highly variable and

sometimes extreme. Modern scientific understanding shows that these weather-related factors are a major contributor to many of the incidents in the region, reducing the need to rely on supernatural explanations.

Magnetic Variations and Navigational Challenges

Navigation in the Bermuda Triangle has long been associated with reports of compass irregularities and directional confusion. From a scientific perspective, these issues are linked to natural variations in the Earth's magnetic field rather than any mysterious or supernatural forces. The Earth has two types of north: true north (geographic north) and magnetic north (the direction a compass points). Normally, there is a difference between these two directions, known as *magnetic declination*. However, in certain regions of the North Atlantic Ocean, including parts of the Bermuda Triangle, the line of zero declination (called the agonic line) passes through. In such areas, a compass may point directly to true north without any correction, which can confuse navigators who are not aware of this phenomenon. In earlier times, when navigation relied heavily on magnetic compasses, even small miscalculations could lead to significant errors over long distances. Pilots and sailors who failed to adjust for these variations might have unintentionally deviated from their intended routes.

This could result in disorientation, especially when combined with poor visibility or adverse weather conditions. Additionally, electronic navigation systems in the past were less advanced and more susceptible to interference. Factors such as atmospheric disturbances, solar activity, or equipment malfunction could further affect navigational accuracy. In the case of the Flight 19 disappearance, reports of compass malfunction and confusion among pilots suggest that navigational challenges played a significant role in the incident. Today, modern navigation technologies such as GPS and satellite-based systems have greatly reduced dependence on magnetic compasses. These advancements provide highly accurate positioning and have significantly minimized navigational errors in the region. In conclusion, magnetic variations and navigational limitations are scientifically valid factors that help explain many of the incidents associated with the Bermuda Triangle. When combined with environmental conditions and human error, they offer a realistic understanding of events that were once considered mysterious. Human Factors and Technical Errors

While natural forces play an important role, many incidents in the Bermuda Triangle can be largely attributed to human factors and technical limitations. In fact, scientific investigations have

shown that human error is one of the most common causes of accidents in marine and aviation environments. One major factor is **navigational error**. In earlier decades, sailors and pilots depended heavily on manual navigation techniques such as compasses, maps, and celestial observations. Even small mistakes in reading instruments or calculating direction could lead to significant deviations from the intended route, especially over vast ocean areas like the North Atlantic Ocean. **Lack of experience and training** also contributed to several incidents. Navigating through a region known for unpredictable weather and strong currents requires skill and situational awareness. In some historical cases, crews were not adequately prepared to handle sudden environmental changes, leading to confusion and poor decision-making.Another important aspect is **equipment failure**. Earlier ships and aircraft had less reliable communication and navigation systems. Malfunctioning compasses, radio failures, or engine problems could quickly escalate into dangerous situations. In the case of the Flight 19 disappearance, reports indicated confusion among pilots and possible instrument issues, which may have contributed to their loss of direction. **Fatigue and psychological stress** are additional human factors that can affect judgment and reaction time. Long hours of operation, combined with challenging environmental conditions, can lead to poor decision-making and increased risk of accidents.

Moreover, the Bermuda Triangle is one of the busiest routes for shipping and aviation. With a high volume of traffic passing through this region, the probability of accidents naturally increases. Many incidents that were once considered mysterious can now be explained by routine operational risks associated with heavily used transport corridors. In conclusion, human factors and technical errors provide a practical and scientifically supported explanation for many of the events associated with the Bermuda Triangle. When combined with environmental challenges, these factors significantly reduce the need to attribute such incidents to unexplained or supernatural causes.

Scientific Perspective vs Popular Myths

The Bermuda Triangle has long been surrounded by a mixture of scientific investigation and popular myths. Over time, media, books, and movies have played a significant role in shaping its image as a mysterious and dangerous region. However, a clear distinction must be made between scientifically supported explanations and fictional or exaggerated claims. Popular myths often attribute disappearances in the region to supernatural causes such as alien abductions, time warps, or the lost city of Atlantis. These ideas are widely circulated because they capture public

imagination and add an element of mystery. However, they lack empirical evidence and are not supported by scientific research. In contrast, scientific studies focus on observable and measurable factors. Oceanographers and meteorologists have identified key natural processes such as strong ocean currents, rapidly changing weather conditions, and complex atmospheric interactions in the North Atlantic Ocean. These factors can adequately explain many of the incidents previously considered mysterious. Another important point is the role of data and statistical analysis. Research indicates that the number of accidents reported in the Bermuda Triangle is not significantly higher than in other heavily trafficked ocean regions. This suggests that the perception of the area as unusually dangerous is largely influenced by selective reporting and media exaggeration. Furthermore, earlier incidents often lacked accurate documentation due to limited technology and communication systems. As a result, incomplete information led to speculation and the development of myths. With advancements in modern technology, including satellite monitoring and improved navigation systems, such unexplained cases have become increasingly rare. In conclusion, while popular myths continue to make the Bermuda Triangle an intriguing topic, scientific evidence strongly supports natural and human-related explanations. Understanding this distinction is essential for approaching the subject from a rational and evidence-based perspective.

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HEALTH BENEFITS OF WOOD APPLE

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Introduction

Wood apple is highly valued for its **digestive benefits**. Its high fiber content and natural laxative properties help regulate bowel movements, relieve constipation, and prevent acidity. It also soothes stomach ulcers and supports gut flora balance, acting as a prebiotic to encourage healthy gut bacteria growth.

Immunity and Antioxidant Support

Rich in **vitamin C, vitamin A, and antioxidants**, wood apple strengthens the immune sy stem, protecting against infections, colds, and flu. Its antioxidant compounds, including flavonoi ds and phenolic compounds, help neutralize free radicals, reduce oxidative stress, and lower the r isk of chronic diseases like cancer and heart disease.

Heart and Blood Sugar Health

The fruit contains **potassium**, which helps regulate blood pressure and maintain cardiova scular health. Its fiber content also contributes to lowering cholesterol levels. Additionally, wood

apple has a **low glycemic index**, making it beneficial for managing blood sugar levels and suppo rting people with diabetes.

Cooling and Detoxifying Effects

Wood apple juice is a natural coolant, helping regulate body temperature and prevent deh ydration, especially during hot weather. The fruit also supports **liver function** and detoxifies the body by flushing out toxins, promoting overall wellness

Skin, Hair, and Anti-Inflammatory Benefits

The antioxidants and vitamins in wood apple improve **skin texture**, reduce acne, and slo w down aging. Its antiinflammatory properties help alleviate respiratory ailments and other infla mmatory conditions. The fruit also strengthens hair follicles, reducing hair fall and promoting he althy hair growth.

Bone and Eye Health

Wood apple is rich in **calcium and other minerals**, which support bone strength and help prevent osteoporosis. Its vitamin A content contributes to maintaining healthy vision and eye fun ction

Additional Benefits

Regular consumption of wood apple can aid in **weight management, energy enhanceme nt, menstrual regulation, and kidney health**. It also helps relieve diarrhea and dysentery, maki ng it a versatile fruit for overall health maintenance.

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MICROALGAE AS THIRD-GENERATION BIOFUEL: A SUSTAINABLE ENERGY IMPERATIVE FOR THE FUTURE

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Abstract

The growing global energy crisis, driven by fossil fuel depletion, environmental degradation, and geopolitical instability, necessitates the development of sustainable energy alternatives. Microalgae-based biofuels, recognized as third-generation biofuels, have emerged as a highly promising solution due to their rapid growth, high lipid productivity, and ability to utilize non-arable land and wastewater resources. Unlike conventional biofuel feedstocks, microalgae eliminate competition with food crops while enabling efficient carbon dioxide sequestration. This review critically examines microalgal biofuel production, focusing on strain selection, cultivation strategies, lipid biosynthesis, and downstream processing technologies. Furthermore, it highlights the potential of microalgae to produce diverse biofuels, including biodiesel, bioethanol, and biogas. Overall, microalgae offer a scalable and sustainable pathway toward enhancing energy security and advancing the global transition to a low-carbon economy.

Keywords: Biofuel, Carbon capture, Lipid synthesis, Micro-algae, Photobioreactors, Renewable energy.

Introduction

Rising global energy demand driven by industrialization and urbanization has increased reliance on fossil fuels, which is becoming unsustainable due to depletion, price volatility, and environmental impacts (Demirbas, 2011). Geopolitical tensions in the Gulf region, particularly around Iran and the Strait of Hormuz, have further exposed energy vulnerabilities. Countries like India, which import about 88–90% of their crude oil largely from the Middle East are especially

at risk from supply disruptions and price fluctuations. Moreover, the combustion of fossil fuels is a major contributor to greenhouse gas emissions, leading to global warming.These challenges highlight the urgent need to shift toward sustainable and renewable energy sources. Biofuels are increasingly recognized as a viable solution for the transportation sector, offering the dual benefits of meeting growing energy demands and reducing carbon emissions (Singh & Gu, 2010). India's National Biofuel Policy (2018) targets 20% ethanol (E20) and 5% biodiesel (B5) blending by 2030. However, first- and second-generation biofuels from crops like sugarcane and soybean face challenges such as food competition, high water use, and deforestation (Lam & Lee, 2012). Third-generation biofuels from microalgae offer a sustainable alternative, as they convert CO_2 into valuable biomolecules through photosynthesis (Hu et al., 2008). Microalgae require less land and provide higher yields than conventional crops, making them an efficient and viable feedstock for biodiesel production (Chisti, 2007).

Microalgae are simple, thallophytic organisms lacking true roots, stems, and leaves, and are found in diverse aquatic environments. Species such as *Chlorella*, *Spirulina*, *Scenedesmus*, and *Nannochloropsis* are widely studied for biofuel production (Mata et al., 2010). They act as efficient photosynthetic systems, converting light and CO_2 into valuable biomolecules like lipids, carbohydrates, and proteins. Due to their rapid growth and high lipid content, microalgae can produce 7–31 times more oil than palm oil per unit area (Sharma et al., 2021). Additionally, they do not require fertile land and can grow in saline water or wastewater, avoiding competition with food and freshwater resources (Abomohra et al., 2016). Wastewater cultivation also supplies nutrients, supports water recycling, and reduces production cost.

Microalgae Production

The production of microalgae primarily involves strain selection, cultivation, and biomass generation under controlled environmental conditions.

Strain Selection:

Selection of suitable microalgal species is a critical step, as different strains vary in lipid, carbohydrate, and protein content. Species such as *Chlorella*, *Nannochloropsis*, and *Spirulina* are commonly used due to their high productivity and biofuel potential (Mata et al., 2010).

Growth Conditions:

Under optimal conditions, microalgae can accumulate hydrocarbons up to 30–70% of their dry weight, producing significantly more oil than conventional crops like soybeans (Sharma

et al., 2012). Their growth is influenced by environmental factors such as light, carbon dioxide (CO_2), temperature, and pH (Brennan & Owende, 2010). Light is essential for photosynthesis and can be supplied through sunlight, artificial sources like LEDs, or both. CO_2 serves as the primary carbon source, and microalgae can efficiently utilize elevated levels, including industrial emissions, contributing to greenhouse gas reduction (Demirbas, 2011). Optimal growth generally occurs at temperatures between 20–24 °C (Converti et al., 2009) and pH 7–9. Microalgae are highly adaptable and grow rapidly with minimal nutrients. They can also utilize wastewater nutrients such as nitrogen and phosphorus, making them effective for low-cost wastewater treatment while simultaneously producing biomass for biofuel (Abomohra et al., 2016).

Cultivation Systems: Microalgae are cultivated using two main systems:

Open Pond Systems:

Open pond cultivation is one of the oldest and simplest methods for large-scale microalgae production, valued for its low cost, easy operation, low energy use, and scalability (Brennan & Owende.,2010). It includes natural systems like lakes and ponds, and artificial systems such as circular and raceway ponds. Circular ponds use central agitators for mixing but are limited by high energy consumption and construction costs. Raceway ponds, the most widely used design, consist of shallow, closed-loop channels with paddlewheels for circulation. They are more energy-efficient and suitable for large-scale production, making them the preferred system in industry. However, open ponds are prone to contamination and environmental fluctuations (Ugwu et al., 2008).

Closed Photobioreactors:

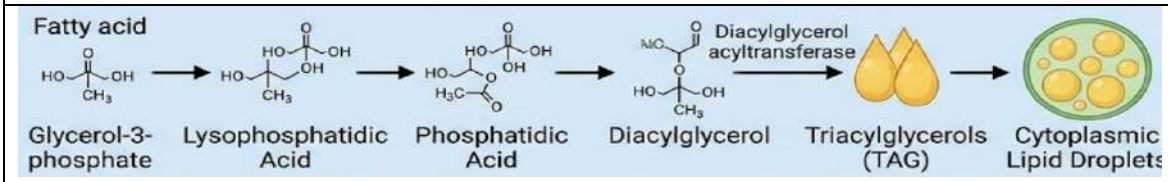
Closed photobioreactors are enclosed systems that enable microalgae cultivation under controlled conditions, allowing contamination-free growth of specific species (Ugwu et al., 2008). They provide precise control over light, temperature, and nutrients, reduce CO_2 loss, and ensure efficient land use. These systems achieve higher biomass productivity due to improved metabolic efficiency (Borowitzka.,2013). Common designs, such as tubular and flat-plate photobioreactors, are especially suitable for producing high-value compounds like DHA and EPA.

Lipid biosynthesis of micro-algae:

Lipid synthesis begins with carbon fixation via the Calvin cycle, producing intermediates such as glyceraldehyde-3-phosphate (G3P), which is further converted into acetyl-CoA (Hu et

al., 2008). Acetyl-CoA serves as a precursor for fatty acid biosynthesis, leading to the formation of C16 and C18 fatty acids. Triacylglycerols (TAGs) are synthesized via the Kennedy pathway (Figure 1) and stored in lipid droplets (Hu et al., 2008). Under stress conditions such as nitrogen deprivation, microalgae enhance lipid accumulation, increasing TAG production (Sharma et al., 2012).

Figure 1: Kennedy pathways for lipid assembly



Steps Involved in Biofuel Production

Once sufficient biomass is produced, several downstream processes are carried out to convert microalgae into biofuels.

- **Harvesting:** involves separating microalgal biomass from the culture medium. Techniques such as centrifugation, flocculation, and filtration are commonly employed. This step is energy-intensive and significantly impacts overall production cost (Brennan & Owende, 2010).
- **Dewatering and Drying:** The harvested biomass contains high moisture content, which must be reduced. Methods such as sun drying, spray drying, or freeze drying are used depending on economic and efficiency considerations (Lam and Lee, 2012).
- **Lipid Extraction:** Lipids are extracted from dried biomass using mechanical or chemical methods, including solvent extraction (e.g., hexane) or advanced techniques like supercritical CO_2 extraction (Lam and Lee, 2012).
- **Conversion to Biofuel:** Different biofuels can be produced from microalgal biomass:
    1. **Biodiesel:** Transesterification of extracted lipids into fatty acid methyl esters (FAME).
    2. **Bioethanol**: Fermentation of carbohydrates present in the biomass.
    3. **Biogas:** Generated via anaerobic digestion of residual biomass, producing methane.
    4. **Bio-oil:** Thermochemical processes such as pyrolysis or hydrothermal liquefaction.

Advantages of algae biofuel compared to others:

Table 1: Comparison between Micro-algae and terrestrial plants

Parameter	**Microalgae**	**Terrestrial Plants (e.g., crops like soybean, palm)**
Lipid (oil) content	Very high (20–70% dry weight)	Moderate (2–5% in most crops)
Growth rate	Extremely fast (can double in hours)	Slow (weeks to months).
Biomass productivity	High productivity per unit area	Lower productivity per unit area
Land requirement	Does not require arable land	Requires fertile agricultural land
Water source	Wastewater, saline, or marine water	Requires freshwater
Food vs fuel conflict	No competition with food crops	Competes directly with food supply
CO_2 utilization	Efficient CO_2 fixation	Lower CO_2 fixation efficiency
Cultivation systems	Photobioreactors or open ponds	Limited to soil-based farming
Harvest cycles	Continuous or frequent harvesting possible	Seasonal harvesting
Environmental impact	Wastewater treatment and carbon sequestration	May cause deforestation, fertilizer runoff
Fuel yield	Higher biodiesel yield per hectare	Lower biodiesel yield per hectare

Conclusion

Microalgae-based biofuels are a promising and sustainable solution to the global energy crisis. As third-generation biofuels, they overcome limitations of earlier feedstocks due to their rapid growth, high lipid productivity, and ability to thrive in diverse environments. Microalgae can produce large amounts of lipids and biomass, making them suitable for biofuel production while also generating valuable co-products that improve economic viability. Technological advances in strain selection, cultivation methods, and lipid biosynthesis have further enhanced

their potential. Integrated biorefinery approaches allow the production of multiple fuels such as biodiesel, bioethanol, biogas, and bio-oil, increasing overall efficiency. These biofuels can significantly reduce greenhouse gas emissions and dependence on fossil fuels, especially in transportation. With continued research, innovation, and supportive policies, microalgae can play a key role in achieving energy security and promoting a sustainable, low-carbon future.

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ZOMBIE PARASITES: HOW NATURE'S PUPPETEERS HIJACK INSECT MINDS

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Introduction

Parasitic organisms that manipulate host behavior, like zombie parasites, showcase a remarkable evolutionary feat. Entomopathogenic fungi—such as *Ophiocordyceps unilateralis* and *Entomophthora muscae*—can precisely control insect behavior to enhance their own reproduction and transmission. Studying these "natural mind-controllers" sheds light on host–parasite interactions, neurobiology, and potential biological pest management strategies.

Parasitic micro-organisms

Entomopathogenic Fungi Capable of Behavioral Manipulation

Taxonomic Groups

Behavior-manipulating fungi are primarily found in two fungal orders. One order is **Hypocreales (Ascomycota)** which includes *Ophiocordyceps* species that infect ants, beetles, and other insects. And second one is the **Entomophthorales (Zoopagomycota)** which includes *Entomophthora muscae* and *Pandora* species that infect flies, aphids, and other dipterans.

Famous Cases of Insect "Zombie" Parasites

One of the most iconic examples of behavioral manipulation in nature comes from the parasitic fungus *Ophiocordyceps*, often called *zombie-ant fungi*. When ants encounter *Ophiocordyceps* spores, the spores penetrate the ant's exoskeleton and infiltrate its body. The fungus proliferates, ultimately influencing the ant's nervous system.

1. ***Ophiocordyceps* Fungi — The Zombie-Ant Phenomenon**

(These show ants infected by the *Ophiocordyceps* fungus — it takes over the ant, forces it to climb up vegetation, and then sprouts fungal structures from the ant's body to release spores after it dies.)

In a dramatic twist of biology, infected ants begin to behave erratically, leaving their colony and climbing vegetation. They bite into plant tissue in a "death grip," where they die. From the ant's body emerges the fungal reproductive stalk, which releases spores onto the forest floor to infect more ants. This precise behavior maximizes fungal transmission.

Molecular research suggests that *Ophiocordyceps* alters host physiology at multiple levels, including the dysregulation of neurotransmitters and immune pathways. Gene expression and metabolite shifts in infected ant brains implicate disrupted neuronal signalling and hormonal changes as part of the manipulation strategy.

2. Entomophthora & "Zombie Flies"

(These images depict flies infected by *Entomophthora muscae* (a parasitic fungus): the fungus takes over the fly's behavior, causing it to climb to a raised spot and cling before it dies — positioning the cadaver to maximize spore spread.)

Other fungi like *Entomophthora muscae* infect fruit flies (*Drosophila melanogaster*), causing a suite of altered behaviors known as *summit disease*. Infected flies show bursts of locomotion at particular times of day — linked to circadian neurons and hormone-producing structures — and adopt postures that facilitate fungal spore dispersal.

This system is a powerful experimental model for studying how parasites affect host nervous systems, neural circuits, and behavioral physiology.

3. Lancet Liver Flukes & Ant Climbing Behavior

(These show ants manipulated by lancet liver flukes (*Dicrocoelium dendriticum*) — the parasite compels infected ants to climb blades of grass and clamp on with their jaws, increasing the chance they'll be eaten by grazing animals and transmitting the parasite's next life stage.)

Not all zombie parasites are fungi. The liver fluke *Dicrocoelium dendriticum* — a type of flatworm — manipulates ants as part of its complex lifecycle. The parasite's larvae induce infected ants to climb blades of grass and cling there when grazers are likely to feed. This behavior ensures that the parasite reaches its final host (often livestock) to complete development.

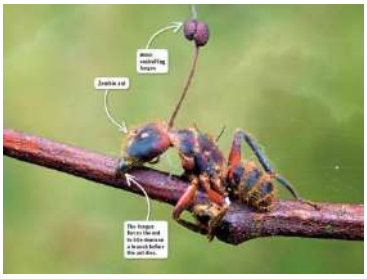
Other Mind-Controlling Parasites in Insects

Beyond fungi and flukes, there are additional examples of parasitic manipulation:

- **Parasitic wasps** (e.g., *Dinocampus coccinellae*) can turn lady beetles into temporary "bodyguards" for wasp pupae by incapacitating and altering their behavior.
- **Hairworms** compel infected crickets to seek water and drown, allowing the worm to emerge and complete its lifecycle.
- Viral agents and other protozoans have also been studied for subtler effects on insect behavior, though these are less well understood.

Infection Process: From Spore to Host Takeover

Spore Attachment and Cuticle Penetration



Fungal infection begins when infectious **spores** come into direct contact with the **insect cuticle**. These spores adhere firmly to the host **exoskeleton** through a combination of **adhesive surface proteins** and **hydrophobic interactions**. After successful attachment, the spores **germinate** and produce **germ tubes** that actively penetrate the insect body. During this process, the fungus secretes a suite of **cuticle-degrading enzymes**, including **proteases**, **chitinases**, and **lipases**. These

enzymes enzymatically digest the **protein**, **chitin**, and **lipid components** of the insect cuticle, weakening this protective barrier. As a result, fungal **hyphae** are able to mechanically breach the cuticle and gain entry into the **hemocoel**, which is the primary **body cavity** of the insect.

Proliferation in the Hemocoel

Inside the hemocoel, the fungus shifts to yeast-like or filamentous forms, evades the host immune system, and absorbs nutrients from tissues and hemolymph, weakening the insect while accumulating secondary metabolites—an internal growth phase crucial for later behavioral manipulation.

Behavioral Syndromes Induced by Zombie Fungi

Summiting Behavior

Infected insects frequently exhibit a distinctive behavior known as **summiting**, in which they climb to **elevated positions** shortly before death. This behavior has been widely documented in **ants**, **flies**, **aphids**, and other insects infected by **behavior-manipulating fungi**. By inducing the host to die at elevated sites, the fungus ensures exposure to favorable **environmental conditions** such as optimal **humidity**, **airflow**, and **temperature**. These conditions significantly enhance fungal **sporulation** and maximize the efficiency of **spore dispersal** to new hosts.

Death Grip or Clamping Behavior

In ants infected with ***Ophiocordyceps*** species, hosts display a highly **stereotyped behavior** commonly referred to as the **death grip**. In this behavior, infected ants bite forcefully onto **leaf veins** or **twigs** shortly before death. This bite is **irreversible** and results from sustained **muscle contraction** rather than voluntary movement. **Physiological studies** indicate that the **mandibular muscles** enter a state of prolonged **tetany**, effectively locking the jaws in place. This fixation ensures that the ant remains securely attached to vegetation, providing a stable platform for **fungal growth** and **spore release** after host death.

Wing and Posture Modification

In **dipteran insects** infected by ***Entomophthora muscae***, pronounced changes in **posture** occur prior to death. Infected flies characteristically **raise and spread their wings**, thereby increasing the **surface area** available for **spore ejection**. Additionally, the **proboscis** is often extended and pressed against the substrate, secreting **adhesive material** that anchors the insect

firmly in place. This posture stabilizes the **cadaver** during **fungal sporulation** and optimizes the mechanical **discharge of spores** into the surrounding environment.

Physiological Basis of Behavioral Control

A. Nervous System Involvement: Neural Targeting Without Brain Destruction

Behavior-manipulating fungi often avoid directly invading the brain. Instead, they accumulate near neural tissues and secrete compounds that alter neuronal signaling, affecting locomotion, circadian rhythms, and neurosecretory activity. Studies in *Drosophila* infected with *Entomophthora muscae* show that even brain removal does not fully stop summiting behavior, indicating a role for peripheral nerves or hormone-mediated pathways.

B. Hemolymph-Mediated Signaling

Experimental studies show that hemolymph from zombie fungus–infected flies can induce partial summiting behavior in healthy flies, indicating that soluble molecules—fungal toxins, alkaloids, modified host hormones, or neuroactive peptides—mediate behavioral changes, allowing the fungus to control the host remotely without direct neural invasion.

C. Endocrine and Circadian Disruption

Fungal infection frequently disrupts the host's **endocrine system** and **circadian regulation**. The **timing of host death** is often synchronized with environmental conditions favorable for **fungal development** and **spore dispersal**. At the molecular level, **circadian gene expression** patterns in infected hosts are altered, leading to abnormal **activity cycles**. **Neurohormones** responsible for regulating **feeding**, **movement**, and **rest** are also dysregulated. This high degree of **temporal precision** suggests that the fungus manipulates the host's **internal biological clock** to optimize its own **life cycle**.

D. Muscle Physiology and Mechanical Control

Fungal infection disrupts the host's endocrine system and circadian rhythms, altering gene expression and neurohormone levels that regulate feeding, movement, and rest. This temporal precision synchronizes host death with conditions optimal for fungal growth and spore dispersal, indicating manipulation of the host's internal clock to benefit the fungus.

Conclusion

Behavior-manipulating parasites blur the lines between biology, behavior, and ecology. From fungi that control ant minds to flatworms that turn ants into grazing bait, these systems showcase evolution's power to shape life cycles through behavioral hijacking. Neuroparasitology

continues to reveal the molecular and neural underpinnings of these extraordinary interactions — offering both scientific insight and a deeper appreciation of nature's complexity.

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SALT STRESS IN WHEAT: A PHYSIOLOGICAL PERSPECTIVE

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Abstract

Wheat (*Triticum aestivum* L.) is a vital staple crop, but its productivity is increasingly threatened by soil salinity, particularly in arid and semi-arid regions. Salt stress arises due to high concentrations of soluble salts such as sodium chloride (NaCl), which adversely affect plant growth. It occurs in two phases: osmotic stress, which restricts water uptake and mimics drought conditions, and ionic stress, characterized by toxic accumulation of Na^+ and Cl^- ions leading to nutrient imbalance and cellular damage. These stresses impair photosynthesis and induce oxidative stress through excessive production of reactive oxygen species (ROS). Wheat plants respond through several physiological mechanisms, including ion homeostasis to maintain K^+/Na^+ balance, osmotic adjustment via accumulation of compatible solutes like proline, and activation of antioxidant defense systems. Hormonal regulation also plays a crucial role in coordinating stress responses. Understanding these mechanisms is essential for improving wheat tolerance to salinity and ensuring sustainable crop production.

Introduction

One of the most important staple crops in the world, wheat (Triticum aestivum L.) provides a sizable amount of the daily caloric intake for a sizable portion of the world's population (Igrejas and Branlard, 2020). Because of this, ensuring its consistent production is crucial to food security. However, growing wheat is challenging, soil salinity is one of the main abiotic stressors

that affects productivity. Salinity affects about 7% of the world's land surface and 20% of irrigated land, resulting in large yield losses (Arora, 2019). Furthermore, due to the continuous increase in the human population, the world's food supply would need to grow by up to 70% by 2050, placing strain on global food security (FAO, 2009). However, soil salinity—a state in which too many salts build up in the soil—is becoming a greater danger to its productivity. In arid and semi-arid areas, where irrigation techniques frequently result in salt accumulation, this issue is particularly serious. Salt stress is a serious threat to the world's food security since it silently lowers crop output and quality.

1. Salt stress

Salt stress occurs when high concentrations of soluble salts, primarily sodium chloride (NaCl), interfere with plant growth. In wheat, which is moderately sensitive to salinity, even small increases in soil salt levels can significantly affect development. Physiologically, salt stress disrupts normal plant functions by affecting water uptake, nutrient balance, and cellular metabolism. The stress develops in two phases: an early osmotic phase and a later ionic phase.

1.1 Osmotic Stress

When salts accumulate in the soil, they lower the soil's water potential. As a result, wheat roots find it difficult to absorb water, even when moisture is present. This condition is similar to drought stress. During this phase, seed germination is delayed or reduced, leaf expansion slows down and plants exhibit wilting symptoms. The plant essentially experiences "physiological drought," which restricts early growth and establishment.

1.2 Ionic Stress

As salt exposure continues, sodium (Na^+) and chloride (Cl^-) ions enter the plant system and accumulate in tissues. Excess sodium is particularly harmful because it interferes with essential nutrients like potassium (K^+) and calcium (Ca^{2+}). This leads to nutrient imbalance, enzyme inhibition and damage to cellular structures. Over time, older leaves may show chlorosis (yellowing) and necrosis (tissue death), reducing the plant's ability to photosynthesize effectively.

2. Impact of salt stress

2.1 Disruption of Photosynthesis

Salt stress has a direct impact on photosynthesis, the process by which plants produce food. It reduces photosynthetic efficiency in several ways by closure of stomata limits carbon dioxide

intake, chlorophyll content decreases and damage occurs in chloroplast structures. As a result, the plant produces less energy, leading to stunted growth and reduced grain yield.

2.2 Oxidative Stress: Cellular Damage

One of the most damaging effects of salt stress is the production of reactive oxygen species (ROS) such as hydrogen peroxide and superoxide radicals. These molecules are highly reactive and can damage proteins, lipids, and DNA. This oxidative stress causes membrane damage, enzyme degradation and premature aging of plant tissues. If not controlled, it can severely impair plant survival.

3. Salinity Tolerance Mechanisms in Wheat

To maintain cellular homeostasis and mitigate the detrimental effects of salt, wheat plants adapt in a number of ways (Shahid et al., 2020). In order to protect themselves from the harmful effects of salt stress, wheat plants have developed a variety of defenses. Wheat plants can restrict the net uptake of sodium at the soil–root interface and its xylem loading in the roots to maintain low sodium levels in the shoot (Bennett et al., 2003). By triggering antioxidant defense systems, ion homeostasis, osmotic adjustment, and wheat lessen oxidative damage caused by excessive salt (Negrao et al., 2017).

3.1. Ion Homeostasis

Ion homeostasis, which helps plants regulate the ratio of harmful sodium (Na+) to beneficial potassium (K+) ions, is essential for wheat's ability to withstand salinity. Under salt stress, excess Na+ can accumulate in plant cells, disrupting enzyme action and producing toxicity. Wheat uses specific transport proteins to limit Na+ uptake, segregate it into vacuoles, or prevent it from entering cells in order to combat this. In order to support cellular functions, it simultaneously maintains sufficient K+ uptake. Wheat plants employ a number of strategies to manage ion toxicity, such as selective ion uptake, which prevents Na+ from accumulating in the cytoplasm, and root cells that preferentially absorb K+ over Na+. Salt-tolerant wheat cultivars either swiftly expel Na+ through the Na+/H+ antiporters in the plasma membrane or stop it from entering root cells (Tester and Davenport, 2003). Wheat plants can prevent detrimental cytoplasmic effects by compartmentalizing Na+ ions into vacuoles.

3.2. Osmotic Adjustment

Wheat plants can alter their cellular osmotic potential in response to salinity stress by accumulating appropriate solutes such sugar alcohols, proline, and glycine betaine. These

osmolytes help maintain the water balance inside cells and protect cellular structures from salt (Kaya et al., 2013). The buildup of these solutes in wheat is sometimes mediated by the overexpression of genes involved in their production, such as P5CS for proline and betaine aldehyde dehydrogenase for glycine betaine. This method decreases the osmotic potential within the cell, allowing it to absorb and hold water despite the high concentration of salt outside. Therefore, by stabilizing proteins, maintaining enzyme function, and protecting cellular structures, osmotic adjustment enables wheat to continue growing and developing in salty soils. Wheat can acquire suitable solutes like proline and glycine betaine to alter its osmotic potential. These solutes help cells retain water, maintain cell turgor, and stabilize proteins and cellular structures under osmotic stress (Bartels and Sunkar, 2005).

3.3. Antioxidant Defense

The accumulation of appropriate solutes, the activation of signaling cascades that modify gene expression patterns, and the strengthening of antioxidant defenses are some examples. Wheat plants can also mitigate the impacts of salinity by producing more plant growth regulators, which can trigger adaptive responses. Additionally, studies have shown that wheat roots' capacity to tolerate salinity depends on their tissue-specific salt accumulation and sequestration (Wu et al., 2015). In order to prevent oxidative damage from reactive oxygen species (ROS), which accumulate in high salinity settings, wheat's antioxidant defense system is activated in response to salt stress. Salinity stress in wheat can cause an overabundance of reactive oxygen species, which can cause oxidative stress that damages cellular components. To combat the effects of oxidative stress, which can arise from the overproduction of reactive oxygen species brought on by salinity stress, wheat plants have developed a variety of antioxidant defense mechanisms, such as the upregulation of genes encoding enzymes like superoxide dismutase, catalase, and ascorbate peroxidase (Sagers et al., 2017).

3.4. Hormonal Regulation

Important plant hormones including gibberellins, auxins (IAA), cytokinins (CK), and abscisic acid (ABA) alter several molecular processes to increase salt tolerance. While other hormones, such IAA and CK, alter growth patterns to conserve resources, gibberellins regulate development (Ahmad et al., 2008). Together, these hormonal shifts enable wheat to adapt its growth and survival strategies in salty environments. Plant hormones are crucial for regulating wheat's resistance to salt. ABA is essential for triggering stress responses as osmolyte

accumulation, stomatal closure, and changes in gene expression. Furthermore, stress signaling pathways are mediated by ethylene (ET), salicylic acid (SA), and jasmonic acid (JA). Hormonal crosstalk regulates plant growth under stress by balancing defiance and development processes (James et al., 2011). ABA increases stomatal closure, improves osmotic adjustment, reduces water loss, and activates stress-responsive genes (DREB, LEA) in stressful situations. JA scavenges ROS, lengthens roots, promotes the synthesis of antioxidant enzymes (SOD, CAT), and modifies antioxidant defense and root growth. ET promotes root architecture and stress adaptability, enhances ROS removal, increases nutrient intake, and regulates root growth. IAA enhances root architecture, boosts food and water intake, stabilizes cell membranes, and regulates cell division and signaling from root to shoot. In the face of unfavorable circumstances, CK maintains cell division, delays senescence, and strikes a balance between growth and stress responses (Ahmad et al., 2008).

Conclusion

Salt stress is a major constraint to wheat production, causing osmotic imbalance, ionic toxicity, and oxidative damage that reduce growth and yield. However, wheat plants adapt through mechanisms such as ion homeostasis, osmotic adjustment, antioxidant defense, and hormonal regulation. Understanding these physiological responses is crucial for improving salt tolerance. Integrating this knowledge with breeding and management practices can help sustain wheat productivity. Enhancing salinity tolerance will be essential to ensure food security under increasing soil salinization and changing climatic conditions.

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CLEAN WATER: A GROWING GLOBAL CHALLENGE

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Abstract

The article *"Clean Water: A Growing Global Challenge"* discusses the increasing problem of freshwater scarcity worldwide. It explains that population growth, industrial activities, climate change, and unsustainable water use are placing heavy pressure on global water resources. The article highlights that water scarcity varies across regions and that billions of people experience water stress each year. It also discusses the rising demand for freshwater, the impacts of water shortages on ecosystems and human societies, and the methods used to assess water scarcity. Finally, it suggests solutions such as efficient water management, wastewater reuse, and technological innovations to ensure sustainable access to clean water.

Introduction

Water is essential for life, yet access to safe and clean water is becoming increasingly difficult across the world. Although Earth is often called the "Blue Planet", the availability of freshwater suitable for human consumption is extremely limited. Rapid population growth, industrial pollution, climate change and unsustainable water management practices are placing tremendous pressure on global freshwater resources. As a result, clean water is becoming one of the most pressing environmental and public health challenges of the 21st century.

"Clean water is the world's first and foremost medicine."

- Slovak proverb

Global Distribution of Water Scarcity

Water scarcity is not evenly distributed across the world. A global assessment by

Mekonnen and Hoekstra (2016) showed that water scarcity varies considerably across regions and seasons. Regions such as the Amazon Basin, the Congo Basin, and parts of Southeast Asia generally experience low water scarcity due to abundant rainfall and extensive forest cover. In contrast, many regions including North Africa, the Middle East, South Asia, and parts of Australia face moderate to severe water scarcity for several months each year. According to global assessments, nearly 4 billion people experience severe water scarcity for at least one month each year. The study also highlighted that densely populated areas and regions with intensive irrigated agriculture, such as India, eastern China, and parts of the United States, experience particularly high levels of water stress. In several river basins, including the Ganges Basin in India and the Murray-Darling Basin in Australia, water consumption often exceeds natural water availability, leading to reduced river flows and declining groundwater levels. Excessive freshwater withdrawal for agriculture, industry, and domestic use has therefore placed enormous pressure on major river systems worldwide. As a consequence, some major rivers, including the Colorado River in the United States and the Yellow River in China, have occasionally failed to reach the sea, highlighting the consequences of unsustainable water use.

Rising Global Demand for Freshwater

Freshwater, often referred to as blue water, plays a crucial role in sustaining human life and supporting economic activities such as agriculture, industry, and domestic consumption. Despite its importance, the total amount of available freshwater on Earth is limited. Over the past few decades, the demand for freshwater has increased significantly due to rapid population growth, economic development, and the expansion of irrigated agriculture. Global water withdrawal increased dramatically during the second half of the twentieth century, rising at an average rate of about 17% per decade between 1960 and 2000, and reaching nearly 4000 km^3 per year by the year 2000 (Vörösmarty *et al*., 2005). While the growth in water withdrawal slowed in regions such as North America and Europe after the 1980s, it continued to increase steadily in Asia, Africa, South America, and Oceania Agriculture is the largest consumer of freshwater globally, accounting for approximately 70% of total freshwater withdrawals worldwide.

As water demand continues to rise, many regions of the world are experiencing growing levels of water scarcity. According to the United Nations World Water Assessment Programme (2009), water scarcity is already beginning to constrain economic growth in several parts of the world, particularly in regions such as India, China, and the Middle East.

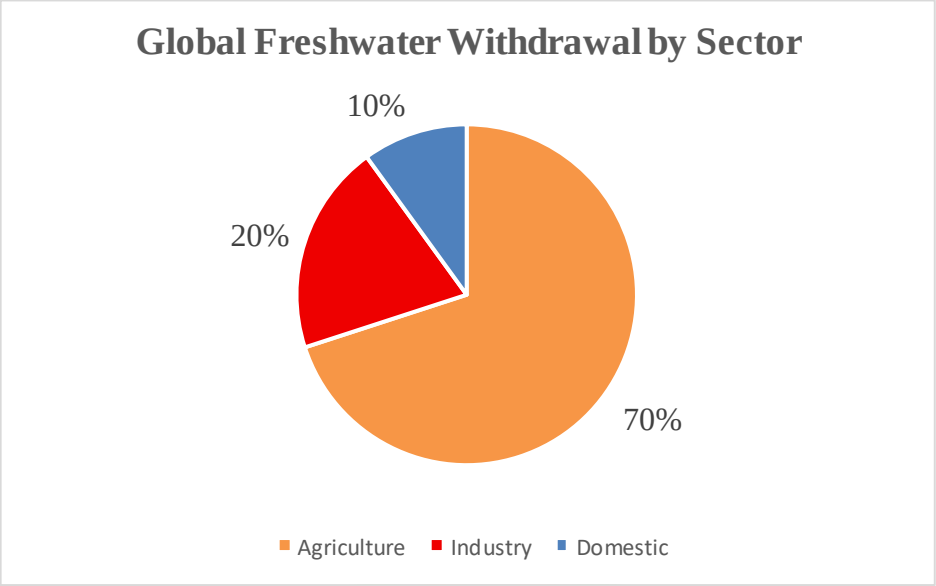

Figure 1: Global Freshwater Withdrawal by Sector

Hydrological assessments using global models further indicate that semi-arid and densely populated regions including Pakistan, northeastern China, North Africa, Iran, Saudi Arabia, and parts of Australia and the United States are particularly vulnerable to water stress due to high irrigation demands and limited freshwater availability (Hanasaki *et al*., 2008; Wada *et al*., 2011). In many of these regions, the demand for water frequently exceeds the available surface water resources, forcing greater dependence on groundwater extraction to meet agricultural and domestic needs.

The increasing imbalance between freshwater demand and availability has intensified global water stress over the past several decades. Studies suggest that the number of people living in regions experiencing high water stress has increased dramatically since the mid-twentieth century. For instance, Kummu *et al*. (2010) estimated that the global population exposed to high water stress increased from approximately 0.3 billion in 1960 to about 2.3 billion by 2005. These trends highlight the growing pressure on freshwater resources and emphasize the urgent need for sustainable water management strategies to ensure long-term water security.

Improved Methods for Assessing Water Scarcity

To better evaluate global water scarcity, researchers have developed improved methods for estimating water availability at the river basin level. In their study, Hoekstra and Mekonnen (2012) estimated natural water availability by using runoff data from global hydrological

assessments and adjusting it to account for human water consumption. An important aspect of their approach was the consideration of environmental flow requirements, which represent the amount of water needed to maintain healthy aquatic ecosystems. In this method, only a portion of the natural river flow is considered available for human use, while the majority must remain in the river to sustain ecological functions. Specifically, researchers suggested that when more than 20% of the natural river flow is depleted, the risk of ecological damage increases significantly.

By combining information on water consumption, environmental flow requirements, and monthly variations in water supply and demand, this approach provides a more accurate assessment of water scarcity at the river basin scale. The method allows researchers and policymakers to identify regions where water use may exceed sustainable limits and where water shortages or ecological degradation are likely to occur. Such improved assessments are essential for developing effective water management strategies and ensuring the long-term sustainability of freshwater resources. The increasing pressure on freshwater resources has significant consequences for ecosystems, economies, and human societies worldwide.

Global Impact of Water Scarcity

Water scarcity has become one of the most serious environmental challenges facing the world today. Rapid population growth, industrial expansion, and increasing agricultural demands have significantly increased the pressure on freshwater resources. As a result, many regions are experiencing severe shortages of clean and reliable water supplies. Studies indicate that a large proportion of the global population lives in areas affected by water scarcity, and millions of people still lack access to safe drinking water. In addition to natural factors such as climate variability and drought, human activities play a major role in intensifying water shortages. The overextraction of groundwater, pollution of water bodies, and inefficient water management practices further aggravate the problem. Water scarcity not only threatens human health but also affects food production, economic development, and ecosystem stability. In many parts of the world, declining water availability has led to reduced agricultural productivity and increased vulnerability to food insecurity. Furthermore, water shortages can contribute to social conflicts and migration in regions where water resources are limited. These challenges highlight the urgent need to address global water scarcity through sustainable and effective water management strategies.

Possible Solutions for Sustainable Water Management

Addressing water scarcity requires a combination of technological, environmental, and policy-based solutions. One important approach is improving the efficiency of water use in agriculture, which accounts for the largest share of global freshwater consumption. Advanced irrigation techniques, such as drip irrigation and precision agriculture, can significantly reduce water wastage. Another critical strategy is the treatment and reuse of wastewater, which can provide an additional source of water for industrial and agricultural purposes. Desalination of seawater has also emerged as an important technological solution, particularly in arid and coastal regions where freshwater resources are limited. Modern desalination technologies, especially membrane-based systems, have greatly improved the efficiency of producing freshwater from seawater. In addition to technological innovations, effective water governance and policy reforms are necessary to ensure equitable and sustainable water distribution. Public awareness and community participation also play a key role in promoting responsible water use. By adopting integrated water management strategies that combine conservation, technological innovation, and policy support, societies can better address the growing challenge of water scarcity and ensure the sustainable use of freshwater resources. By 2050, global water demand is projected to increase by 20–30%, mainly due to population growth and economic development.

Conclusion

Ensuring access to clean and sustainable water resources is one of the most critical challenges facing humanity in the twenty-first century. Increasing population growth, expanding industrial activities, climate change, and unsustainable water management practices continue to place significant pressure on global freshwater supplies. If these trends continue unchecked, water scarcity could threaten food security, economic stability, and ecosystem health in many parts of the world. Addressing this challenge requires a comprehensive approach that combines efficient water use, improved wastewater treatment, technological innovations such as desalination, and strong environmental policies. Equally important is raising public awareness about responsible water consumption and protecting natural water ecosystems. Through coordinated efforts by governments, scientists, industries, and communities, it is possible to safeguard freshwater resources and ensure that future generations have access to clean and reliable water supplies.

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POSTHARVEST QUALITY AND VASE LIFE IMPROVEMENT IN GOLDENROD

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Introduction

Goldenrod (*Solidago canadensis*) is an important ornamental filler flower belonging to the family Asteraceae. It is widely valued in the floriculture industry for its attractive bright yellow feathery inflorescences, which are commonly used as filler material in bouquets, floral arrangements and decorative designs. The crop is native to North America and is now cultivated in many parts of the world for commercial cut flower production.

Goldenrod is gaining popularity in India due to its adaptability, high yield potential and continuous demand in the floral market. However, like many cut flowers, goldenrod is also perishable after harvest. Proper postharvest handling techniques are essential to maintain flower quality, reduce postharvest losses and improve the vase life of harvested goldenrod stems.

Importance of postharvest management in Goldenrod

Postharvest management is important in maintaining the quality and longevity of goldenrod (*Solidago canadensis*) cut flowers. After harvesting, the flowers continue to respire and undergo physiological changes that may lead to wilting and reduced freshness. Improper handling can cause microbial blockage in the stem and reduce water uptake. This can shorten the vase life and affect the decorative value of the flowers used in floral arrangements. Proper postharvest practices such as timely harvesting, conditioning and use of floral preservatives help maintain freshness and extend vase life. Effective postharvest management also improves the market quality and profitability of goldenrod in the floriculture industry.

Harvesting stage

The stage of harvesting plays an important role in determining the vase life and quality of goldenrod flowers. Flower spikes should be harvested when about 25–30 per cent of the florets on the panicle have opened, while the remaining florets are still in bud stage. Harvesting at this stage allows gradual opening of flowers after placement in water, resulting in a longer display period.

Harvesting should preferably be carried out during early morning or late evening when the plant tissues are fully hydrated and temperatures are relatively low. This helps reduce water stress and prolong the freshness of the stems. Sharp and sterilized secateurs should be used for cutting to prevent damage to stems and reduce the chances of infection.

Immediate Postharvest Handling

Immediately after harvesting goldenrod (*Solidago canadensis*) stems, they should be placed in clean buckets containing fresh water to prevent dehydration and maintain freshness. Delay in placing stems in water may cause loss of turgidity and reduce vase life. Lower leaves that remain

in water should be removed to prevent microbial growth. The stems are then graded based on length, straightness and inflorescence quality before packing and transport.

Conditioning of cut stems

Conditioning helps restore the water balance in freshly harvested goldenrod flowers. In this process, cut stems are kept in clean water or preservative solution for several hours in a cool environment. This improves water uptake and maintains cell turgidity. Proper conditioning helps the flowers recover from harvest stress and improves vase life.

Pulsing treatments

Pulsing is a postharvest treatment in which freshly harvested goldenrod (*Solidago canadensis*) stems are placed in chemical solutions for a short period to improve their postharvest performance. These solutions usually contain sugars and antimicrobial substances that help maintain metabolic activity and prevent microbial blockage in the stem vessels. Common pulsing treatments include sucrose 2 to 5 (%) as an energy source, 8-hydroxyquinoline citrate (8-HQC) to control microbial growth and silver nitrate or silver thiosulphate to delay senescence. Such treatments enhance water uptake, maintain freshness and help extend the vase life of goldenrod flowers.

Storage conditions

Proper storage conditions are essential for maintaining the freshness and quality of goldenrod stems. Cold storage slows down respiration and other metabolic processes, thereby extending shelf life.

Goldenrod stems can be stored at 2–4°C with high relative humidity (90–95**%)** for short periods. Low temperature storage reduces moisture loss and helps maintain the freshness of the inflorescences during transportation and marketing. Proper packaging using moisture-resistant materials and careful handling during transport are also important to prevent mechanical damage to delicate flower spikes.

Vase solution and vase life improvement

The vase life of goldenrod (*Solidago canadensis*) flowers can be increased by using appropriate vase solutions containing sugars and antimicrobial compounds. These solutions help improve water absorption and prevent microbial growth in the stem vessels. Practices such as using clean containers, trimming stems before placing them in water and removing leaves below the water level also help maintain flower freshness.

With proper care, goldenrod stems can retain their decorative quality for about 7–10 days.

Role of good handling practices

Careful handling of goldenrod flowers during harvesting, grading, packaging and transportation is essential to preserve their quality. Rough handling may damage the delicate flower clusters and reduce their ornamental appeal. Maintaining hygiene in buckets, tools and storage areas helps minimize microbial contamination. Proper handling practices therefore play an important role in maintaining freshness and extending the vase life of goldenrod flowers

Conclusion

Goldenrod (*Solidago canadensis*) is an important filler flower widely used in the floriculture industry for its bright yellow inflorescences and decorative value. Its market quality and longevity depend greatly on proper postharvest handling practices. Techniques such as harvesting at the right stage, conditioning and suitable storage help extend the vase life of the flowers. Effective postharvest management improves both the quality and market potential of goldenrod.

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ARTIFICIAL LIGHT AT NIGHT (ALAN) AND ITS IMPACT ON AQUATIC ORGANISMS

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Abstract

Artificial Light at Night (ALAN) is increasingly recognized as a significant environmental stressor influencing aquatic ecosystems. Rapid urbanization, coastal development, and expanding infrastructure have introduced widespread artificial illumination that disrupts the natural day–night cycles to which aquatic organisms are adapted. Light penetrating water bodies can alter biological rhythms, feeding behavior, migration patterns, and reproductive activities of various aquatic organisms including plankton, fishes, crustaceans, and amphibians. In particular ALAN has been shown to interfere with plankton vertical migration, modify predator–prey interactions, and influence habitat selection and physiological processes in fishes. Such disturbances can cascade through aquatic food webs and potentially affect ecosystem productivity and biodiversity. As artificial lighting continues to expand globally, understanding its ecological consequences becomes increasingly important. Implementing environmentally sensitive lighting strategies and management practices is therefore essential to reduce light pollution and protect aquatic biodiversity.

Keywords: Artificial Light at Night (ALAN); Light Pollution; Aquatic Ecosystems; Circadian

Rhythm; Plankton Migration; Fish Behaviour; Aquatic Biodiversity; Environmental Stressors.

1. Introduction

For most of Earth's history, nights were naturally dark. After sunset, aquatic ecosystems such as rivers, lakes, wetlands, estuaries, and oceans experienced only faint illumination from the moon and stars. This predictable cycle of daylight and darkness played a crucial role in shaping the behaviour and physiology of aquatic organisms. Many species have evolved biological rhythms that depend on these natural light cycles. Darkness signals feeding times for certain fish, triggers vertical migration in plankton, and regulates reproductive events in numerous marine organisms.

However, over the past century, rapid urbanization and technological development have significantly altered the natural nighttime environment. Artificial lighting now illuminates vast areas of the planet throughout the night. Streetlights, coastal infrastructure, ports, industries, bridges, and tourist facilities emit constant light that spreads into nearby ecosystems. This widespread illumination has created a phenomenon known as **Artificial Light at Night (ALAN)**. Although often overlooked, artificial light pollution is increasingly recognized as an important environmental stressor. Scientists now understand that light can influence ecosystems just as strongly as other environmental factors such as temperature, nutrients, or chemical pollutants. Even relatively low levels of artificial illumination can disturb biological rhythms and alter ecological interactions. As a result, aquatic ecosystems that once experienced natural darkness are now exposed to continuous light, with consequences that extend from individual organisms to entire food webs.

2. ARTIFICIAL LIGHT AS AN EMERGING ENVIRONMENTAL POLLUTANT

2.1 Redefining Pollution in the Modern Era

Environmental pollution is typically associated with physical contaminants such as chemicals, plastics, oil, or heavy metals. However, scientists now recognize that pollution can also occur when natural environmental conditions are altered in ways that disrupt ecosystems. Artificial light represents one such form of ecological disturbance. Unlike chemical pollutants, artificial light does not accumulate in the environment. Instead, it changes the natural darkness that many organisms rely upon for survival. Darkness itself is an ecological resource because numerous biological processes occur only during nighttime conditions.

When artificial lighting removes or reduces natural darkness, organisms may lose the environmental signals that guide their behaviour and physiological functions.

2.2 Role of Modern Lighting Technologies

The widespread adoption of energy-efficient lighting technologies has accelerated the spread of light pollution. Modern LED lights are highly efficient and widely used in urban infrastructure, but they emit large amounts of blue-wavelength light. Blue light penetrates water more effectively than longer wavelengths, allowing artificial illumination to travel deeper into aquatic systems. Another important factor is **skyglow**, which occurs when artificial light is scattered by particles in the atmosphere. Skyglow can illuminate large areas far beyond the original source of light. Consequently, even remote ecosystems located far from cities may experience increased nighttime brightness. These factors have contributed to the rapid expansion of artificial light pollution across both terrestrial and aquatic environments.

3. SOURCES OF ARTIFICIAL LIGHT AFFECTING AQUATIC ECOSYSTEMS

3.1 Urban Waterfront Development

Urban areas located near rivers, lakes, and coastlines are major contributors to artificial lighting. Streetlights, residential buildings, and commercial establishments situated along waterfronts often cast direct illumination onto nearby water bodies.

3.2 Transportation Infrastructure

Bridges and highways crossing rivers or estuaries are frequently illuminated for safety and navigation. While these lights are essential for transportation, they can significantly increase nighttime brightness in aquatic habitats.

3.3 Ports and Coastal Industry

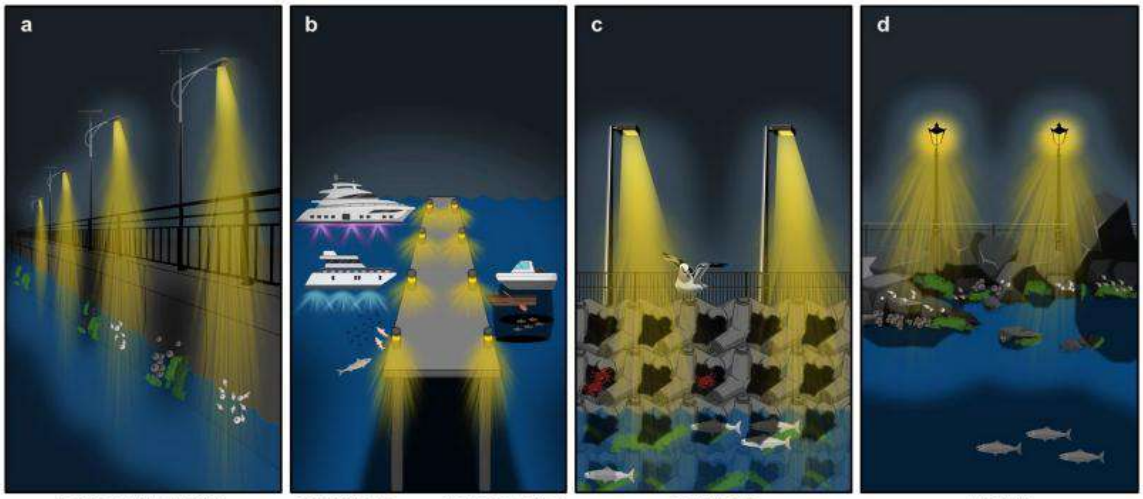
Ports and harbours are among the most brightly illuminated areas along coastlines. These facilities operate continuously throughout the night and require intense lighting for navigation, cargo handling, and security purposes. As a result, surrounding waters may remain illuminated for long periods.

3.4 Tourism and Recreational Lighting

Coastal tourism also contributes significantly to light pollution. Beach resorts, waterfront promenades, and recreational facilities often maintain decorative lighting throughout the night. Although such lighting enhances aesthetic appeal, it may unintentionally affect nearby aquatic ecosystems.

3.5 Offshore Structures and Aquaculture Facilities

Offshore oil platforms, fishing vessels, and aquaculture farms also emit strong artificial lighting. In some cases, these lights are used intentionally to attract fish or plankton. However, such practices may alter natural ecological interactions in surrounding waters.



DIFFERENT FORMS OF ALAN

4. ECOLOGICAL PATHWAY OF ARTIFICIAL LIGHT EFFECTS

Artificial light affects aquatic ecosystems through a series of interconnected processes that begin with the introduction of light and eventually influence entire ecological communities.

Mechanism of ALAN Impact

Human Urbanization and Coastal Development

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Increased Artificial Lighting

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Light Penetration into Water Bodies

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Disruption of Natural Photoperiod

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Physiological and Behavioural Changes

in Aquatic Organisms

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Altered Predator–Prey Relationships

↓

Changes in Aquatic Food Webs

↓

Ecosystem Imbalance

This sequence demonstrates that artificial light can initiate ecological disturbances that propagate through multiple trophic levels.

5. DISRUPTION OF BIOLOGICAL AND CIRCADIAN RHYTHMS

5.1 Importance of Circadian Rhythms

Many aquatic organisms possess internal biological clocks known as **circadian rhythms**. These rhythms regulate daily cycles of activity such as feeding behaviour, metabolic processes, hormone secretion, and reproduction. Light serves as the primary environmental signal that synchronizes these internal clocks with the external environment.

5.2 Effects of Artificial Light on Hormonal Regulation

Artificial light at night interferes with natural circadian rhythms by creating conditions that resemble daylight. One of the most significant physiological consequences is the suppression of **melatonin**, a hormone that signals darkness and regulates biological timing. When melatonin production is disrupted, organisms may experience altered activity patterns, increased stress levels, and reduced physiological performance.

5.3 Impacts on Fish Physiology

Fish exposed to continuous nighttime illumination may exhibit abnormal swimming behaviour, changes in feeding patterns, and disturbances in energy metabolism. Over time, these disruptions may affect growth, survival, and reproductive success.

6. BEHAVIOURAL CHANGES IN AQUATIC ORGANISMS

6.1 Phototaxis and Attraction to Light

Many aquatic organisms exhibit **phototactic behaviour**, meaning they are attracted to or repelled by light sources. Zooplankton, small fish, and certain invertebrates are often drawn toward illuminated areas. Artificial lighting near docks, piers, or harbour structures can therefore create zones where organisms aggregate in unusually high densities.

6.2 Consequences for Predator–Prey Interactions

These aggregations may attract predators that exploit the improved visibility provided by

artificial lighting. Predatory fish can locate prey more easily under illuminated conditions, leading to increased predation rates. Over time, such changes can alter natural population dynamics and disrupt ecological balance within aquatic ecosystems.

7. DISRUPTION OF DIEL VERTICAL MIGRATION

7.1 The Largest Daily Migration on Earth

Diel vertical migration (DVM) is one of the most remarkable phenomena in aquatic ecosystems. Every night, billions of zooplankton ascend toward the water surface to feed on phytoplankton. During daylight hours, they retreat to deeper waters to avoid predators.

7.2 Influence of Artificial Light

Artificial lighting can interfere with this migration by simulating daylight conditions at the water surface. When zooplankton detect light, they may remain in deeper waters instead of migrating upward. This behavioural change reduces feeding efficiency and may affect the transfer of energy through aquatic food webs.

8. IMPACTS ON AQUATIC INSECTS AND INVERTEBRATES

8.1 Attraction of Aquatic Insects to Artificial Lights

Many aquatic insects emerge from water bodies at night to reproduce. Artificial lights strongly attract these insects, often causing them to congregate around illuminated structures rather than returning to water bodies.

8.2 Consequences for Ecosystem Functioning

This attraction can lead to increased mortality and reduced reproductive success. Declines in aquatic insect populations may subsequently affect predators such as fish, birds, and amphibians that depend on insects as a food source.

8.3 Effects on Coral and Marine Invertebrates

Marine invertebrates such as corals also rely on natural light cycles. Many coral species synchronize spawning events with lunar phases. Artificial illumination from coastal developments can interfere with these natural cues and disrupt reproductive timing.

9 EFFECTS ON PRIMARY PRODUCERS

Artificial light can influence primary producers such as algae and phytoplankton by extending the duration of light exposure. Under natural conditions, photosynthesis occurs only during daylight hours. However, artificial lighting may prolong photosynthetic activity during nighttime.

Extended illumination can alter nutrient uptake patterns and favour certain algal species over others. In nutrient-rich waters, this may contribute to the development of algal blooms, which can affect water quality and ecosystem stability.

10. MITIGATION AND SUSTAINABLE LIGHTING PRACTICES

- **Improved Lighting Design**

  Directional lighting systems that focus light downward can prevent unnecessary illumination of surrounding environments.

- **Spectral Management**

  Reducing the use of blue-rich LED lighting and adopting warmer color temperatures may minimize ecological disruption.

- **Temporal Lighting Control**

  Switching off unnecessary lights during late-night hours can significantly reduce exposure for nocturnal organisms.

- **Dark Sky Conservation Areas**

  Establishing protected areas with minimal nighttime lighting helps preserve natural darkness in ecologically sensitive habitats.

Conclusion

Artificial Light at Night has emerged as an important but often overlooked environmental challenge affecting aquatic ecosystems worldwide. By altering natural patterns of darkness, artificial lighting disrupts biological rhythms, modifies animal behaviour, and reshapes ecological interactions.These effects extend across multiple trophic levels, influencing organisms from microscopic plankton to fish and coral reef communities. As urbanization and coastal development continue to expand, addressing light pollution will become increasingly important for protecting aquatic biodiversity.

Through improved lighting technologies, responsible infrastructure planning, and increased environmental awareness, it is possible to reduce the ecological impacts of artificial lighting and preserve the natural darkness upon which many aquatic organisms depend.

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IN SITU DETERMINATION OF PIGMENT CONCENTRATION IN AQUATIC ECOSYSTEMS

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Abstract

In situ determination of pigment concentration is a modern approach that measures photosynthetic pigments directly in aquatic environments, enabling real-time, high-resolution assessment of ecosystem dynamics. Photosynthetic pigments, including chlorophylls, carotenoids, and phycobilins, play a vital role in capturing solar energy and are widely used as indicators of phytoplankton biomass, primary productivity, and water quality. Among these, chlorophyll a is the most commonly used proxy for evaluating trophic status and biological productivity in both marine and freshwater systems. Traditional laboratory-based methods such as spectrophotometry and high-performance liquid chromatography (HPLC) provide accurate results but are often time-consuming and labour-intensive, and are prone to pigment degradation during sampling and processing. In contrast, in situ techniques employ advanced optical instruments such as fluorometers, spectroradiometers, and multi-parameter sondes to measure fluorescence and light absorption directly in the field. Remote sensing technologies further enhance large-scale monitoring capabilities. However, measurement accuracy can be affected by environmental factors such as light intensity, temperature, turbidity, and species composition, necessitating proper calibration and quality control. Overall, in situ pigment determination is a powerful and efficient tool for environmental monitoring, aquaculture management, and climate research.

Introduction

Photosynthetic pigments are fundamental biochemical compounds that enable autotrophic organisms such as phytoplankton, macroalgae, cyanobacteria, and higher aquatic plants to capture solar energy and convert it into chemical energy through photosynthesis. These pigments include chlorophylls, carotenoids, and phycobilins, each with distinct absorption characteristics and ecological significance. Among these, chlorophyll-a is the most important and widely used indicator of phytoplankton biomass and primary productivity in aquatic ecosystems. The distribution and concentration of pigments provide critical insights into ecosystem health, trophic status, nutrient availability, and biological productivity. Traditionally, pigment analysis has been carried out through laboratory-based techniques such as spectrophotometry and high-performance liquid chromatography (HPLC). These methods require water sampling, filtration, pigment extraction (usually using organic solvents like acetone), and subsequent analysis. While highly accurate, such methods are:

- Time-consuming
- Labor-intensive
- Limited in spatial and temporal resolution
- Susceptible to pigment degradation during handling

Instrumentation and Techniques

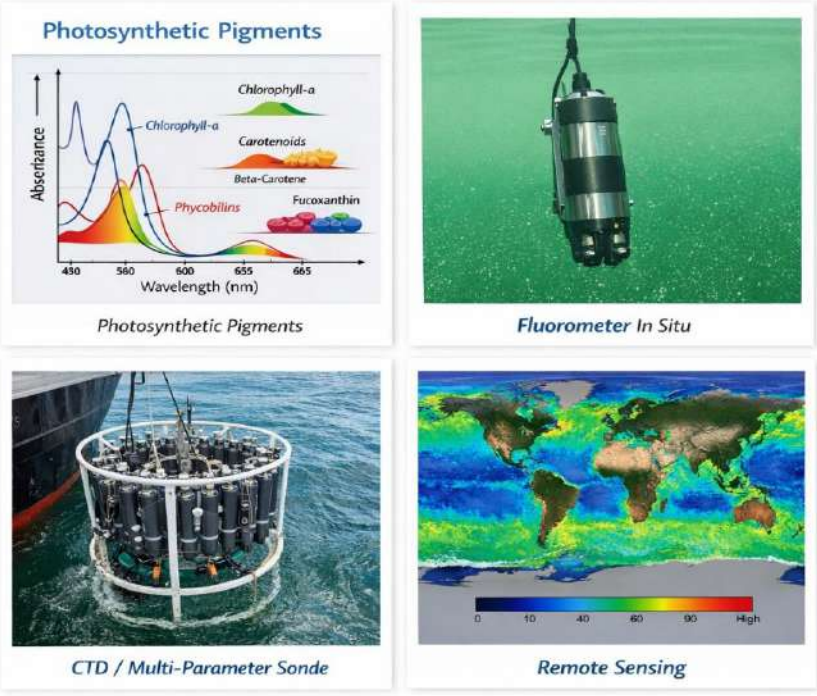
The advancement of in situ pigment determination has been largely driven by the development of sophisticated instruments capable of measuring optical signals in aquatic environments. Among these, fluorometers are the most widely used devices. Fluorometers operate by emitting light at a specific excitation wavelength, which is absorbed by the pigment molecules, causing them to fluoresce. The emitted fluorescence is then detected and converted into an electrical signal, which is proportional to the pigment concentration. Submersible fluorometers can be deployed directly in water bodies to provide continuous, real-time measurements of chlorophyll-a and other pigments. These instruments are highly sensitive and can detect even low concentrations of pigments, making them suitable for a wide range of applications.

Spectroradiometers represent another important class of instruments used in in situ pigment determination. These devices measure the spectral distribution of light in water, including both absorption and reflectance. By analyzing the spectral signatures of different

pigments, spectroradiometers can provide detailed information about the composition and distribution of phytoplankton communities. Hyperspectral radiometers, in particular, offer high spectral resolution and are capable of detecting subtle variations in pigment composition.

Multi-parameter sondes, often integrated with CTD (conductivity, temperature, depth) sensors, are commonly used for profiling pigment concentrations in the water column. These instruments allow researchers to measure chlorophyll fluorescence along with other physical and chemical parameters, providing a comprehensive understanding of water quality and ecosystem dynamics. The ability to obtain vertical profiles is particularly important in stratified water bodies, where pigment concentrations can vary significantly with depth.

Remote sensing technologies have further expanded the scope of pigment determination by enabling large-scale monitoring of aquatic ecosystems. Satellite-based sensors such as MODIS and SeaWiFS measure ocean color by detecting the spectral reflectance of sunlight from the water surface. Using bio-optical algorithms, these measurements are converted into estimates of chlorophyll concentration and other pigment-related parameters. Remote sensing provides synoptic coverage of vast oceanic and coastal regions, making it an invaluable tool for studying global patterns of primary productivity and detecting large-scale phenomena such as algal blooms.



Types of Pigments and Their Ecological Significance

Photosynthetic pigments are essential biochemical compounds present in aquatic primary producers such as phytoplankton, macroalgae, and cyanobacteria, where they play a central role in capturing light energy for photosynthesis. These pigments can be broadly classified into three major groups: chlorophylls, carotenoids, and phycobilins. Each group possesses distinct structural characteristics, absorption properties, and ecological functions, making them important indicators of species composition, environmental conditions, and ecosystem productivity.

Chlorophylls are the primary pigments responsible for photosynthesis and are present in all oxygenic photosynthetic organisms. Among them, chlorophyll-a is the most significant, as it directly participates in the light reactions of photosynthesis and serves as a universal indicator of phytoplankton biomass and primary productivity in aquatic ecosystems. Chlorophyll-a absorbs light mainly in the blue (~430 nm) and red (~665 nm) regions while reflecting green light, which gives aquatic plants and algae their characteristic color. Other forms, such as chlorophyll-b and chlorophyll-c, function as accessory pigments that broaden the range of light absorption. Chlorophyll-b is commonly found in green algae and higher plants, while chlorophyll-c is typical of diatoms, dinoflagellates, and brown algae. The presence and relative proportions of these chlorophyll types are often used to identify different phytoplankton groups and assess community composition in marine and freshwater environments. Ecologically, chlorophylls are crucial for estimating primary productivity, monitoring eutrophication, and evaluating the trophic status of water bodies.

Carotenoids form the second major class of pigments and are widely distributed among phytoplankton and algae. These pigments include compounds such as β-carotene, fucoxanthin, and peridinin, each associated with specific algal groups. Carotenoids absorb light primarily in the blue-green region (400–550 nm), complementing the absorption spectrum of chlorophylls and enhancing the efficiency of photosynthesis under varying light conditions. In addition to their role in light harvesting, carotenoids serve an important protective function by dissipating excess light energy and preventing oxidative damage to the photosynthetic apparatus. This photoprotective role is particularly significant in environments with high light intensity or fluctuating light conditions. Ecologically, carotenoids are valuable biomarkers for identifying phytoplankton composition; for instance, fucoxanthin is characteristic of diatoms, while peridinin is associated with dinoflagellates. Thus, the study of carotenoid distribution helps in

understanding phytoplankton dynamics, ecological succession, and environmental stress responses.

Phycobilins constitute the third major group of pigments and are water-soluble proteins found primarily in cyanobacteria and red algae. The main types include phycoerythrin, which appears red, and phycocyanin, which appears blue. These pigments absorb light in the green to orange wavelengths (approximately 500–650 nm), enabling organisms to utilize light that is not efficiently absorbed by chlorophylls. This adaptation is particularly advantageous in deeper or turbid waters where light penetration is limited and shifted toward longer wavelengths. Phycobilins are organized into structures called phycobilisomes, which efficiently transfer absorbed energy to chlorophyll-a for photosynthesis. Ecologically, these pigments are important indicators of cyanobacterial populations and are widely used in monitoring harmful algal blooms (HABs), especially those dominated by toxin-producing cyanobacteria. Their presence can signal changes in nutrient conditions, particularly increased nitrogen and phosphorus levels, which favor cyanobacterial growth.

In addition to these major groups, some minor pigments and degradation products also contribute to ecological interpretations. For example, pheophytin is a degradation product of chlorophyll and indicates senescence or stress in phytoplankton populations. Similarly, xanthophylls, a subclass of carotenoids, play a role in non-photochemical quenching mechanisms that protect cells from excess light. The diversity and variability of these pigments provide a comprehensive picture of phytoplankton physiology and environmental conditions.

Calibration and Quality Control

Calibration and quality control are essential for ensuring accurate in situ pigment measurements. Optical sensors such as fluorometers and spectroradiometers estimate pigment concentration indirectly through fluorescence or light absorption, which can be influenced by environmental and biological factors. Therefore, proper calibration is required to establish a reliable relationship between sensor output and actual pigment concentration. Calibration is performed using standard solutions with known concentrations of pigments, typically chlorophyll-a. A calibration curve is generated by relating sensor response to known concentrations, and laboratory methods like spectrophotometry or HPLC are often used for validation. Regular calibration is necessary due to sensor drift caused by fouling, aging, and

changes in sensitivity. Biofouling is a major issue, making routine cleaning and maintenance essential.

Quality control involves standardized data collection procedures, including proper instrument deployment, avoiding direct sunlight, and taking replicate measurements. Outliers are removed, and results are often cross-validated with laboratory analyses. Environmental factors such as temperature, light intensity, turbidity, and CDOM can affect sensor readings. Corrections and compensation algorithms are applied to improve accuracy. Variations in species composition and physiological state of phytoplankton can also influence measurements, requiring region- or species-specific calibration models. Recent advances include automated calibration systems, real-time validation, and the use of machine learning to enhance data accuracy and detect sensor anomalies.

Environmental Factors Influencing Measurements

- Light intensity affects pigment measurement by causing fluorescence quenching and reducing accuracy.
- Temperature influences the fluorescence efficiency of pigments and sensor performance
- Turbidity interferes with measurements by scattering light due to suspended particles
- Colored dissolved organic matter (CDOM) affects readings by absorbing similar wavelengths as pigments.
- Phytoplankton species composition influences results because different species contain varying pigment levels.
- The physiological condition of cells alters fluorescence depending on stress and nutrient availability.
- Depth affects pigment concentration as light penetration decreases with increasing depth.
- Water movement such as currents and mixing causes variation in pigment distribution.
- Salinity indirectly affects optical measurements by changing water properties.
- Nutrient availability influences pigment concentration and composition in phytoplankton
- Biofouling on sensors reduces measurement accuracy by blocking optical signals.
- Dissolved oxygen and pH indirectly influence pigment stability and measurement reliability.

Applications of In Situ Pigment Determination

- In situ pigment determination is widely used to estimate phytoplankton biomass and

primary productivity in aquatic ecosystems.

- It plays an important role in monitoring water quality by detecting changes in chlorophyll concentration.
- It is used to assess eutrophication levels by identifying excessive nutrient enrichment in water bodies.
- It helps in the early detection and monitoring of harmful algal blooms, including toxic cyanobacterial blooms.
- In aquaculture, it is applied to evaluate natural food availability and maintain optimal water conditions.
- It is useful in studying spatial and temporal variations of phytoplankton in marine and freshwater environments.
- It supports climate change research by providing data on carbon cycling and ocean productivity.
- It is used in remote sensing validation to improve satellite-based chlorophyll estimation.
- It aids in ecological studies by analyzing phytoplankton community structure and dynamics.
- It is applied in environmental monitoring programs for sustainable management of aquatic resources.

Advantages

- In situ pigment determination provides real-time measurement of pigment concentration in natural aquatic environments.
- It allows continuous monitoring with high spatial and temporal resolution. The method is non-destructive and does not require sample collection or laboratory processing.
- It reduces errors associated with sample handling, storage, and pigment degradation.
- It is rapid, sensitive, and suitable for detecting even low concentrations of pigments.
- It is highly useful for large-scale and long-term environmental monitoring programs.

Limitations

- Fluorescence quenching due to high light intensity can lead to underestimation of pigment concentration.

- Measurements can be affected by environmental factors such as temperature, turbidity, and CDOM.
- Different phytoplankton species have varying pigment content, causing calibration difficulties.
- Biofouling on sensor surfaces can reduce accuracy over time.
- Regular calibration and maintenance of instruments are required.
- In situ methods have limited ability to distinguish between different pigment types compared to laboratory techniques.

Recent Advances and Future Perspectives

Recent developments in hyperspectral sensors, autonomous monitoring platforms, and machine learning techniques are revolutionizing the field of in situ pigment determination. Hyperspectral sensors provide high-resolution spectral data that can be used to identify multiple pigments simultaneously. Autonomous platforms such as gliders, buoys, and Argo floats enable continuous monitoring of remote and inaccessible regions.

The integration of artificial intelligence and big data analytics is enhancing the interpretation of complex datasets and improving predictive capabilities. Future research is expected to focus on the development of low-cost, high-precision sensors and the integration of in situ and remote sensing data for comprehensive ecosystem monitoring.

Conclusion

In situ determination of pigment concentration represents a significant advancement in the study and management of aquatic ecosystems. By enabling direct, real-time measurement of photosynthetic pigments, these techniques provide valuable insights into phytoplankton dynamics, primary productivity, and environmental conditions. Although challenges related to calibration and environmental interference remain, continuous technological innovations are enhancing the accuracy and applicability of these methods. As a result, in situ pigment determination is becoming an indispensable tool in oceanography, aquaculture, environmental monitoring, and climate research, contributing to the sustainable management and conservation of aquatic resources.

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INTEGRATED NEMATODE MANAGEMENT IN VEGETABLE CROPS

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Introduction

Vegetable crops play a significant role in the economy, providing livelihoods, employment, and contributing significantly to the national GDP. It also improves economic stability and reduces vulnerability in the price fluctuations. India is the second-largest producer of vegetables in the world after China, contributing more than 200 million tonnes annually. Vegetable cultivation is a major source of income, nutrition, and employment. Globally, nematodes are responsible for huge economic losses in vegetable production, sometimes reducing yields by as much as 30–40%. In Tamil Nadu, vegetables are cultivated on a large scale under irrigated and peri-urban farming systems. The state shows relatively high productivity due to better irrigation, hybrid seeds, and intensive cultivation

However, productivity is still below potential due to hidden soil pests like nematodes, which alone can cause 30–40% yield loss. In high-value crops like tomato and brinjal, losses can be even higher under severe infestation. This directly affects income to the farmers, supply to the market and nutritional security.

There are several types of nematodes that affect vegetable crops. The most important nematodes include:

- Root-knot nematodes (*Meloidogyne* spp.)
- Lesion nematodes (*Pratylenchus* spp.)

- Burrowing nematodes (*Radopholus similis*)
- Sting nematodes (*Hoplolaimus* spp.)
- Potato cyst nematodes (*Globodera* spp.)

Common symptoms

Below- ground symptoms

- Root galls (knots) symptoms
- Low population → few, separate galls, visible egg masses
- High population → clustered galls, deformed roots, egg masses inside roots
- Affects water & nutrient absorption

Above-ground symptoms

- Yellowing
- Wilting
- Stunted growth
- Nutrient deficiency symptoms
- Severe infection → damping-off & plant death
- Reduces flowering and fruit yield/size

Major components of INM

- Cultural methods
- Chemical control
- Biological methods
- Physical control
- Resistance and plant breeding

Cultural Practices

Crop rotation: Growing non-host crops like sesame, mustard, wheat and barley etc. Helps break the nematode life cycle

Use of trap crops: These attract nematodes but do not allow them to reproduce the crops such as *Crotalaria spectabilis*.

Cover crops: It reduces nematode population, breaks the life cycle of the nematode and improves soil health and the crops like sunhemp, cowpea, marigold.

Green manuring: Certain plants release substances that suppress nematodes population the crops such as daincha, gliricida and sunhemp.

Intercultural operations: The intercultural operations like proper irrigation management, maintaining soil health through good drainage and application of organic matters.

Resistant varieties: Use of resistant varieties is the one of the effective methods. For instance, in tomato Hisar Lalit and potato Kufri Swarna are the best resistant varieties.

Chemical Control

Nematicides can be used when nematode infestation is severe. These chemicals helps to reduce nematode population quickly. However, they are expensive, they may harm beneficial organisms themselves

- Fluensulfone
- Fluopyram
- Oxamyl
- Fosthiazate

Biological Control

Biological methods are eco-friendly and sustainable. This is a method of using a living organism such as predacious nematodes, predacious fungi, nematode trapping fungi, and bacteria to manage the nematode populations. They involve the use of beneficial organisms such as:

- *Pochonia chlamydosporia*
- *Paecilomyces lilacinus*
- *Pseudomonas fluorescens*
- *Bacillus* spp.

Physical methods

Soil solarization:

Soil solarization is an environmentally friendly method of controlling soil-borne pests, diseases, and weeds by using solar energy to heat the soil. And the process lasts for 4 to 6 weeks during the summer period, and the temperature is 60 degree Celsius.

Resistance and Plant Breeding

Developing and using nematode-resistant crop varieties is an effective strategy. Resistant plants can reduce nematode multiplication and protect yields.

However, resistance may break down over time, so continuous research and breeding efforts are needed.

Environmental and Economic Aspects

- Integrated management reduces dependence on chemicals, making it safer for the environment. It also improves soil fertility and supports sustainable farming.
- Although some methods may require initial investment, INM is cost-effective in the long run due to improved yield and reduced input costs.

Major challenges of INM

- Lack of awareness among farmers
- Limited availability of biocontrol agents
- Slow action compared to chemicals
- Need for proper knowledge and planning

Future Prospects

New technologies such as bio fumigation, nanotechnology, and molecular tools are being developed for better nematode management. Increasing farmer awareness and research support will further improve INM practices.

Conclusion

Nematodes are a hidden but serious threat to cultivation of vegetable crops. Managing them requires a scientific and requires a balanced approach. Integrated Nematode Management offers an effective solution through combining different methods in a sustainable way. Healthy soil leads to healthy crops, and integrated management is the key to achieving long-term agricultural success.

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GENOME-WIDE ASSOCIATION STUDIES (GWAS) IN CROP IMPROVEMENT: FROM MARKERS TO TRAITS

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Abstract

Genome-Wide Association Studies (GWAS) have emerged as a powerful approach in plant genetics and breeding for dissecting complex traits. By exploiting natural genetic variation and high-density molecular markers, GWAS enables the identification of marker–trait associations with high resolution. This review provides a comprehensive overview of GWAS principles, methodology, statistical models, applications in crop improvement, and future prospects. The integration of GWAS with modern breeding tools such as genomic selection and gene editing offers immense potential for accelerating crop improvement and ensuring food security.

Keywords

GWAS, SNP, Linkage Disequilibrium, Plant Breeding, QTL Mapping, Genomic Selection

Introduction

Understanding the genetic basis of complex traits is a major objective in plant breeding. Traditional QTL mapping approaches are limited by low resolution and biparental populations (Collard and Mackill, 2008). Genome-Wide Association Studies (GWAS) overcome these limitations by utilizing diverse germplasm and historical recombination events (Mackay and Powell, 2007; Zhu et al., 2008).

GWAS identifies associations between genetic markers, primarily single nucleotide polymorphisms (SNPs), and phenotypic traits. With advancements in next-generation sequencing (NGS) and high-throughput phenotyping, GWAS has become an indispensable tool in modern crop improvement programs (Korte and Farlow, 2013).

The unified mixed linear model approach significantly improved GWAS accuracy by controlling population structure and kinship effects (Yu et al., 2006). Further refinements using PCA-based correction have enhanced the control of false-positive associations (Price et al., 2006; Devlin and Roeder, 1999).

Principle of GWAS

GWAS is based on the concept of linkage disequilibrium (LD), which refers to the non-random association of alleles at different loci (Mackay and Powell, 2007). When a marker is in LD with a gene controlling a trait, it shows statistical association with the phenotype.

Key Requirements:

- Diverse population (natural or germplasm collection)
- High-density molecular markers (SNPs)
- Accurate phenotyping
- Statistical models to control false associations

Methodology of GWAS

GWAS involves the use of diverse germplasm panels, precise phenotyping, and high-density SNP markers to detect marker–trait associations (Zhu et al., 2008). Statistical models are then applied to correct population structure and kinship effects to reduce spurious associations (Yu et al., 2006; Kang et al., 2010).

Step 1: Selection of Population

- Diverse germplasm panel
- Landraces, elite lines, or core collections

Step 2: Phenotyping

- Precise measurement of traits
- Multi-location and multi-season evaluation

Step 3: Genotyping

- SNP markers using NGS platforms
- High-density genome coverage

Step 4: Data Analysis

- Statistical association between markers and traits
- Correction for population structure and kinship

Statistical Models in GWAS

General Linear Model (GLM)

- Simple model
- Does not account for population structure

Mixed Linear Model (MLM)

- Accounts for population structure (Q) and kinship (K)
- Reduces false positives (Yu et al., 2006; Kang et al., 2010).

Advanced Models

- FarmCPU (Fixed and random model Circulating Probability Unification)
- BLINK (Bayesian-information and Linkage-disequilibrium Iteratively Nested Keyway)

GWAS Workflow (Flowchart)

Germplasm Collection

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Phenotyping (Traits)

↓

Genotyping (SNP Markers)

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Data Quality Control

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Population Structure & Kinship Analysis

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Statistical Analysis (GWAS Models)

↓

Significant Marker–Trait Associations

↓

Candidate Gene Identification

↓

Application in Breeding

Applications of GWAS in Crop Improvement

GWAS has been widely applied in identifying loci controlling yield, disease resistance, and abiotic stress tolerance in crops (Atwell et al., 2010; Varshney et al., 2017).

It has facilitated the discovery of genes associated with agronomic and quality traits, enabling precise crop improvement strategies.

Yield and Yield Components

- Identification of loci controlling grain yield, plant height, flowering time

Biotic Stress Resistance

- Disease resistance genes (blast in rice, rust in wheat)
- Insect resistance traits

Abiotic Stress Tolerance

- Drought tolerance
- Salinity tolerance
- Heat stress adaptation

Quality Traits

- Grain quality, protein content, oil content

Table 1. Representative applications of GWAS in major crops

Crop	Trait Studied	GWAS Outcome	Breeding Relevance
Rice	Blast resistance	Significant SNPs linked to resistance loci	Marker-assisted selection
Wheat	Rust resistance	Candidate genes/QTL regions identified	Resistant variety development
Maize	Drought tolerance	Stress-responsive SNP markers detected	Climate-resilient breeding
Soybean	Seed protein/oil	Marker–trait associations identified	Quality improvement

Advantages of GWAS

- High mapping resolution
- Utilizes natural populations
- No need for population development
- Simultaneous analysis of multiple alleles

Limitations of GWAS

- False positives due to population structure
- Rare allele detection is difficult

- Requires large population size
- High computational requirements

Integration of GWAS with Modern Breeding

GWAS and Marker-Assisted Selection (MAS)

- Significant markers can be used for selection

GWAS and Genomic Selection (GS)

- GWAS contributes to genomic prediction models, improving breeding efficiency and genetic gain (Heffner et al., 2009; Crossa et al., 2017).

GWAS and Genome Editing

- Candidate genes identified can be edited using CRISPR/Cas (Chen et al., 2019).

Future Prospects

- Multi-trait GWAS
- Integration with phenomics and envirotyping
- Use of artificial intelligence in GWAS analysis
- Development of climate-resilient crops

Conclusion

GWAS has revolutionized the field of plant genetics and breeding by enabling precise identification of genetic loci associated with complex traits. Despite certain limitations, its integration with advanced genomic and breeding tools holds great promise for accelerating crop improvement. Continued advancements in sequencing technologies and statistical methods will further enhance the efficiency and applicability of GWAS in sustainable agriculture.

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LIQUID CLUES: HOW ENVIRONMENTAL DNA (EDNA) DETECTS DISEASE IN AOUACULTURE SYSTEMS

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Abstract

Traditional aquaculture management relies on visual signs, often detecting disease too late. Environmental DNA (eDNA) technology provides a non-invasive alternative by identifying genetic material shed by organisms into their surroundings. The eDNA workflow—comprising sampling, filtration, extraction, and amplification—detects pathogens at trace levels before clinical symptoms appear. This allows for early intervention, significantly reducing mortality and economic losses. Beyond pathogen surveillance, eDNA supports biosecurity and ecosystem health assessment. While challenges like DNA degradation and initial costs exist, the technology facilitates a shift toward precision aquaculture. By integrating eDNA with artificial intelligence and real-time sensors, water is transformed into a source of biological intelligence. This evolution from reactive treatment to proactive prevention enhances the sustainability and resilience of aquaculture systems, turning every drop of water into a vital diagnostic tool.

Keywords: eDNA, health monitoring, pathogen detection

Introduction: The Invisible Crime Scene

In aquaculture systems, maintaining proper water quality and stock health is very important. Farmers rely mainly on visual signs, but aquaculture systems often appear stable and productive until a sudden disease outbreak. By the time visible symptoms or mortality are observed, the infection has spread. To overcome this, Environmental DNA (eDNA) offers a

powerful approach as water itself holds critical biological information long before disease becomes visible, enabling early detection and more effective management practices.

What is eDNA?

Environmental DNA (eDNA) refers to the genetic material released by organisms into their surroundings. In aquatic ecosystems, microorganisms, fish and shrimp continuously shed DNA through mucus, faeces, scales, gametes, and decomposing tissues. These genetic traces tend to remain suspended in water, allowing us to detect the organisms without direct sampling. Hence, eDNA provides a non-invasive method for monitoring both cultured species and potential pathogens in the aquaculture environments.

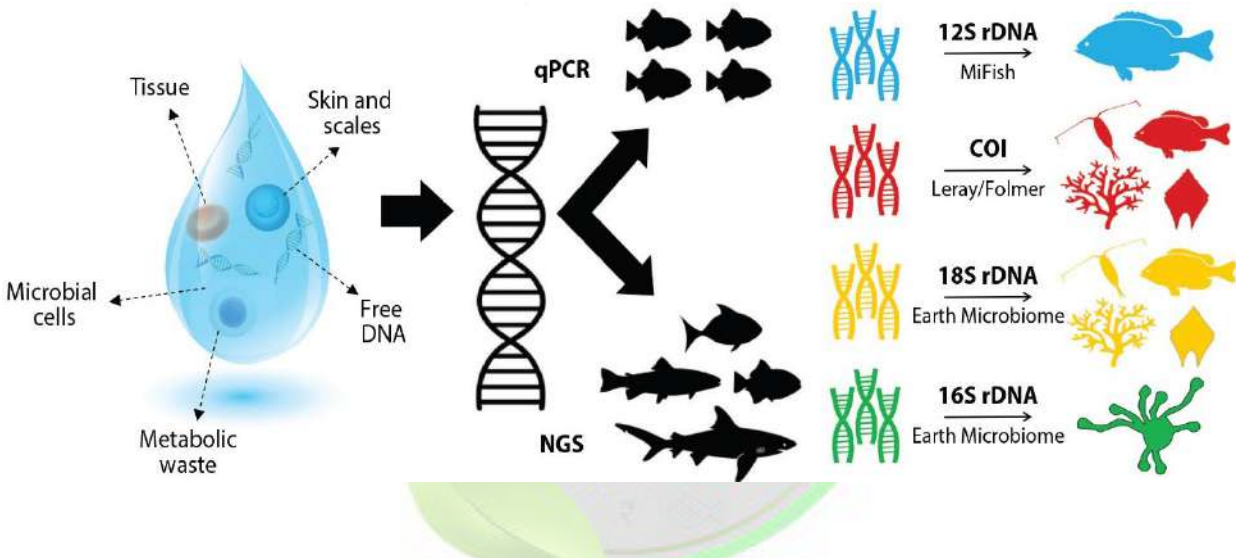

Figure 2: eDNA suspended in water containing living cells, metabolic waste, parts of organisms, or dissolved material (Chavenz et al., 2021)

From Drop to Data: How eDNA Works

The eDNA analysis process involves multiple key steps as follows:

- **Water Sampling:** Since it is the foundation of analysis, it should represent the culture environment accurately. Sampling should cover all the possible aspects, like both surface and bottom layers of water, areas near feeding zones or aerators, sampling time, water movement and mixing patterns
- **Filtration:** Water contains a very low concentration of DNA, so the collected water is filtered to concentrate DNA fragments and microbial cells present.

- **DNA Extraction:** The captured material is then processed to extract the DNA, removing the impurities that may interfere with analysis. Efficient extraction ensures high-quality DNA for accurate detection.
- **Amplification:** The extracted DNA is then amplified using molecular techniques such as PCR or qPCR, which increase the quantity of specific DNA sequences. This allows even trace amounts of pathogen DNA to be detected, making it possible to identify disease-causing organisms at very early stages.
- **Detection and Identification:** DNA is matched with reference databases to identify pathogens and microbial communities.
- **Data Interpretation:** The results provide early warning of disease risks and support farm decisions like treatment, water management, and biosecurity.

Early Detection: A Breakthrough in Disease Management

One of the most significant advantages of eDNA is its ability to detect pathogens before clinical signs appear. Disease-causing organisms such as bacteria, viruses, and parasites can be identified at very low concentrations.

This early detection capability enables timely interventions, reduced mortality rates and lower economic losses. By shifting the focus from treatment to prevention, eDNA strengthens overall health management goals in aquaculture.

Application of eDNA in Aquaculture

Pathogen Surveillance

eDNA enables continuous monitoring of harmful microorganisms, including bacterial, viral and parasitic agents. It allows for early identification and detection of potential pathogens and disease threats within the systems.

Stock Health Monitoring

Changes in microbial communities detected through eDNA indicate stress conditions in the culture environment. This provides valuable insights towards the overall stock health and system stability.

Biosecurity Management

The risk of introducing pathogens into the aquaculture systems can be reduced by using eDNA to screen the incoming water sources.

Ecosystem Health Assessment

eDNA helps maintain ecological stability within aquaculture systems by tracking biodiversity and microbial balance, ensuring a healthy culture environment.

Why It Matters: Advantages Over Traditional Methods

Compared to conventional diagnostic approaches, eDNA offers several benefits:

- It is non-invasive, thereby eliminating the need to handle organisms, causing unnecessary stress.
- The test is highly sensitive and capable of detecting pathogens even at low levels.
- It enables early disease detection and management
- It allows for simultaneous monitoring of multiple organisms and improves long-term cost efficiency through prevention
- Reduces dependence on visual observations

Challenges and Limitations

Despite the advantages, eDNA technology does face certain limitations:

- Possibility of false positives from residual DNA
- DNA degradation due to environmental conditions
- Requirement of specialised equipment and technical expertise
- Lack of standardised protocols across systems
- Initial cost barriers for small-scale farmers.

Addressing these challenges is important for broader adoption in aquaculture.

The Future: Toward Precision Aquaculture

The integration of eDNA with emerging technologies is expected to transform aquaculture practices. Real-time monitoring systems, biosensors, and automated sampling tools are being developed to enhance the data collection and analysis.

Combined with artificial intelligence, these advancements may enable predictive disease management, allowing farmers to anticipate and prevent outbreaks before they occur. This marks a shift toward precision aquaculture, where decisions are guided by continuous data insights.

Conclusion: Every Drop is a Diagnosis

Environmental DNA is redefining how aquaculture systems are monitored and managed. By transforming water into a source of biological intelligence, eDNA enables early detection of

disease and supports proactive health management.

As aquaculture continues to evolve, the ability to interpret these "liquid clues" will play a crucial role in improving sustainability, productivity, and resilience. In this new aspect, every drop of water is no longer just a medium for cultivation but a diagnosis waiting to be understood.

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SUCCESS STORY: VALUE ADDITION FOR ECONOMIC EMPOWERMENT

Article ID: AG-VO6-I04-79

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1. Introduction

Smt. Neeta ben, who belongs to Gopaliya Village in Narmada district, is a successful Entrepreneur, who has set an example for the women of Dediapada .She started her income generation activities by producing bamboo pickle and rice papad with locally available raw materials. She sold the products in the local market and friend circle. However, the income was not up to her satisfaction

Name : Neeta Ben Mukesh bhai **Village** : Gopaliya Ta: Dediapada Distt-Narmada **Age** : 34 years **Education** : 10th std **Land holding** : 5 acre	

2. Plan, Implement and Support

She approached KVK, Narmada in the year 2018, seeking know how and guidance for improving her skill In order to enhance the productivity and acceptability of her products, KVK Narmada organized Vocational trainings on income generation She was Participated in the 7 days on campus Vocational training of preparation of papad, conducted at KVK. Rice, Ragi, mushroom flour & Potato Papad, which is primarily a snack item, is very popular in Gujarat and it's eaten as a snack or along with meals also. Soon after the training she started production of value added papad with added natural herbs carom seeds, cumin seeds, Coriander, mint, red chilli etc.)

The detailed information on activities carried out by KVK and support in building farmers skills in adoption of training is shown below:-

Sr. No.	Year	Name of activity	No. of participants
1.	2017-18 to 2020-21	On campus Training	12
		Off campus Training	14
		SHG meeting	12
		Method Demonstration	10
		FLD Visit	20
		Field day	10

3. Output:

Neeta lives with a family of eight people in Gopaliya village Dediapada taluka of Narmada district in Gujarat. Her family relies mostly on farming for their diets and livelihood. She is a woman who has been actively engaged with self-help groups and has worked with KVK for the last 3 years. She joined KVK and attended training programmes, she said that prior her technical knowledge was poor now she is happy with their efforts

Vocational training

Participation in farmers fair

Potato papad

4. Outcome:

During the present lockdown, due to corona virus it is selling like home/pure products/. The demand has increased manifold and she is working overtime to meet the demand. In training programs she was given first-hand experience in demonstrating the preparation of papad, spices /ragi biscuits and red rice products. Prior to KVK her income was very less. But now after the intervention and coupled with her hard work and sincerity, her income has increased manifold.

Over the last few months, she is earning a net income of about Rs. 15,000/- (Rupees fifteen thousand) per month. She is a successful Woman Entrepreneur and a perfect example of women empowerment.

5. Impact:

It can be concluded that income generation trainings found effective in view of income generation for farm women During the trainings she got new contacts (Self-Help Groups) among the trainees, from sagbara taluka of Narmada districts, who readily accepted to take up the profession of papad making. And they have started making papad at household level by taking raw materials from her.

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USE AND IMPORTANCE OF SOCIAL MEDIA IN LIVESTOCK DEVELOPMENT

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Introduction

Predominant population of India is practicing agriculture as main occupation with animal husbandry as subsidiary occupation. Considering current situation, the demand for food derived from livestock is rapidly increasing around the globe and it has led to greater changes in the livestock production supported by major technological innovations and structural modifications.

The agriculture and livestock research, education and extension are significant factors for promotion of production and efficiency with blooming developments and progression. But, due lack of adequate human resource in extension system, it is posing difficulties for systemic transfer of knowledge from lab to land because of lack of extension workers. The right information at right place at right time is the need of the hour for larger population under the changing contexts of production, technology and marketing.

However, nowadays the information and communication technologies are greatly influencing these information sources and dissemination. With the introduction of internet and social media tools like Facebook, WhatsApp, Twitter, YouTube, LinkedIn, etc., have become greater ways of sharing information.

USE OF SOCIAL MEDIA

On analysis it is evident that more than two third of livestock farmers owned smart mobile phones and more than half utilized internet connectivity in their smartphones. The efforts of Government of India for digitalization which affords cheaper mobile data and increased

broadband services leading to elevated smart phone usage. Small ruminant farmers comparatively having less awareness about social media. More than 50% of livestock farmer possessed social media account which indicates the diffusion of mobile technology and internet facility throughout the country which has greatly influenced social media awareness and account holding.

Most of the livestock farmers possessed WhatsApp and YouTube than the other social media account. Social messaging applications like WhatsApp provided user friendly communication needs such as sharing messages, photos, videos, documents, voice and video calls, which are similar to basic message service providers and special features for the creation of common interest groups. Further, YouTube, which streams animal husbandry practices through videos, was advocated by a good number of farmers.

Moreover around 58.33% of the livestock farmers in total utilized social media for accessing various livestock information needs. Since WhatsApp is being a popular application in smartphones, many farmers are exploring the opportunity to fulfill their information needs. The majority of the respondents also utilized YouTube as it contains both audio and video formats of a large amount of agriculture and livestock- related information, which implies "seeing is believing" through it is virtual. It was also noted that among the respondents, poultry farmers used WhatsApp and YouTube extensively and this accredit the need for information with the present demand in the market and changing government policies. On analysis around 82% farmers primarily used social media for obtaining latest information on livestock production and management systems followed by communication with different stakeholders, obtaining information related to housing, feeding, breeding etc., and information on health and disease management since scientific information is much needed for profitable farming.

More than 50% of livestock farmers also shared livestock-related information with farmers which indicate the potential of social media to disseminate information, generate groups and promote discussion among group members. Around 52% of livestock farmers as well advocated social media for adoption of technologies of animal husbandry and 39% to find out solutions to the problems of farming.

Since social media provides opportunities for carrying out communication and gain knowledge without being cosmopolite, many farmers had explored this utility. On analysis it is

evident that social media had higher benefits than other ICT tools in livestock farming, which might be due to the universal and instant nature of social media.

IMPORTANCE OF SOCIAL MEDIA

- Social media is defined as "websites and computer programs that allow people to
- communicate and share information on the internet using a computer or mobile phone".
- To increase production and meet the growing population's demand, livestock education,
- research, and extension play a major role.
- In this context knowledge or information is very critical for improving the production under the present extension delivery system in India
- There are several emerging ways to provide knowledge and information, and mass media is one such emerging way.
- Most of the stakeholders, including farmers around the globe use mass media
- Majority of the farmers are aware of social media and possessed social media accounts with thehighest number of WhatsApp accounts being possessed by the farmers.

Easily accessible

- The main aspect of social media which contributes to its enormous success, is the ease of access it provides to its user.
- Anyone with a mobile device or a computer along with an internet connection can easily become a user
- So, farmers can have access to new farming products via social media and also the fellow farmer ever far end of the world.

Create and share visuals and content

- Users can create content using visuals, audio, or text. They can start private forums, public
  discussions, audio pods, and even blogs
- So, farmers can find content, visuals, and audio across genres and on any varied topic related to farming and livestock rearing.

Communication with a large group at the same time

- Social media helps in widespread to an extreme population
- Any news can become viral and reach everyone on time.

• It helps farmers in sharing information such as natural disasters, and disease outbreaks, sooner than any other way.

Everyone is an active participant

• On social media platforms, all the users are participants. Compare it with traditional media like newspapers, wherein, information is simply imparted

• Social media platforms work on a two-way basis. You can share your experience, give your opinions, reviews, exchange information on a real-time basis.

Flexible and dynamic

• Since users are active participants; the contents and tools are continuously updated and improved

• They are always improved to provide better user experiences.

Cost-effective

• The user needs to bear only the internet expense to enter the social media world. Also, retaining these platforms does not require any cost.

• We need not spend lots of money to advertise or communicate.

EMERGING TECHNOLOGIES

Interactive broadcasting

• Production process that prepare the audiovisual assets and computer programmes for an interactive TV end user experience.

• Augmented reality –blends real environment with interactive computer graphics that are controlled either at the TV studio or at end user terminal.

Satellite radio

• The satellite's signal are broadcast nation wide, across a much wider geographical area than terrestrial radio stations.

Videodisc

• It is a product of the optical disc family and it has tremendous capacity to store information, data, visuals and voice.

• It can be interfaced with a computer to create an interactive environment.

Compact disc-interactive

• Is an optical storage system and an interactive tool

• Sophisticated audio-video tool that supports a variety of playback format.

• It can also support animation, video and photographic quality images.

Mobile Communication

• Allows us to communicate with others in different locations without the use of any physical connection.

Use of social media tools in livestock development

1.Education and knowledge sharing

YouTube:

Farmers can create educational videos on livestock management practices, breeding techniques, disease prevention, and treatment protocols. This helps in disseminating expert knowledge widely and accessibly.

Facebook groups:

Join or create groups focused on specific livestock breeds or farming techniques to share experiences, advice, and solutions to common problems.

LinkedIn:

Share and access research papers, case studies and industry reports that can help farmers stay updated with the latest advancements in livestock development.

2.Marketing and sales

Facebook and Instagram

Promote livestock sales and farm products through visually appealing posts and advertisements. Stories and posts can highlight special offers, success stories and customer testimonials to build trust and attract buyers.

Twitter:

Use hashtags and real -time updates to announce sales events, new arrivals and market prices. Engaging with industry trends can also help increase visibility.

TikTok:

Showcase unique aspects of livestock and farm life in a fun and engaging way to attract a younger audience. Viral content can significantly boost awareness and interest in livestock products.

3.Community engagement and advocacy:

Facebook and Instagram:

Share stories and updates about farm activities, animal welfare practices and

sustainability efforts to build a community of supporters and advocates.

Twitter:

Participate in advocacy campaigns and engage in conversations about agricultural policies, sustainability and animal welfare. This can help influence public opinion and policy decisions.

LinkedIn:

Connect with agricultural organisations, policymakers and other stakeholders to advocate for industry needs and share the farm's impact and achievements.

4.Networking and professional development

LinkedIn:

Join professional groups and networks related to animal husbandry and agriculture. This facilitates knowledge exchange, collaborations and staying informed about industry trends and opportunities.

Facebook groups and twitter:

Participate in discussions and forums to connect with other farmers, researchers and professionals, sharing experiences and learning from each other.

5.Crisis management and misinformation control

Twitter and Facebook:

Quickly address misinformation and provide accurate information about livestock practices and farming challenges. Engaging directly with consumers and the public helps build credibility and trust.

YouTube:

Post detailed videos explaining complex issues or addressing specific incidents to provide transparency and clarity, mitigating negative perceptions.

6.Customer interaction and Feedback:

Instagram and Facebook:

Use direct messages, comments and interactive posts to engage with customers, answer their questions and gather feedback on products and services.

Twitter:

Respond to customer inquiries and feedback promptly, using the platform's real-time capabilities to maintain open lines of communication.

7.Innovative Use of Technology:

Social media management tools:

Platforms like Pinnacle Livestock solutions offer professional services to manage social media presence, create content, and analyze performance metrices. This helps farmers focus on their core activities while maintaining an effective online presence.

Conclusion

The need for current and relevant information through social media has become essential for improving agriculture and livestock production. The WhatsApp, YouTube, and Facebook were the most commonly used social media tools by majority of the livestock farmers to gain scientific information on various aspects of livestock production. Therefore, these findings project that, respondents predominantly perceived that social media tools had higher benefits in attaining livestock related information and utilization of virtual knowledge into practice. Further, these results also encourage the adoption of farmer friendly social media tools for association between farmers and dissemination of information ultimately leading to improvement in livestock production and sustainability.

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COMMON WHEAT DISEASES IN INDIA

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Introduction

Wheat is highly susceptible to a wide range of fungal, bacterial, and viral diseases, among which rusts and smuts are the most significant. This article focuses on the major wheat diseases, with special emphasis on their field identification to enable farmers and researchers to adopt timely and effective preventive measures for minimizing damage and safeguarding crop yield.

1. **Leaf Rust**

Causal organism: *Puccinia recondita*

Commonly known as brown or orange rust, this is the most prevalent rust disease of wheat in northern and eastern India, particularly in Punjab, Bihar, and Uttar Pradesh. It is the earliest rust to appear, usually on 6-week-old plants during late November. The urediospores are initially orange, later turning brown, and are spherical, measuring 16-28 µm in diameter, with finely echinulate walls and 7-10 germ pores. Infection occurs when germ tubes penetrate the host through stomata. The teliospores are brown, smooth, and typically 2-3-celled. Under favourable conditions, rapid disease spread can significantly affect crop growth and productivity.

Symptoms: The earliest symptom of leaf rust is the appearance of minute, orange sori irregularly distributed on the leaves and, less frequently, on the leaf sheath or stem. The pustules are circular or slightly elliptical and filled with masses of orange to orange-brown urediospores. Primary infections are usually mild and originate from wind-borne urediospores, which may travel long distances before reaching the host. Under favourable environmental

conditions, successive generations of urediospores can develop every 10-14 days, leading to rapid disease spread. As the disease progresses, the telial stage forms within the same pustules. The telia are small, oval to linear, black structures covered by the epidermis. Severe early infections can result in substantial yield losses, primarily due to: reduction in the number of kernels per spike, decreased test weight and poor kernel quality.

2. **Yellow Rust**

Causal organism: ***Puccinia striiformis***

Commonly known as stripe rust, this disease primarily affects wheat and barley. In India, it is common in the Gangetic plains but occurs rarely on wheat in the western and peninsular regions. The urediospores of the pathogen are spherical, bi-nucleate, and unicellular. Their size is variable, and the spore wall is colourless and echinulate, possessing 6-16 germ pores. The teliospores are dark brown, usually flattened at the tip, and are bi-celled.

Symptoms: The characteristic pustules of stripe rust contain yellow to orange-yellow urediospores and are typically arranged in narrow, elongated stripes along the leaves, positioned between the veins. Under severe infections, pustules may also appear on the leaf sheaths, stems, spikelet's, glumes, and even on the grains. The sori are elongated and form linear rows, which is a diagnostic feature of the disease. Stripe rust develops rapidly under conditions of optimum moisture combined with moderate temperatures. However, at temperatures above 25°C, urediospores production declines or ceases, and black teliospores are frequently formed instead.

3. Stem Rust

Causal organism: ***Puccinia graminis* sp. *tritici***

Black rust, or late rust, is widespread in Indian wheat-growing regions. It usually appears near maturity, causing limited losses, but early infection can severely reduce tillering, grain weight, and quality. The pathogen produces oval, brown, single-celled urediospores (25-30×17-20 µm) with spiny walls that aid dispersal.

Symptoms: The initial symptoms of stem rust appear as small, pale flecks on the leaves, leaf sheaths, culms, and occasionally on floral structures. These flecks develop into uredosori, which appear as oblong, reddish-brown pustules. In light infections, the pustules remain separate and scattered, but under heavy infections, they coalesce and eventually burst open, releasing masses of brown urediospores. The teleutosori are linear or oblong, dark brown to black in colour, and

may merge to form long streaks. Primary infections are usually mild and originate from wind-borne urediospores that may travel long distances. At an average temperature of around 20°C, the first generation of urediospores develops within 10-15 days, enabling rapid secondary spread. Upon maturity, the teleutosori burst open, releasing masses of dark brown teliospores. In severe infections, affected plants often become stunted, producing small spikes with shriveled grains, which can result in substantial yield losses if the disease appears early in the crop cycle.

4. Foliar blight

Causal organism: ***Bipolaris sorokiniana***

This disease causes substantial damage to wheat crops in the warm and humid regions of India, particularly in the eastern states such as Bihar, West Bengal, Uttar Pradesh, and Odisha. In recent years, it has also emerged as a significant threat in the northwestern Indo-Gangetic plains, indicating a widening geographical spread and increasing epidemic potential under favorable environmental conditions.

Symptoms: The disease begins with small, oval, discoloured lesions that are scattered irregularly across the leaf surface. As these lesions mature, their centers turn light brown and are surrounded by an irregular dark brown ring, giving them a distinct appearance. Initial infections generally appear on the lower leaves as chlorotic flecks or small spots, which gradually enlarge, darken, and often coalesce, covering large areas of the leaf. In severe infections, the affected leaves may dry up and die prematurely. When the disease occurs early and is accompanied by favourable environmental conditions, it can cause complete defoliation of the plant. Such infections often result in the production of highly shriveled kernels, leading to significant yield losses and a noticeable decline in grain quality.

5. **Loose Smut**

Causal organism: ***Ustilago nuda tritici***

In India, the disease is widespread across most wheat-growing regions, affecting both plains and hills. The pathogen produces olivaceous-brown, oval to spherical spores (5-9 µm) with spiny walls aiding dispersal. It survives as dormant mycelium in infected seeds, which become a primary source of infection under favourable conditions.

Symptoms: Loose smut is one of the most destructive diseases of wheat, as it can completely replace grains with black spore masses, leading to total yield loss in infected spikes. The disease becomes visible only at ear emergence, often a few days earlier than in healthy plants. Almost all

spikelets are affected and transformed into black, powdery masses, with only the rachis remaining intact, rendering the spike sterile. Primary infection occurs when wind-borne teliospores land on open wheat flowers and infect the developing embryos within the kernels. The fungus remains dormant inside the seed until the next sowing season. Upon germination, the mycelium grows systemically along with the plant. At flowering, particularly under cool and humid conditions, the pathogen invades floral tissues and replaces them entirely with smut spores. Its systemic and seed-borne nature makes detection difficult and contributes to its high destructiveness.

6. Karnal bunt

Causal organism: ***Tilletia indica***

Commonly known as partial bunt. Karnal bunt is more widespread than the stinking smut or hill bunt which is restricted to the cooler hilly areas of North India.

Symptoms: This disease is a seed or soil-borne and is usually evident after harvest. In infected kernels, the endosperm is replaced by a mass of black teliospores, and the pericarp may be intact or ruptured. The embryo is usually unaffected and partially infected grains may germinate and produce healthy plants. The fishy odour in the infected kernels was due to trimethylamine. The inoculum germinates on or near the soil surface, producing sporidia that are carried by wind to floral structures. These sporidia then germinate and penetrate into the glumes, rachis, or ovary. The fungus grows in the intercellular space between the endosperm and seed coat. Spike emergence and grain filling stages are dependent on conducive environmental conditions.

7. Powdery Mildew

Causal organism: ***Erysiphe graminis* sp. *tritici***

The disease is common in the cool, lower hills of Northern India and parts of Rajasthan, affecting wheat, barley, oats, rye, and grasses. Infection causes defoliation and reduced photosynthetic area, weakening plant growth and resulting in shorter ears, lighter grains, and significant yield and quality losses under favourable conditions.

Symptoms: The upper leaf surface is more severely affected than the lower surface. Initial symptoms appear as white to pale grey mycelial colonies and conidia on the upper side of leaf sheaths. Under favourable environmental conditions, the infection may spread to stems and glumes. The fungus produces superficial white, powdery colonies composed of conidia, which later turn greyish or reddish-brown with the formation of cleistothecia. As the disease

progresses, the infected leaves that remain attached become wrinkled and deformed. Severely affected plants exhibit stunted growth due to reduced leaf size and number. Disease severity increases under cool and humid conditions, particularly when relative humidity ranges between 75-100%. These conditions favour rapid fungal growth, sporulation, and spread, leading to significant yield losses. Continuous high humidity further accelerates disease development, making powdery mildew a major constraint in susceptible cultivars grown under conducive environmental conditions.

7. Ear cockle

Causal organism: ***Anguina tritici***

Commonly known as Tundu or yellow ear rot when associated with a gram-positive bacterium (*Clavibacter tritici*) alongside the nematode. Ear cockle is an important disease in the eastern parts of India, particularly in Uttar Pradesh, Bihar, and Jharkhand.

Symptoms: The disease is favored by cool and humid conditions. Infected plants show twisted and wrinkled leaves, affecting normal leaf emergence. During flowering, affected florets exude a yellowish, sticky, sweet-smelling substance visible on the glumes. In ergot disease, grains are replaced by hard, black sclerotia measuring 3-5×2-3 mm, sometimes reaching up to 20 mm. In ear cockle disease, grains are replaced by galls filled with nematode larvae, which become visible upon soaking and crushing. Infection may begin early in plant development. Nematode larvae alone cause ear cockle symptoms, while their association with *Clavibacter tritici* leads to yellow ear rot. In ergot, primary infection arises from ascospores released from sclerotia of the previous crop. These infect florets and produce honeydew containing conidia, which are spread by insects. Sclerotia persist in soil for years, especially under dry conditions.

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USE OF SEMIOCHEMICALS IN PEST MANAGEMENT

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Abstract

Semiochemicals are behavior-modifying chemical signals that play a crucial role in insect communication and have emerged as effective tools in sustainable pest management. Unlike conventional pesticides, they alter pest behavior, thereby reducing environmental risks and resistance development. Recent field studies and technological innovations have demonstrated their effectiveness in reducing pest populations, improving crop yields, and enhancing biological control. This article highlights field-level applications, key achievements, and emerging technologies in semiochemical-based pest management within Integrated Pest Management (IPM) systems[1,3].

Keywords: Semiochemicals, pheromones, IPM, mating disruption, sustainable pest management

Introduction

Modern agriculture faces increasing challenges such as pesticide resistance, environmental contamination, and the decline of beneficial organisms. These concerns have necessitated eco-friendly pest management approaches. Semiochemicals, which mediate insect behavior through chemical communication, have gained importance as sustainable alternatives[2].

Unlike synthetic pesticides, semiochemicals influence behaviors such as mating and host location without causing direct mortality. This makes them highly selective and environmentally safe. Advances in chemical ecology and formulation technologies have enabled their transition from laboratory research to field-level applications in IPM programs[3,4].

Field-Based Applications and Outcomes

Field-Level Efficacy

Field studies confirm the effectiveness of semiochemicals under real farming conditions.

A study conducted in Andhra Pradesh (2023–2024) on pests such as *Helicoverpa armigera*, *Spodoptera litura*, *Bemisia tabaci*, and *Nilaparvata lugens* reported:

- Pest reduction: 46.7–59.1%
- Attraction efficiency: up to 83.3%
- Yield increase: up to 22.8% in cotton

These results demonstrate that semiochemicals provide measurable agronomic benefits and support their inclusion in IPM programs[5].

Mating Disruption

Mating disruption using sex pheromones is a widely adopted strategy that interferes with pest reproduction. It has been successfully used to manage:

- Pink bollworm (*Pectinophora gossypiella*) in cotton
- Codling moth (*Cydia pomonella*) in orchards

This approach leads to long-term population suppression and reduced dependence on chemical insecticides[3],[6].

Advanced Formulations (SPLAT Technology)

Recent innovations such as SPLAT have improved the field performance of semiochemicals. These formulations provide:

- Controlled release for 2–6 months
- Reduced crop damage
- Increased yields

In tomato affected by *Tuta absoluta*, SPLAT treatments recorded yields of 32.8 t/ha compared to 21.5 t/ha under conventional practices[7].

Lure-and-Infect Approaches

Semiochemicals are increasingly combined with biological agents:

- Lure-and-infect systems attract pests to pathogens
- Auto-dissemination allows pests to spread pathogens within populations

These strategies provide self-sustaining pest control, particularly against invasive pests[8].

Monitoring and Precision Pest Management

Semiochemical traps are widely used as monitoring tools in IPM. They:

- Provide early warning of pest outbreaks
- Enable targeted pesticide application

- Reduce unnecessary sprays
- Support pest forecasting

Such tools enhance decision-making and reduce indiscriminate pesticide use[9].

Biological Control Enhancement

Semiochemicals attract natural enemies such as parasitoids and predators, improving biological control efficiency. Plant volatiles help natural enemies locate pests, thereby enhancing ecological balance[3],[4].

Climate Influence

Environmental factors influence semiochemical effectiveness. Optimal performance is observed under moderate climatic conditions, while extreme weather reduces efficiency. This necessitates region-specific deployment strategies[5].

Recent Advances

Recent developments have expanded the scope of semiochemicals:

- Integration with entomopathogenic fungi
- Development of auto-dissemination systems
- Genetic engineering for pheromone production
- Improvement in push–pull strategies
- Use in precision agriculture

Field studies in India report yield improvements of up to 22%, along with enhanced pest monitoring[5],[8].

Advantages and Limitations

Advantages

- Environmentally safe and non-toxic
- Species-specific
- Reduced pesticide residues
- Compatible with IPM
- Low resistance risk

Limitations

- High cost of synthesis
- Limited spectrum
- Environmental sensitivity

- Low farmer awareness

Table 1. Semiochemical-Based Strategies and Applications

Strategy	Target Pest	Crop	Outcome
Mating disruption	*P. gossypiella*	Cotton	Reduced infestation
Mass trapping	*H. armigera*	Pulses	Reduced population
SPLAT	*T. absoluta*	Tomato	Increased yield
Lure-and-infect	Fall armyworm	Maize	Self-control mechanism
Monitoring traps	Multiple pests	Various	Early detection

Future Prospects

Future research focuses on nano-formulations, AI-based pest forecasting, genetic engineering, and multi-species attractants. These innovations will strengthen semiochemicals as key tools in climate-smart agriculture.

Conclusion

Semiochemicals have emerged as effective and eco-friendly tools in pest management. Field evidence demonstrates their ability to reduce pest populations, improve crop yields, and minimize pesticide use. With continued advancements, semiochemicals will play a central role in sustainable agriculture and IPM systems.

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EVOLUTION OF AGRICULTURAL INSURANCE, POLICY ISSUES AND CHALLENGES IN INDIA

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Introduction

Agriculture remains a critical pillar of the Indian economy, supporting nearly half of the country's workforce while contributing significantly to food security and rural livelihoods. However, Indian agriculture is inherently vulnerable to risks such as erratic monsoons, pest attacks, price volatility, and climate change. Agricultural insurance has emerged as an essential financial instrument to mitigate these risks and stabilize farm incomes.

The launch of the **Pradhan Mantri Fasal Bima Yojana (PMFBY)** in 2016 marked a paradigm shift in India's crop insurance landscape, aiming to provide affordable and comprehensive risk coverage to farmers.

Government made major upgrades: **Budget allocation:** ₹12,242 crore for 2025-26.

Evolution of Agricultural Insurance in India

India's agricultural insurance system has evolved through multiple phases:

- Comprehensive Crop Insurance Scheme (CCIS) (1985)
- National Agricultural Insurance Scheme (NAIS) (1999)
- Weather-Based Crop Insurance Scheme (WBCIS)
- PMFBY (2016 onwards)

PMFBY introduced:

- Uniform premium rates
- Use of technology (satellite imagery, digital land records)
- Faster claim settlement mechanisms

This evolution reflects a shift from subsidy-driven schemes to risk-sharing mechanisms with technological integration.

PMFBY:

- Launched in 2016, PMFBY is the largest crop insurance scheme in the world by farmer enrollment and third-largest by premium.
- Area yield based insurance scheme
- Maximum Premium Payable by farmers capped at 2%, 1.5% or 5% for Kharif, Rabi and commercial &Horticultural crops, respectively
- Insurance cover-Natural disasters: Drought, flood, hailstorm, cyclone, landslide, Pest attacks and crop diseases Post-harvest losses (rain, hail within 14 days of harvest), Prevented sowing (unable to plant due to weather), Mid-season adversities, **NEW coverage 2025:** Wild animal damage, waterlogging
- NOT covered: War, theft, deliberate destruction
- 27 States/ UTs in one or more seasons
- 3.75 Cr approx– Farmers insured in a year (FY24)
- 6.00 crore + hectares –Area insured yearly
- Crop insurance's market share doubled from 6% (2010-2015) to 12% (2016-2023), ranking it as the 3 rd largest line in GI.
- Farmer applications processed yearly 14.00 Cr Approx.
- Every year, **more than ₹30,000 crore** is collected as **insurance premium** under the crop insurance scheme.
- Claims paid: ₹1,55,977 crore (5x the premiums paid!)
- 18 Insurance companys – Empanelled ICs (5 Public Sector Insurers and 13 Private Sector Insurers)
- Over **77,000 Common Service Centre (CSC) Village Level Entrepreneurs (VLEs)** help farmers enroll and access services at the local level.
- More than **1.7 lakh bank branches** assist farmers with enrollment, premium payment, and claim processing.

CCIS & NAIS:

Comprehensive Crop Insurance Scheme (CCIS)

1. Started with sum insured at 150% and reduced to 100% of loan disbursed in 1988 for growing insured crops.
2. Premium charged was 2% for rice, wheat and millets and 1% for pulses and oilseeds.
3. The premium was further subsidized by 50% for small and marginal farmers.

National Agricultural Insurance Scheme (NAIS) (Rashtriya Krishi Bima Yojana - RKBY)

1. The minimum Sum Insured (SI) was equal to loan availed, extendable up to the value of 150% of average yield.
2. Premium charged:

Kharif

- Cereals, Millets & Pulses -2.50%
- Oilseeds & Bajra - 3.50%

Rabi

- Wheat -1.50%
- Other Food Crops & Oilseeds-2%

3. Small/Marginal farmers were further subsidized in premium to the extent of 50 percent, which was reduced to 10% gradually.
4. Government of India and States shared claims beyond 100% of premium for food crops & oilseeds equally

WBCIS

Weather based insurance scheme

- Claims based on weather data (rainfall, temperature, humidity, wind) instead of crop cutting.
- Best for: Horticultural crops, weather-sensitive crops
- Premium: Similar to PMFBY

Gaps in Agriculture Insurance:

- The total cropped area is about 192 million hectares, out of which only 61.15 million hectares are insured, resulting in a coverage of just 31.85%. This means that nearly two-thirds of the agricultural land remains uninsured, exposing a large portion of farmers to risks such as crop failure and natural disasters.

- Similarly, out of the 14.64 crore total farm holdings, only 3.75 crore farmers are insured, which accounts for 25.6% coverage. In other words, only one out of every four farmers have access to crop insurance, leaving the majority without financial protection.
- From an economic perspective, the country's GDP stands at ₹173.82 lakh crore, while the total crop insurance premium is only about ₹0.31 lakh crore (₹31,000 crore). This represents just 0.18% of the GDP, indicating that agricultural insurance has a very small share in the overall economy despite agriculture being a critical sector.

Scale of Agricultural Insurance in Tamil Nadu

- Over the **last 3 years**, about **24.5 lakh farmers** received crop insurance benefits
- Total claims paid: **₹4,336 crore**
- Tamil Nadu has a **moderate coverage base**, but compared to total farmers (~60–70 lakh estimated), coverage is still **partial (around one-third or less)**.
- Tamil Nadu agriculture is **highly climate-sensitive**
    - Cyclones (coastal districts)
    - Drought (interior regions)
    - Erratic monsoons

Recent example:

- Crop damage in 2024–25 affected **5.66 lakh acres**
- Relief provided to **3.6 lakh farmers** (₹289 crore)
- Frequent shocks increase the **need for insurance**, but also **strain the system financially**.
- ₹4,336 crore claims in 3 years → ~₹1,400 crore/year average
- Compared to Tamil Nadu's agricultural GDP → **still a small fraction**
- This indicates Insurance acts as a **relief mechanism**, not a **core financial pillar**

Agriculture Insurance –Operational Challenges

- Delay in receipt of premium subsidy
- Increasing premium rate
- Timely settlement of eligible claims and technology
- adoption by various stakeholders
- Delay in receipt of yield data
- Delay in receipt of yield data

- Over-insurance
- Reinsurance capacity constraint
- ICs are pulling out of Scheme State Governments opting out
- **Public Finance Burden**
- Premium is **heavily subsidized** (major share paid by Centre + States)
- Farmers pay only **1.5–5% of sum insured** (policy design)
- This creates a **fiscally intensive but shallow system**, where:
- Government bears most risk
- Market-based pricing signals are weak

Claims vs Premium Imbalance

- One of the most debated structural issues:
- Premium collected (2023–2025): ₹82,015 crore
- Claims paid: ₹34,799 crore
- Claim ratio ≈ 42%

State-Level Example

- Haryana (2023–2025):
  - Premium: ₹2,827 crore
  - Claims: ₹731 crore
  - Significant surplus retained by insurers
    - In some regions/years: insurers profit significantly
    - In disaster years: claims spike sharply

This reflects:

- High volatility in payouts
- Regional asymmetry
- Political economy concerns (fairness, transparency)

Measures & Possibilities -Way Forward:

- **Credit Eligibility Certificate as Proof of Insurable Interest**: The Eligibility Certificate issued by State Govt. for Tenant/ Landless farmers must be accepted as proof of insurable interest.

- **Universalization of Basic Cover**: Compensation for the losses in yield at the end of the season. Premium for Add-on covers to be borne by the farmers.
- **Active involvement at District/Block Level**: More efforts by the State Government Nodal Departments for IEC activities though active involvement at of insurable interest. borne by the farmers involvement at District/block/village level.
- Any direct compensation by the Government for crop loss to the farmers in the event of any widespread calamity may be linked with enrolment under crop insurance scheme.
- Development of Digital Cadastral Maps and Village Boundaries by all the States and utilizing the same for easy, faster and accurate integration of technology and yield/loss assessment works.
- Use of Advanced Technology such as drones, remote sensing, and geographical information system for final yield estimation and localized loss assessment

Conclusion

- Large-scale but low-penetration system
- Subsidy-driven rather than actuarially efficient
- Expanding but structurally imbalanced
- 18 insurance companies (5 public + 13 private)
- Heavy reliance on:
    - Banks (1.7 lakh branches)
    - CSC network (77,000+)

Overall, the agricultural insurance market in India can be described as **oligopolistic**, with a limited number of insurers, and largely **state-driven** rather than market-driven. Strengthening competition, improving actuarial practices, enhancing outreach, and ensuring timely claim settlement are essential for making the system more efficient, inclusive, and sustainable.

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INNOVATIVE AMENDMENTS AND TECHNOLOGIES FOR SUSTAINABLE SALINE SOIL RECLAMATION

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Introduction

It is possible to define a novel approach to the reclamation of saline soils. Black or dark coal powder, perhaps from coal mine waste, should be added to the soil. The powder can be used as aqueous suspensions or in an air-dry state. Depending on the characteristics of the soil, doses of at least 20 t ha^{-1} may be advised. The soil is enhanced by stable organic matter with strong cation exchange capacity and aggregation qualities due to the presence of humus-like compounds in coal materials. The gradual release of humus-like substances into the soil may be made possible by the high stability of coals. As a result, the coal material might be thought of as a semi-permanent supply of organic matter that resembles humus. In amounts equal to the gypsum dose, iron II sulphate can be applied concurrently as a water solution. Its oxidation and hydrolysis can produce amorphous iron hydroxides, which act as cementing agents, and further lower the pH of the soil. Industrial wastes containing iron might also be used. The top layer of the saline soil under reclamation should be combined with the additional additives. There is no need for further soil irrigation. By interacting with soil minerals and solutes, the additional materials should reduce hazardous salt concentrations and stabilise the soil's aggregation state (Mary et al., 2020). The following are some benefits of the suggested approach:

• Reducing the amount of soluble salt and its harmful effects on plants,

• Adding organic materials that forms structure to the soil,

• Reducing the risk of environmental pollution,

• Reducing financial involvement (no hydro-technical improvement),

• Permitting the environmentally responsible use of industrial waste.

Physical Method of Reclamation

Scraping: Mechanical methods can be used to remove the salts that have accumulated on the surface. If the area is fairly tiny, like as a small garden lawn or a patch in a yield, this is the easiest and most affordable method of recovering salt soils. Plant growth is only momentarily improved by this since the salts keep building up.

Flushing: Using flushing water to remove surface salts. This is particularly feasible for soils with limited permeability and a crust. But this is not a good habit.

Leaching: The only feasible method of eliminating excess salts from the soil is leaching with high-quality water, irrigation, or rain. If drainage facilities are available, it will lower the water table and remove the salts by draining the salt-rich wastewater.

Leaching requirement: The percentage of irrigation water that must be leached through the root zone or soil profile in order to regulate soil salinity at any particular level (Salt balance) is the amount of water required to remove the excess soluble salts from the saline soils (Shankar et al., 2019).

Requirement for Leaching (LR)

$$LR = \frac{EC_{iw}}{EC_{dw}} \times 100 \text{ or} \frac{D_w}{D_{iw}} \times 100$$

Where,

EC = Electrical Conductivity in dS m^{-1}

iw = EC of Irrigation water in dS m^{-1}

dw = EC of Drainage water in dS m^{-1}

$D_{(w)}$ = Depth of drainage water in inches

$D_{(iw)}$ = Depth of irrigation water in inches

Methods of Saline Soil Reclamation Using Agronomy and Cultural methods

The following cultural methods are used in regions with low soil permeability, a shallow saline water table, or exclusively saline irrigation water.

1. Crop Rotation and Selection

Crop tolerance to soil salinity or irrigation water quality can be used to categorise crops into four groups:

Barley, sugar beetroot and date palm are examples of highly tolerant crops.

Tapioca, mustard, coconut, spinach, amaranthus, pomegranate, guava, and ber are all tolerable.

Ashguard, bitter gourd, brinjal, cabbage, cluster bean, pea, lady's finger, muskmelon, onion, potato, dolichos, sweet potato, tomato, turnip, and water melon are all semi-tolerant.

Radish, carrot, coriander, cumin, mint, grape, and sweet orange are all sensitive.

2. Method of Raising Plants

Rather of germinating the seeds, crops (particularly vegetables, flowers, and fruit trees) should be raised by transplanting seedlings. Wild root stocks (mango, citrus, guava, and ornamental plants like rose) grafted with high-quality but salinity-sensitive scions.

3. Methods of Irrigation

Water application techniques include sprinkler irrigation, subsurface irrigation systems, and furrow or drip irrigation.

Irrigation frequency: Regular irrigation can improve water supply and lower salinity, but it shouldn't be done excessively.

Using mulching materials, such as plastic sheets and straws, to stop evaporation losses.

Drainage Technique for Recovering Saline Soil

Drainage is the process of removing excess water and salts from land. Generally speaking, there are two types of drainage:

Drainage on the Surface

The gathering and evacuation of water from the soil's surface is known as surface drainage. Low locations that collect water from nearby higher land and impermeable soils that lack the potential to expel excess water by moving downward through the soil profile are two circumstances that promote the usage of surface drainage.

Drainage beneath the surface

Gravitational water can be swiftly and affordably removed in underground drainage ditches. However, drainage ditches are difficult to utilise with machinery and need to be cleaned on a regular basis. Depending on specific local circumstances, each of these drainage schemes has advantages and disadvantages.

Subsurface Drainage Contributing Factors

The area's natural hydrological characteristics; The amount of seepage from canal irrigation and other sources that could increase groundwater recharge; and the extra leaching needed for

hydrotechnical soil development.

Saline Soil Reclamation Using a Biological Approach

It is common knowledge that the breakdown of plant residues and animal manures in the soil releases organic acids and carbon dioxide, which both neutralise the alkali and assist dissolve any insoluble calcium salts in the soil solution. Water-stable aggregates are increased and soil permeability is enhanced by decomposing organic materials.

Enhancing Saline Soil with Organic Amendments

The following soil amendment techniques can be used to improve and reclamate salinity-affected soil over time: farmyard manure, molasses, sugar factory press-mud, green manures, crop leftovers, various weeds, etc.

Crop Residues and Green Manuring

Dhaincha or janta (Sesbania aculeata), sunnhemp (Crotalaria juncea), berseem (Trifolium alexandrinum), senji (Melilotus parviflora), cowpea (Vigna sinensis), and other crops are frequently used for green manuring. In addition to acting as a calcium solubilizer and balancing the high pH of alkali soils, they serve as sources of easily accessible nutrients during decomposition. Soil reclamation is aided by subsequent increases in biological activity and soil permeability. Sesbania aculeata has proven to be the most effective of all the plants utilised as green manure on saline soils.

The following are crucial traits of green manuring crops:

Alkalinity can be neutralised by legume crops. The highest calcium content based on ash. Do well in environments that are somewhat salinised.

On the salty soils of Andhra Pradesh's southern coast, applying 5–10 tonnes of Sesbania green manure per hectare has been quite successful in gelling higher paddy yields.

Reforestation

The plant species like Acacia arabica, Melia azadirachta, Prosopis juliflora, Butea monosperma, Tamarix articulata and Albizzia lebbeck can grow within certain limits on the salt affected soils. Certain species, such as Salvadora oleoides, Zizyphus, Capparis horrida, and Capparis aphylla, can be cultivated or even naturally occur on some types of saltwater terrain.

By loosening the subsurface and increasing permeability through the action of the root system, the forest development improves the soil. Leaf litter and root residues contribute organic matter. Calcium is mobilised to replace exchangeable sodium by carbonic acid, which is created by

organic material decomposition and root activity. Additionally, microbial activity and microclimate control lead to an overall improvement in soil and ecology.

Bulky Organic Manures

In Punjab and Haryana, saline-alkaline soils have been successfully treated with farm manures. The application of 10 tonnes of farmyard manure with 15 tonnes of Sesbania green leaves proved almost as beneficial as 30 tonnes per hectare of Sesbania green manuring, in increasing the yield of paddy.

Chemical Improvement

Chemical amendments used for reclamation include soluble calcium salts like gypsum and calcium chloride, relatively less soluble ground limestone and pressmud from sugar factories and slag from iron factories, or acid and acid formers that act as calcium mobilisers like sulphuric acid, sulphur, iron sulphate, aluminium sulphate, lime sulphur, etc.

Gypsum

The 0.59 mm fineness of gypsum was more effective in reclamation of saline and alkali soils. It is less expensive, safe, and increases soil permeability by supplying calcium to lower the amount of exchangeable salt in soils. It also helps in reducing the salts from root zone depth by the smooth flow of water in the soil profile.

Nanotechnological approach

Nano-management of soil salinity can be achieved through many approaches, which mainly aim to enhance plant growth, its tolerance to salinity stress, and improvements in soil structure and quality. These strategies could involve using conventional techniques (nano-gypsum, nano-hydroxyapatite, nano-sulfur, etc.), nano-nutrients (nano-calcium, nano-selenium, nano-silicon, nano-ZnO, etc.), nano-amendments (nanobiochar, nano-compost, nano-chitosan, etc.), and nano-halophytes and genotypes that can withstand salt. Carbon nanomaterials against stress on crops were also investigated, including many carbon-NMs such as carbon nanotubes, carbon nanodots, nanographene, and nanofullerene.

Furthermore, zero-valent iron-NP (nZVI) and nanobiofertilizers, or biological nanofertilizers, are also effective approaches to mitigating soil salinity. More details will be presented in the following sub-sections (Edrisi et al., 2021):

The main mechanism of this mitigation may involve decreasing the uptake of Na^+ by roots and their accumulation in the shoots, the Na^+/K^+ ratio, and increasing the K^+ uptake. NPs can

improve plant salt tolerance by elevating the expression of Na^+/H^+ anti-port and tonoplast H^+-ATPase at the root membranes and shortening the root apoplast barrier, thus limiting Na^+ translocation to tissues of the shoot and reducing Na^+ toxic effects. The mode of action of applied nano fertilizers mainly depends on the soil, plant, and environmental factors in addition to the characteristics of nanoparticles

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FROM OVERFISHING TO SUSTAINABILITY: RETHINKING THE FUTURE OF GLOBAL FISHERIES

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Abstract

The fisheries and aquaculture sector plays a crucial role in global food security, nutrition, employment, and economic development. However, the sustainability of marine fisheries is increasingly threatened by overexploitation driven by technological advancements, rising demand for seafood, harmful subsidies, and illegal, unreported, and unregulated (IUU) fishing. Recent global assessments indicate that a significant proportion of fish stocks are harvested beyond biologically sustainable limits, raising concerns about long-term resource availability and ecosystem stability. This study examines sustainable fisheries within an ecological-economic framework, focusing on the need to balance resource extraction with the regenerative capacity of marine ecosystems. It identifies key drivers of overfishing and evaluates their ecological and socio-economic consequences, including fish stock depletion, biodiversity loss, trophic imbalances, and threats to coastal livelihoods. The analysis also highlights the economic importance of the fisheries sector at global and national levels, with particular reference to India, where fisheries contribute significantly to employment, income generation, and export earnings. Further, the study discusses core principles of sustainable fisheries management, including the precautionary approach, ecosystem-based management, and maximum sustainable yield, along with key policy instruments such as catch limits, marine protected areas, and seasonal closures. It also emphasizes the importance of multi-stakeholder participation involving fishers, governments, and consumers in achieving sustainability. The findings suggest that effective governance, science-based management, and responsible consumption are essential to ensure the

long-term sustainability of fisheries while maintaining ecological integrity and economic viability.

Keywords:-Sustainable fisheries management, Overexploitation, IUU fishing, Fisheries sustainability

Introduction

Oceans are a vital source of food and livelihoods, supporting millions of people worldwide through fisheries and related activities. Sustainable fishing refers to harvesting fish at a level that allows populations to regenerate naturally while maintaining healthy marine ecosystems for future generations (FAO, 2022). When managed effectively, fisheries can provide long-term food security, employment, and economic benefits.

Global fish production has reached unprecedented levels, exceeding 223.2 million tonnes, reflecting the growing demand for fish as a major source of animal protein (FAO, 2025). Encouragingly, about 77.2% of fish landed for human consumption comes from biologically sustainable stocks. However, the sector is under increasing pressure due to overexploitation, which occurs when fish are harvested faster than they can reproduce. Recent estimates show that only 64.5% of fish stocks are within sustainable limits, while 35.5% are overfished, a proportion that continues to rise (FAO, 2025). This highlights the widening gap between well-managed and poorly managed fisheries, particularly in developing regions where communities heavily depend on marine resources.

Fish stocks can be understood as natural capital, where growth represents “interest,” and sustainable fishing involves harvesting only this surplus without depleting the base resource (Quaas et al., 2012). Excessive fishing, however, reduces this capital, threatening long-term productivity. These trends underscore the urgent need for improved fisheries governance, responsible harvesting practices, and stronger international cooperation to ensure the sustainability of marine resources for future generations.

1. Drivers of Overexploitation

Technological Advancement: Modern fishing technologies such as sonar, satellite navigation, and bottom trawlers have significantly increased harvesting efficiency. However, they also enable large-scale capture of fish schools and cause damage to sensitive habitats like coral reefs and seagrass beds (FAO, 2022; Pauly et al., 2002).

Harmful Fisheries Subsidies: Subsidies for fuel, vessels, and gear sustain fishing activity even when stocks decline, leading to overcapacity. Global fishing capacity is estimated to be about 2.5 times higher than sustainable levels (Sumaila et al., 2019).

Rising Demand for Fish: Fish is a key protein source for over 3 billion people, and demand continues to rise with population growth, increasing pressure on marine resources (FAO, 2022).

Illegal, Unreported, and Unregulated (IUU) Fishing: IUU fishing contributes significantly to overexploitation, accounting for up to 30% of catches in some fisheries and generating substantial economic losses, thereby undermining management efforts (Agnew et al., 2009).

2. Consequences for Future Generations

Overexploitation of marine resources has serious long-term implications for food security, ecosystem stability, and climate resilience.

Food and Economic Insecurity: Nearly 600 million people depend on fisheries for livelihoods. Declining fish stocks reduce income, employment opportunities, and access to affordable protein, particularly in developing regions (FAO, 2022).

Ecosystem Imbalance: Overfishing disrupts marine food webs by removing key species, especially predators, leading to trophic imbalances, biodiversity loss, and degradation of ecosystems such as coral reefs (Pauly et al., 2002; Worm et al., 2006).

Reduced Climate Resilience: Unsustainable fishing weakens ecosystem resilience to climate change. Healthy fish populations are better able to withstand impacts such as ocean warming, acidification, and shifting species distribution (FAO, 2022).

3. Regional Highlight: India (2025)

India is one of the leading fish-producing nations, with total production reaching about 195 lakh tonnes in 2024–2025. Fisheries play a crucial role in food security, employment, and economic growth. However, sustainability remains a concern, as nearly 30% of marine fish stocks are overexploited (Government of India, 2025; FAO, 2022).

The sector also exhibits inequality in resource distribution: although about 90% of fishers are small-scale or artisanal, they contribute only a small share of total marine catch, while mechanised fleets dominate production. To address these challenges, initiatives such as the Marine Fisheries Census 2025 aim to improve data systems and support sustainable management aligned with SDG 14 (Department of Fisheries, 2025).

4. Economic Importance of Fisheries

The fisheries and aquaculture sector is a major contributor to the global economy, producing around 191–193 million tonnes annually and supporting food systems, trade, and livelihoods (FAO, 2022).

Global Trade and Growth: Fish is one of the most traded food commodities, with about 67 million tonnes (38% of production) entering international markets. Aquaculture remains the fastest-growing food production sector, with substantial increases in production and value (FAO, 2022; World Bank, 2017).

Employment and Livelihoods: Approximately 59.5 million people are directly engaged in fisheries and aquaculture, with millions more employed in allied sectors such as processing, transport, and marketing. Small-scale fisheries serve as a key livelihood safety net, while women contribute significantly, especially in post-harvest activities (FAO, 2022).

Food Security and Nutrition: Fish provides nearly 20% of animal protein intake for over 3.1 billion people and supplies essential nutrients such as omega-3 fatty acids, vitamins, and minerals. Small fish species are particularly important for low-income populations due to their affordability and nutritional value (FAO, 2022; Béné et al., 2015).

Value Addition and By-products: Fish waste and low-value species are utilized in producing fish meal, fish oil, and other industrial products, improving resource efficiency and supporting sectors such as aquaculture, pharmaceuticals, and cosmetics (FAO, 2022).

India's Economic Contribution: India contributes about 8% of global fish production and is a major aquaculture producer. The sector accounts for around 1.07–1.12% of total GVA and over 6.7–7.2% of agricultural GVA, supporting 28–30 million livelihoods. Seafood exports exceed US$7–8 billion annually, with shrimp as the dominant commodity. Production has more than doubled over the past decade (Government of India, 2025; Department of Fisheries, 2025).

Environmental and Social Sustainability Sustainable fisheries management is central to the Blue Economy, balancing economic growth with environmental protection. Globally, about 81% of assessed fish stocks remain biologically sustainable under effective management (FAO, 2022).

Key tools include Marine Protected Areas (MPAs), catch regulations, and ecosystem-based management, which help conserve biodiversity while maintaining productivity. In India, initiatives such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY) promote sustainable

practices, infrastructure development, and emerging activities like seaweed farming, supporting long-term resource sustainability (Government of India, 2025).

5. Problems due to unsustainable fishing

Unsustainable fishing is a multi-dimensional crisis that threatens global food security and marine biodiversity. Leading international organizations and researchers have identified the following key problems, categorized by their ecological and socio-economic impacts.

5.1 Ecological Impacts:

Unsustainable fishing has led to significant ecological damage. Around 34.2% of global marine fish stocks are overfished (FAO, 2022). Over the past four decades, marine biodiversity has declined substantially, with overfishing as a major driver. Targeting apex predators disrupts food webs, causing trophic imbalances and ecosystem degradation (Pauly et al., 2002; Worm et al., 2006). Destructive practices such as bottom trawling damage seabed habitats, while high levels of bycatch and ghost fishing further threaten marine species and biodiversity.

5.2 Socio-Economic Impacts:

Overfishing poses serious risks to global food security, as more than 3 billion people depend on fish for protein. It also threatens the livelihoods of millions engaged in fisheries (FAO, 2022; WWF, 2020). In addition, IUU fishing is often associated with illegal activities, including human rights violations. Harmful subsidies further distort markets by promoting overcapacity and unsustainable fishing practices (Sumaila et al., 2019).

5.3 Climate and Environmental Feedback:

Unsustainable fishing contributes to environmental degradation by releasing carbon stored in seabed sediments and increasing microplastic pollution from discarded fishing gear, thereby intensifying climate and ecological challenges (FAO, 2022; Sala et al., 2021).

6. Concept of Sustainable Fisheries Management

Sustainable fisheries management aims to maintain fish stocks at biologically safe levels while ensuring long-term ecosystem health and socio-economic benefits (FAO, 2022).

6.1 Core Principles:

- Precautionary approach to avoid irreversible damage
- Ecosystem-based management considering species interactions
- Maximum Sustainable Yield (MSY) to regulate harvest levels
- Social and economic equity for fishing communities

6.2 Key Management Strategies:

- Catch limits and quota systems
- Marine Protected Areas (MPAs)
- Selective fishing gear to reduce bycatch
- Seasonal closures during breeding periods

6.3 Benefits of Sustainable Management:

- Conservation of marine biodiversity
- Long-term food security
- Enhanced climate resilience
- Stable and profitable fisheries

6.4 Shared Responsibility for Sustainable Fisheries

Sustainable fisheries require coordinated action from multiple stakeholders.

Fishers:

Fishers play a frontline role by complying with regulations, adopting selective gear, and contributing traditional ecological knowledge. Responsible practices such as accurate reporting and reduced habitat damage can significantly improve sustainability (MSC, 2021).

Government:

Governments ensure sustainability through science-based policies, enforcement, and monitoring systems. Measures such as Total Allowable Catch (TAC), regulation of IUU fishing, and subsidy reforms are critical. In India, initiatives like PMMSY, FIDF, and seasonal fishing bans support sustainable development and conservation (Government of India, 2025).

Consumers:

Consumers influence sustainability through responsible purchasing decisions. Certification systems (MSC, ASC) and awareness programs such as Seafood Watch encourage sustainable consumption patterns and reduce pressure on overexploited species.

Conclusion

Sustainable fishing is not merely an environmental necessity but a socio-economic imperative for the future. The growing imbalance between resource exploitation and regeneration highlights the urgent need for a transition toward responsible fisheries management. Without timely intervention, continued overexploitation will undermine marine biodiversity, weaken ecosystem resilience, and threaten the livelihoods and food security of millions worldwide.

Achieving sustainability requires an integrated approach that combines scientific management, effective governance, and stakeholder participation. Fishers must adopt responsible harvesting practices, governments must enforce evidence-based regulations, and consumers must support sustainable seafood choices. Importantly, bridging the gap between well-managed and poorly managed fisheries remains a critical global challenge.

If these efforts are aligned, fisheries can continue to function as a renewable resource, supporting economic growth, nutritional security, and ecological balance. Ensuring the sustainability of marine resources today is essential to safeguarding the well-being of future generations and maintaining the long-term productivity of the world's oceans.

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NO FORESTS, NO FUTURE: WHY EARTH DAY NEEDS A NEW MEANING?

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Introduction

Every year on Earth Day (April 22), millions of people around the world participate in tree planting drives, environmental campaigns, and awareness programs. While these efforts are important, they often remain symbolic. In the face of accelerating climate change, biodiversity loss, and widespread deforestation, it is necessary to rethink the meaning and purpose of Earth Day.

Forests: Lifelines of the Planet

Forests are among the most vital ecosystems on Earth. They cover nearly 31% of the global land area and provide essential ecosystem services such as carbon sequestration, climate regulation, soil conservation, and water cycle maintenance (FAO, 2020). Forests also support more than 80% of terrestrial biodiversity and provide livelihoods for over 1.6 billion people worldwide (UNEP, 2021). One of the most critical roles of forests is their ability to act as carbon sinks. By absorbing carbon dioxide from the atmosphere, forests help mitigate global warming. According to the Intergovernmental Panel on Climate Change, deforestation and land-use changes contribute significantly to greenhouse gas emissions, making forest conservation a key strategy in combating climate change (IPCC, 2021).

Changing Forest Scenario: A Growing Crisis

Despite their importance, forests are under unprecedented pressure. Rapid urbanization, agricultural expansion, industrial development, and infrastructure growth have led to large-scale deforestation and forest degradation. The Food and Agriculture Organization reports that millions of hectares of forest are lost annually due to human activities (FAO, 2020). In

developing countries like India, forests are increasingly fragmented due to population pressure and land-use changes. In regions such as Northeast India, shifting cultivation, unplanned urbanization, and infrastructure expansion have further intensified the stress on forest ecosystems. Climate change has also exacerbated the situation by increasing the frequency of extreme events such as forest fires, droughts, and pest outbreaks (IPCC, 2021).The consequences of forest loss are severe. Biodiversity decline, disruption of ecosystem services, soil erosion, and reduced resilience to climate change are some of the major impacts. The World Wildlife Fund highlights that wildlife populations have declined drastically in recent decades due to habitat loss, much of which is linked to deforestation (WWF, 2020).

Why Earth Day Needs a New Meaning

Earth Day has played a significant role in raising environmental awareness. However, the scale of current environmental challenges demands more than awareness, it requires sustained action and accountability. Traditional Earth Day activities, such as planting saplings or organizing awareness rallies, are insufficient if not followed by long-term care and policy support. Planting trees without ensuring their survival does little to offset the loss of mature forests. Therefore, Earth Day must emphasize:

i. Protection of existing forests
ii. Sustainable forest management practices
iii. Restoration of degraded landscapes
iv. Community participation and ownership
v. Strong environmental policies and governance

Earth Day should also encourage measurable commitments, such as increasing forest cover, reducing deforestation rates, and enhancing biodiversity conservation efforts.

Community and Indigenous Role in Forest Conservation

Local and indigenous communities have long been the custodians of forests. Their traditional knowledge and sustainable practices have helped maintain ecological balance for generations. Integrating this knowledge into modern forest management can significantly improve conservation outcomes (Jose, 2008). Community-based forest management approaches have shown promising results in many parts of the world. Empowering local communities through participatory governance not only enhances conservation but also improves livelihoods.

Across India, especially in the North-East and Central regions, several community-led initiatives demonstrate how decentralized governance and indigenous stewardship can effectively protect forest ecosystems. The Khasi and Jaintia tribes of Meghalaya have conserved forest patches known as sacred groves for centuries. These groves are protected due to religious beliefs, where extraction of resources is strictly prohibited. Studies show that these groves serve as biodiversity hotspots, preserving rare and endemic species (Tiwari et al., 1998). A well-known example is the Mawphlang sacred grove, which remains ecologically intact due to strict community protection. The Apatani tribe practices a unique and sustainable land-use system that integrates forestry with wet rice cultivation. Their indigenous practices ensure efficient water management, soil conservation, and biodiversity preservation. This system has been recognized for its sustainability and ecological balance (Kala, 2005).In Nagaland, nearly 85–90% of forests are owned and managed by local communities. Village councils regulate forest use, enforce hunting bans, and establish community conservation areas.

The Khonoma village has successfully protected wildlife and declared itself a "green village" (Kikon, 2014).The Joint Forest Management (JFM) program is a collaborative approach between forest departments and local communities. In states like Madhya Pradesh, Chhattisgarh, and Odisha, JFM has led to improved forest regeneration and enhanced livelihoods through benefit-sharing mechanisms (Sundar et al., 2001).The Gond and Baiga tribes have traditionally depended on forests for non-timber forest products such as mahua, tendu leaves, and lac. Their cultural practices emphasize sustainable harvesting and conservation, helping maintain ecological balance (Poffenberger, 2000). Mendha-Lekha village is a pioneering example of community forest governance under the Forest Rights Act, 2006. The Gram Sabha manages forest resources, regulates bamboo harvesting, and ensures equitable benefit sharing. This model has led to both forest conservation and improved livelihoods (Sarin et al., 2010).

Urban Perspective: Forests beyond Wilderness

In today's rapidly urbanizing world, forests are not limited to remote landscapes. Urban green space such as parks, avenue plantations, and urban forests play a crucial role in improving environmental quality and human well-being. They help reduce air pollution, mitigate urban heat island effects, and enhance mental health. However, urban green spaces are often undervalued and replaced by infrastructure development. Celebrating Earth Day in urban areas should focus on expanding and maintaining these green spaces, promoting urban forestry, and encouraging

citizen participation. In Mumbai, citizens, resident welfare associations, and NGOs have actively adopted the Miyawaki technique to create dense, native forests in small urban spaces. Organizations such as Afforestt have collaborated with communities to plant fast-growing native species. *(Sharma, 2019; Afforestt, 2020).* In Delhi, citizen groups and NGOs have actively participated in restoring degraded areas of the Delhi Ridge, a critical green lung of the city. Removal of invasive species like *Prosopis juliflora*, Plantation of native species such as Neem and Dhak, Awareness campaigns and community plantation drives Organizations like Delhi Greens have played a major role in mobilizing volunteers.*(Delhi Greens, 2021; GNCTD, 2020).* In Bengaluru, several citizen-led groups have taken initiatives to plant and protect trees. Groups like SayTrees organize regular plantation drives. Citizen volunteers adopt saplings and ensure their survival .Focus on restoring lakes and surrounding green belts.

These efforts have contributed significantly to increasing urban tree cover and improving microclimate conditions *(Nagendra and Gopal, 2011; SayTrees, 2022).*In Hyderabad, citizen participation under the "Telangana Ku Haritha Haram" program has led to large-scale urban afforestation. Residents participate in planting and maintaining trees, Development of urban forest parks, increased awareness about environmental conservation *(Government of Telangana, 2019).*In Pune, local communities and NGOs have actively engaged in urban forestry. Tree plantation along roads and open spaces, Protection of existing trees from illegal felling, School-based awareness programs. Groups like Jeevitnadi focus on river and green space restoration *(PMC, 2020; Jeevitnadi, 2021)*

From Awareness to Action: The Way Forward

To redefine Earth Day in the present context various aspects are important:

1. Policy Interventions**:** Implementation of strict laws to prevent deforestation
2. Scientific Management: Use of remote sensing and GIS for monitoring forest cover
3. Education and Awareness: Integrating environmental education into curricula
4. Sustainable Practices: Promoting agroforestry and eco-friendly land-use systems
5. Public Participation: Encouraging community-driven conservation initiatives

Conclusion

Earth Day must go beyond symbolic celebrations and become a catalyst for real change. Forests are indispensable for maintaining ecological balance and ensuring the survival of life on Earth. The message "No Forests, No Future" is not just a slogan, it is a reality that demands

immediate action. By redefining Earth Day as a day of commitment, accountability, and sustained effort, we can move closer to a more sustainable and resilient future.

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UREA CYCLE AND NITROGEN REUTILIZATION IN RUMINANTS

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Introduction

During the 1970s and 1980s, multiple studies were conducted on the utilization of urea as a replacement for protein in ruminant diets, especially its effect on dry matter intake, rumen fermentation, milk yield and reproduction-related parameters. Ruminants can utilize non protein nitrogen as a dietary protein source via their rumen microorganisms. Urea and ammonia, in addition to amino acids (AA), peptides and microbial crude proteins (MCP), play an important role in nitrogen digestion and metabolism in ruminants. Also, urea could be used to replace a portion of dietary protein in ruminants.

In most mammalian species, a substantial proportion of endogenous urea nitrogen (urea-N) is excreted via urine. In contrast, ruminants have developed an efficient physiological mechanism that facilitates the continuous recycling of urea-N to the gastrointestinal tract (GIT), particularly the rumen. Within the rumen, recycled urea-N serves as a nitrogen source for microbial protein synthesis, which represents the primary contributor to the metabolizable protein supply available to the small intestine.

The recycling of urea-N to the GIT and its subsequent anabolic utilization are regulated by various dietary and ruminal factors. Key dietary determinants influencing the proportion of hepatic urea production that is redirected to the GIT, as well as its metabolic fate, include dietary nitrogen concentration and intake, total dry matter intake, feed processing methods, fluctuations in dietary nitrogen supply, and both the quantity and frequency of rumen-degradable nitrogen intake.

Ammonia Production and Ammonia Toxicity:

Usually, ruminants are much less efficient than non ruminants in utilizing high quality dietary proteins. A dominant feature of N digestion and metabolism is microbial conversion of some dietary protein to NH_3. In ruminants, ammonia is generated by amino acids obtained from the diet, from catabolism of glutamine by enterocytes, or from peripheral tissues such as skeletal muscle.

The primary source of NH_3 within the rumen is dietary protein, except for ruminants consuming diets very low in protein. The UIP and indigestible intake protein (IIP) usually pass to the duodenum without affecting NH_3 production in the rumen. Degradable dietary NPN can be converted rapidly and quantitatively to NH_3 dissolved nucleic acids in the rumen are also degraded extensively by rapid action of bacterial peptidases and deaminases to produce NH_3. Much of the daily ammonia load is derived from the catabolism of amino acid obtained from dietary proteins. In animals with high protein intake, 10% to 15% of the protein is deaminated and used for energy, with resultant ammonia production. Urea recycling in ruminants is closely associated with ammonia (NH_3) production and absorption within the gastrointestinal tract (GIT). Ammonia absorbed across the ruminal epithelium, small intestinal mucosa, and large intestinal mucosa is transported via the portal vein to the liver; in addition, ammonia derived from peripheral tissues is also delivered to the liver. Hepatic metabolism plays a central role in the regulation and integration of whole-body nitrogen metabolism. Within the liver, ammonia is detoxified through its conversion to urea via the urea cycle. The synthesized urea may subsequently be recycled to the rumen, small intestine, or large intestine. Urea can enter the rumen directly through diffusion across the rumen wall or indirectly via salivary secretion. Alternatively, it may be excreted by the kidneys or secreted in milk and sweat.

Metabolism of Urea in the Liver:

Under normal physiological and nutritional conditions, ammonia (NH_3) entering the portal circulation is efficiently extracted by the liver and detoxified through conversion to urea or glutamine. Across a broad range of portal NH_3 concentrations and dietary conditions, the liver removes approximately 70–95% of portal NH_3, resulting in hepatic NH_3 clearance that slightly exceeds portal NH_3 absorption (by ~4% on average).

The structural and functional organization of the liver underscores its critical role in preventing the accumulation of toxic NH_3 in the bloodstream of ruminants and other mammals. Enzymes

of the ornithine (urea) cycle and those involved in transamination reactions are strategically compartmentalized within the mitochondria and cytosol of periportal and perivenous hepatocytes. This zonation facilitates the efficient conversion of NH_3, primarily absorbed from the gastrointestinal tract, into urea, while also enabling glutamine synthesis as an auxiliary pathway for NH_3 detoxification. Periportal hepatocytes are primarily responsible for NH_3 uptake from portal blood and its conversion to urea via the urea cycle. In contrast, perivenous hepatocytes specialize in the synthesis of glutamine through the activity of glutamine synthetase, thereby providing a secondary mechanism to scavenge residual NH_3 before blood exits the liver via the hepatic veins and enters the systemic circulation. This two-stage hepatic NH_3 detoxification system is tightly integrated with other metabolic processes, including gluconeogenesis, acid–base homeostasis, and inter-organ nitrogen shuttling, ensuring optimal regulation of substrate utilization, product formation, and overall nutrient balance in the organism.

Rumen Ureolytic Bacteria

Rumen ureolytic bacteria play an important role in dietary urea hydrolysis, for they produce ureases that catalyze the breakdown of urea to ammonia (NH_3) and carbon dioxide. In the rumen, the ammonia can be assimilated by many rumen bacteria for the synthesis of microbial proteins.

Urea transport Across the Rumen Epithelium:

Urea produced in the liver is transferred across the rumen wall from the blood and then it is hydrolyzed to ammonia by resident bacteria. As is already known, urea transport across the ruminant wall is mediated via urea transporters in the epithelium membrane. In ruminants the amount of urea-N recycled to the GIT (as a proportion of total hepatic urea-N output) varies between 29 to 99%, which is much greater compared to non-ruminants (15 to 39%). Available data from literature shows that between 27 to 60% (combined salivary contributions and transfer across the rumen wall) of the GIT entry is to the rumen. The quantity of urea-N transfer to different sections of the GIT is regulated by characteristics of the ruminant diet. Urea-N can enter the rumen via direct transfer of blood urea-N across the ruminal wall or via salivary secretions. Salivary urea-N entry to the rumen calculated as difference between total splanchnic flux and urinary excretions rate as a percent of total hepatic urea-N production represented 72% in steers fed high forage diets as compared to 21% in those fed high concentrate diet. High

roughage diets stimulate rumination, thus increasing the flow of salivary secretions to the rumen. Small amounts of urea-N are recycled to the hind gut (cecum and colon) and, even though bacteria residing in the hind gut utilize recycled urea-N for protein synthesis, because there are no mechanisms for digestion and absorption of microbial protein formed in the hind gut, it is eventually lost in the feces.

Factors Affecting Urea Recycling:

All factors that influence the production, absorption, and transfer of NH3 and urea will affect urea recycling in ruminants. Increasing intraruminal ammonia concentration decreases the urea flux across the rumen wall. According to Remond *et al.* ammonia absorption may be responsible for reducing urea flux. Production of urea is largely a substrate-driven process. Thus, animal productivity can impact urea recycling by impacting how much N is available for urea synthesis.

Conclusion

Urea is one of the major non-protein nitrogen feeds for ruminants and the optimal utilization of urea in feed can alleviate to some extent the cost of dietary protein. Urea is hydrolyzed quickly by ureolytic bacteria in the rumen. The ability of the liver to detoxify NH_3 to urea appears to be similar in ruminant and non ruminant species, the principal difference being that the production of NH_3 by foregut fermentation in ruminants is extremely variable and dependent on feed sources, whilst in non-ruminants, NH_3 is produced in the hindgut and, therefore, absorption into the portal vein is affected far less by diurnal feed cycles. Despite the high rates of uptake from the gut, which result from rapid fermentation of soluble N in forage diets, the ruminant liver is extremely adept at detoxifying NH_3 to urea.

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POST-HARVEST MANAGEMENT OF POTATO IN FIROZABAD DISTRICT

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Abstract

Potato is a major cash crop in Firozabad district of Uttar Pradesh, contributing significantly to the western UP potato belt. However, post-harvest losses remain a critical issue, often ranging from 8-15% due to improper harvesting, handling, and bruising, sprouting, and inadequate storage facilities. This article examines current post-harvest management practices, including curing, grading, packaging, and cold storage utilization in the district. It highlights key challenges such as price volatility, limited modern infrastructure, high storage costs, and lack of processing facilities that force distress sales among small and marginal farmers. The study also discusses improved strategies like diffused light storage, CIPC treatment, and better transportation to minimize losses and enhance farmer income. Strengthening post-harvest management is essential for sustaining potato production and improving livelihoods in Firozabad.

Key words: Bruising, Curing, Cold storage, Farmer income, Firozabad district, Post-harvest management, Potato, Post-harvest losses. Potato production, Potato storage, Potato processing, Sprouting, Quality preservation

Introduction

The potato (*Solanum tuberosum*) belongs to the solanaceae family of flowering plants. It originated and was first domesticated in the Andes mountains of South America.

Potato is a high-energy, hunger-relieving crop. The potato is the third most important food crop in the world after rice and wheat in terms of human consumption. More than a billion people worldwide eat potato, and global total crop production exceeds 300 million metric tons.

India produces about 8% of the world's potatoes. Potato is a nutrient-rich crop that contains glucose, protein content, dietary fibre, necessary components, and micronutrients. It can be eaten after being boiled, fried, micro waved, or baked. After harvesting, potatoes may suffer from physiological, pathological, and pest losses. Several techniques have been devised to reduce these losses, including low-temperature and elevated temperature of 10–12 °C potato storage with sprout suppressants. Potato can be used to make a variety of value-added products such as chips, French fries, potato flour, potato flakes, potato starch, potato bioethanol, and probiotics. Storing potatoes at optimal temperatures and keeping processing of quality tubers are critical in order to achieve high-quality processed goods from preserved potatoes. The United Nation declared **2008** the '**The International Year of the Potato**'.

In India, potatoes can grow from sea level up to 3000 meters above sea level.

Low Altitude/Plains (Sea Level to ~1500m): Grown as a winter crop (Rabi season) in tropical and subtropical regions such as Uttar Pradesh, West Bengal, Bihar, and Punjab.

High Altitude/Hills (Up to 3000m): Grown as a summer crop in hilly areas such as the Himalayas, Himachal Pradesh, and Uttarakhand.

Factors affecting post-harvest losses:

Potato tubers are in a dormant state at the time of harvest, and several hormonal factors influence this dormancy. As the post-harvest storage period is extended, the dormancy of the tubers is broken, leading to sprouting. This sprouting process involves numerous biochemical changes that can have detrimental effects on both the nutritional value and processing qualities of potatoes. Hormones play a significant role in regulating potato tuber dormancy. Abscisic acid (ABA) and ethylene (ET) are responsible for inducing dormancy in potato tubers, while only ABA is needed to maintain bud dormancy Thakur *et al*., 2023b). Post-harvest losses in potatoes can significantly impact both quality and quantity Wang *et al*., 2023). These losses can stem from various factors, including physiological, entomological (related to insects), and pathological (related to diseases) reasons Rezaee *et al*., 2013. Several factors contribute to post harvest losses in potatoes:

→ Sprouting of tubers (**Biotic Factors**)

→ Soft and dry rot caused by pests and pathogens (**Pests and Diseases**)

→ Losses due to respiration processes (**Biochemical Changes**)

→ Low temperatures and sweetening of potatoes (**Abiotic Factors**)

→ Bruising and physical damage during handling and storage (**Mechanical Losses**)

It can be achieved through proper management practices and the use of suitable storage conditions and designs.

Physiological losses

Tubers are considered semi-perishable commodities because their tubers undergo active metabolism during the post-harvest period (Mukherjee *et al*., 2023). The storage of potatoes (tubers) leads to various physiological and morphological changes effected by several factors, including:

1. Respiration: Potatoes continue to respire after harvest, leading to the consumption of stored energy reserves and resulting in a decrease in quality over time.

2. Dry Matter Content: Changes in the dry matter content of potatoes affect their texture and culinary qualities during storage.

3. Carbohydrate Content: Variations in carbohydrate content can impact the flavor, texture, and suitability of potatoes for processing or consumption (Paul *et al*., 2014).

4. Dormancy: The dormancy status of potato tubers plays a critical role in preventing or encouraging sprouting.

5. Moisture Losses: Excessive moisture loss can lead to shriveling and reduced quality.

6. Skin Thickness: Changes in the thickness and condition of the potato skin can affect its visual appeal and suitability for certain culinary uses.

7. Sprouting: The initiation and growth of sprouts can render potatoes less desirable for consumption or processing.

High-quality fresh market potatoes are characterized by their turgidity, well-shaped appearance, and free from various physiological disorder. These physiological disorder include diseases, sprouts, black spots, black heart (a physiological disorder), freezing injury, and various types of browning and necrosis (Sharma *et al*., 2023).

8. Greening:

One significant challenge in storing potato tubers is the occurrence of greening, where the tubers develop a green appearance due to the accumulation of chlorophyll. Despite being modified stems and non-photosynthetic organs, potatoes can undergo this greening process when exposed to light (Nayak *et al*., 2022). This greening occurs because light exposure can trigger the conversion of amyloplasts into chloroplasts in the peripheral layers of the tuber cells

(Eschemback *et al*., 2020). Several factors effect the greening of potato tubers, including cultural, physiological, genetic, and environmental factors. These factors encompass planting depth, physiological age of the tubers, atmospheric oxygen levels, lighting conditions, and storage temperatures (Tanios *et al*., 2018).

Pathological losses

Several factors contribute to yield loss in potatoes, both in the field and during storage.

1. Post-Harvest Management: Poor post-harvest management practices can lead to significant losses in potato yield. Factors such as improper handling, transportation, and storage can result in damage to potato tubers (Lal *et al*., 2022).

2. Field Diseases: Diseases affecting potato crops in the field, including viral, fungal, nematode, insect, and bacterial infections, can cause direct or indirect losses. These diseases threaten both tuber quality and yield.

3. Environmental Factors: Adverse environmental conditions like frost and heavy rains can also contribute to yield losses in potato cultivation (Jaiswal *et al*., 2023).

4. Rots: Potato tubers, which contain more than 70% water, are highly susceptible to various forms of rot during handling, transportation, and storage. Dry rot is a particularly problematic disease, with the potential to cause yield losses of up to 25% (Wharton *et al*., 2006).

5. Skin Blemish Diseases: Skin blemish diseases, such as silver scurf, can lead to significant losses in potato crops (Gachango *et al*., 2012)

6. Scab: Potato scab is another serious disease that can cause yield losses of more than 10% of the dry weight of potatoes. Tuber damage is considered significant if more than 25% of the surface area is affected (Tiwari *et al*., 2021)

Efforts to manage and mitigate these factors are essential for ensuring the productivity, quality, and profitability of potato cultivation.

Post-harvest management of potato

Poor harvesting, handling, storage, and transportation practices, however, lead to a significant loss of potato production before it reaches consumers. Post-harvest management techniques for potatoes are most importance as they ensure the availability of fresh, high-quality potatoes throughout the year and provide suitable materials for the production of healthy potato products (Altaf *et al*., 2022). Storage of potatoes requires preventing excessive moisture loss, the development of rots and sprouts, and the accumulation of excessive sugar levels. Therefore,

factors such as temperature, humidity, and air movement play an integral role in the process (Mandal *et al*., 2022). Choosing the right storage conditions and handling practices can have a significant impact on potato quality (Bentini *et al*., 2009).

Traditional methods of storage

In India, traditional methods of potato storage have been commonly used for short-term storage in various regions.These methods are often practical for small-scale farmers and are adapted to local conditions.

S. N.	Traditional Storage Method	Description	Advantages	Disadvantages
1.	Root Cellar	An underground storage chamber with controlled temperature & humidity.	Natural insulation, low energy use.	Requires suitable land and construction.
2.	Pit Storage	Potatoes are buried in pits in the ground, covered with straw, soil, or other insulating materials.	Low-cost, simple method.	Vulnerable to rodents, moisture, and pests.
3.	Clamps or Heaps	Potatoes are stacked in mounds, covered with straw or soil, and often enclosed with walls.	Easy to set up, good for small-scale storage.	Accessibility and monitoring can be challenging.
4.	Ventilated Crates or Bins	Wooden crates or bins with ventilation to allow air circulation.	Good air circulation, easy access.	Requires storage infrastructure and management.
5.	Sacks and Burlap Bags	Potatoes are stored in sacks or burlap bags, hung or stacked in a cool, dry location.	Inexpensive, suitable for small quantities.	Limited protection against pests and moisture.
6.	Bushel Baskets	Baskets with good ventilation for storing potatoes in a well-ventilated area.	Easy to move, suitable for short-term storage.	Limited capacity and protection.
7.	Outdoor Stacks	Potatoes are stacked in the open air, covered with straw, and protected from rain.	Simple and low-cost.	Vulnerable to weather, pests, and theft.

1. Cool Rooms with Ventilation: Potatoes are stored in cool rooms with proper ventilation. They can be stored on the floor or on bamboo racks. This method is frequently adopted in the plains of India for short term potato storage.

2. Storage in Pits or Heaps: In Assam and Meghalaya, farmers use pit or heap storage methods. For example, it was reported that the most common method for short-term potato storage involved creating heaps of potatoes on a thick soil layer (Sah *et al*., 2009). In places like Ujjain, Dewas, Indore, and Uttar Pradesh, Heaps of potatoes up to 1.8 meters in height use. Additionally, underground pits with a storage capacity of 30 metric tons were popular in Madhya Pradesh (Dahiya *et al*., 1997). Karnataka farmers used pit storage for 45-60 days and heap storage for on-farm potato storage for 15-30 days (Karnic, 1996).

3. Nawallas in Egypt: In Egypt, potatoes have been stored in nawallas, which are structures made of mud bricks. These structures don't provide much lower temperatures than the ambient temperature outside.

4. Wooden Platforms in Peru: The use of wooden platforms for home consumption potato storage in Peru.

To reduce post-harvest losses and ensure the availability of potatoes year-round, it's essential to explore and implement more advanced storage technologies and practices, especially for larger-scale production and distribution. While traditional storage methods may be suitable for short-term storage.

Refrigeration at low temperature

Storage at lower temperatures has been found to have several benefits, including lower physiological losses and reduced reducing sugar content.

For longer storage periods, such as when storing seed potatoes, maintaining a temperature range of 2-4°C with a relative humidity of 95% is recommended (Ezekiel and Singh, 2007b). Evaporative cooled storage (16-30°C, 70–90% RH) led to a significant increase in reducing sugar content (52.4–242.1%) in potato tubers, while refrigerated storage (2–4°C, 90–95% RH) resulted in a somewhat lower increase (90.5–484.2%) over a 14-week storage period (Mehta *et al*., 2010). Specifically, storage at 5-8°C has been found to inhibit both sprouting and glycoalkaloid formation (Şengül *et al*., 2004).

Storage at elevated temperature

Different storage temperatures can impact the quality and characteristics of stored potatoes

various purposes, including processing and seed use:

(A). 8-12°C for Processing: Potatoes stored at temperatures ranging from 8-12°C are typically used for processing purposes, as this temperature range helps maintain the quality of the potatoes. It is recommended to treat these potatoes with a sprout suppressant to prevent unwanted sprouting (Ezekiel and Singh, 2007a).

(B). 2°C for Seed Purpose: For seed potatoes, a lower storage temperature of 2°C is recommended. Seed potatoes are those intended for planting to grow a new crop, so maintaining their quality and preventing sprouting is crucial.

(C). Effect of Temperature on Sugar and Starch Concentration: The storage temperature can significantly affect the sugar and starch content of potatoes. Potatoes stored at higher temperatures may have starch with more swelling power compared to those stored at lower temperatures. Higher temperatures can lead to increased respiration rates, resulting in the utilization of carbohydrates and potential deterioration in potato quality.

(D). Reducing Sugars and Sucrose Content: Potatoes stored at higher temperatures (8-25°C) tend to contain lower levels of reducing sugars and sucrose compared to those stored at 4°C. Storage at 12°C is recommended for ware/processing potatoes due to less sugar accumulation and lower lipid peroxidation, resulting in better quality tubers after extended storage (Kumar *et al*., 2012).

(E). Invertase Activity: Total invertase activity can influence cold storage sweetening, which can deteriorate the processing quality of potatoes. Interestingly, low invertase activity is observed at elevated storage temperatures compared to cold storage conditions (Raigond *et al*., 2018).

(F). Wound Healing: The rate of wound healing in stored potatoes is directly related to temperature. Potatoes stored at 5°C exhibit wound healing three times slower than those stored at 10°C, and potatoes stored at 10°C show three times slower wound healing compared to those stored at 20°C (Wigginton, 1974).

Storage of potato under chemical sprout suppressant

Sprout suppressants are chemicals in use to prevent the formation of sprouts on stored potatoes under controlled storage conditions. Various compounds have been identified for their ability to inhibit sprouting in potatoes. These chemicals play a crucial role in maintaining the quality of potatoes, these include:

1. Alcohols: Certain alcohols have been found effective as sprout suppressants.

2. Acetaldehyde: Acetaldehyde is another compound known to help prevent sprouting.

3. Ethylene: Ethylene gas can be used to suppress sprouting in stored potatoes.

4. Naphthalene Acetic Acid (NAA): NAA and its derivatives, such as methyl ester of alpha-naphthalene acetic acid (MENA), have been used as sprout suppressants.

5. 2,4-Dichlorophenoxy Acetic Acid (2,4-D): This compound has demonstrated sprout-suppressing properties.

6. 2,4,5-Trichlorophenoxy Acetic Acid (2,4,5-T): Like 2,4-D, 2,4,5-T has been used to inhibit sprouting in stored potatoes.

7. 1,4-Dimethyl Naphthalene (DMN): DMN is another compound with sprout suppressant capabilities.

8. Synthetic Sprout Suppressants: Commercially available synthetic sprout suppressants include Maleic hydrazide, Tetrachloro nitrobenzene, and 1, 4 DMN.

9. S-Carvone: S-Carvone is another chemical that can be used for sprout suppression.

10. Isopropyl-N-Chlorophenyl Carbamate (CIPC): CIPC is one of the most commonly used sprout suppressants and is the only chemical registered in India for commercial application on potatoes (Singh *et al*., 2003). It acts as a mitotic inhibitor and is typically applied in storage in the form of a fog using a fogging machine.

These sprout suppressants play a vital role in extending the storage life of potatoes and preventing unwanted sprouting, which can lead to reduced quality and market value.

Conclusion

Post-harvest management plays a vital role in minimizing losses and enhancing profitability of potato cultivation in Firozabad district. Despite being a major potato-producing area in western Uttar Pradesh, farmers continue to face significant challenges such as high post-harvest losses due to improper handling, bruising, sprouting, inadequate modern cold storage, and price volatility. Adoption of improved practices like proper curing, diffused light storage, better grading, packaging, and use of CIPC can substantially reduce these losses. Strengthening infrastructure, promoting Farmer Producer Organizations (FPOs), and government support for processing units are essential. Effective post-harvest management will not only reduce distress sales but also ensure sustainable income and livelihood security for potato growers in the district.

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A CIRCULAR BIOECONOMY APPROACH FOR SUSTAINABLE AGRICULTURE AND AQUACULTURE: FROM FISH WASTE TO ORGANIC OKRA AND BACK TO FEED

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Abstract

The transition towards sustainable food production requires efficient utilization of biological resources through circular approaches. This article presents a framework integrating fisheries and agriculture through a circular bioeconomy model, focusing on fish waste utilization, organic cultivation of *Abelmoschus esculentus*, and feed development. Fish waste generated from aquaculture and processing units is rich in essential nutrients and can be converted into organic fertilizers through biological and chemical processes. These fertilizers enhance the growth, yield, and quality of organically cultivated okra. The biomass produced, including leaves, stems, and non-marketable pods, can be reutilized in aquafeed formulations as feed ingredients or natural binders. This creates a closed-loop nutrient cycle that minimizes waste generation, reduces dependence on synthetic inputs, and improves farm sustainability. The model provides a viable pathway for both small-scale and commercial farming systems to achieve economic efficiency and environmental sustainability.

Keywords: Circular bioeconomy, Organic okra, Fish waste recycling, Sustainable aquaculture, Nutrient cycling, Integrated farming, Aquafeed

1. Introduction

The concept of a circular bioeconomy has gained increasing importance in recent years as a sustainable alternative to conventional linear production systems. Traditional agricultural and aquaculture practices often operate independently, leading to inefficient resource use and accumulation of organic waste. In particular, fish processing and aquaculture industries generate

substantial quantities of organic residues that are frequently underutilized or improperly disposed of, contributing to environmental pollution.

Simultaneously, modern crop production systems rely heavily on chemical fertilizers, which may degrade soil health and increase production costs over time. Integrating fisheries and agriculture through nutrient recycling offers a promising solution to these challenges. In this context, okra (*Abelmoschus esculentus*) emerges as an ideal crop due to its adaptability, short growth cycle, and high responsiveness to organic nutrient inputs.

Organic cultivation of okra using fish-derived fertilizers not only enhances productivity but also promotes environmentally friendly farming practices. Furthermore, the biomass generated from okra cultivation can be recycled into aquafeed formulations, thereby completing a circular loop. This article explores the scientific and practical aspects of linking fish waste utilization, organic okra production, and feed technology within a circular bioeconomy framework.

2. Botanical Characteristics of Okra (*Abelmoschus esculentus*)

A clear understanding of the botanical features of okra is essential for its effective integration into circular bioeconomy systems, particularly when linking plant growth with nutrient recycling from fish waste.

2.1 Taxonomic Classification

Okra belongs to the family Malvaceae and is scientifically classified as follows:

Kingdom: Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Order: Malvales
Family: Malvaceae
Genus: Abelmoschus
Species: *Abelmoschus esculentus*

This classification highlights its close relationship with other economically important crops such as cotton and hibiscus.

2.2 Morphological Characteristics

Okra possesses a well-developed taproot system with lateral branches, enabling efficient absorption of water and nutrients and contributing to moderate drought tolerance. The stem is

erect, green, and herbaceous, often hairy, and can grow up to 1–2 meters depending on the variety. Leaves are large, alternate, and palmately lobed, enhancing photosynthetic efficiency. The plant produces large, yellow, bisexual flowers with a dark center, resembling hibiscus. The fruit is an elongated capsule (pod) containing numerous seeds and is harvested at a tender stage. Seeds are round and rich in oil and protein, making them potentially useful in feed formulations.

Okra flower

Okra pod

Full matured okra

2.3 Reproductive Biology

Okra is predominantly self-pollinated, though cross-pollination may occur via insects such as bees. Flowers open in the early morning, with pollination and fertilization occurring within a short period, leading to rapid pod development and continuous flowering under favorable conditions.

2.4 Growth and Development

The growth of okra is influenced by temperature, soil, water, and sunlight, with optimal conditions being 25–35°C and well-drained fertile soils (pH 6.0–7.5). The crop undergoes stages of germination, vegetative growth, flowering, and pod formation. The use of fish-based organic fertilizers enhances nutrient availability, improving plant growth, vigor, and yield.

3. Fish Waste Recycling in Circular Bioeconomy Systems

Fish waste represents a significant yet underexploited resource in the context of sustainable agriculture and aquaculture. It includes a wide range of organic materials generated from fish processing and aquaculture activities, and its proper utilization plays a crucial role in developing sustainable and resource-efficient farming systems.

3.1 Nature and Composition of Fish Waste

Fish waste includes various processing by-products such as heads, bones, viscera, and scales, as well as aquaculture residues like uneaten feed and faecal matter. These materials are inherently rich in essential nutrients required for plant growth. In particular, they contain high levels of nitrogen derived from protein residues, phosphorus from bones, and a range of essential

micronutrients. Due to this nutrient-rich composition, fish waste has significant potential for use as an organic input in agricultural systems.

3.2 Conversion into Organic Inputs

Fish waste can be transformed into organic fertilizers through several biological and biochemical processes. Fermentation is commonly used to produce fish amino acids, which serve as effective liquid fertilizers rich in readily available nutrients. Enzymatic hydrolysis is another important method that breaks down complex organic compounds into simpler forms, resulting in nutrient-rich liquid fertilizers suitable for crop application. Additionally, composting fish waste along with plant residues promotes the gradual decomposition of organic matter, improving its suitability as a soil amendment. These processes convert complex organic materials into plant-available nutrients, making them highly suitable for organic farming systems.

3.3 Role in Sustainable Agriculture

The use of fish-derived fertilizers plays a significant role in promoting sustainable agricultural practices. It reduces dependence on synthetic chemical fertilizers, thereby lowering input costs and minimizing environmental impacts. Moreover, these organic inputs enhance soil fertility by improving nutrient availability, stimulating microbial activity, and strengthening soil structure. As a result, the application of fish waste contributes to environmentally sustainable farming practices while supporting the principles of a circular bioeconomy.

4. Organic Cultivation of Okra Using Fish-Based Fertilizers

Okra (*Abelmoschus esculentus*) is well suited for organic cultivation due to its rapid growth and high nutrient demand. It thrives in warm temperatures (25–35°C), well-drained fertile soils, and adequate sunlight and irrigation, conditions that can be effectively supported by fish-based organic fertilizers. The application of these fertilizers enhances vegetative growth, root development, flowering, and pod formation, ultimately improving yield and quality by supporting key physiological processes. Additionally, organic fertilization improves soil structure, aeration, water retention, and microbial diversity, contributing to long-term soil health and sustainable crop production.

5. Organic Okra: Nutritional and Economic Perspectives

The cultivation of organic okra provides both nutritional and economic advantages, making it an important component of sustainable and integrated farming systems. Its high

nutrient content and strong market demand contribute significantly to both human health and farmer livelihoods.

5.1 Nutritional Significance

Okra is a rich source of essential nutrients required for maintaining good health. It contains important vitamins such as A, C, and K, which play vital roles in vision, immunity, and blood clotting. In addition, it provides essential minerals like calcium and potassium, which are necessary for bone health and proper physiological functions. Okra is also high in dietary fiber and antioxidants, which support digestive health and help in reducing the risk of chronic diseases. Organic cultivation further enhances the safety and quality of okra by minimizing the presence of chemical residues, thereby making it a healthier option for consumption.

5.2 Economic Benefits

Organic okra cultivation offers several economic benefits to farmers. It often fetches higher market prices due to increasing consumer preference for organic produce. The use of recycled inputs, such as fish waste-derived fertilizers, reduces dependency on external inputs and lowers production costs. Additionally, okra is a short-duration crop, allowing farmers to obtain quick returns and multiple harvests within a year. These factors collectively make organic okra cultivation a profitable and sustainable component of integrated farming systems.

6. Utilization of Okra Biomass in Aquafeed Development

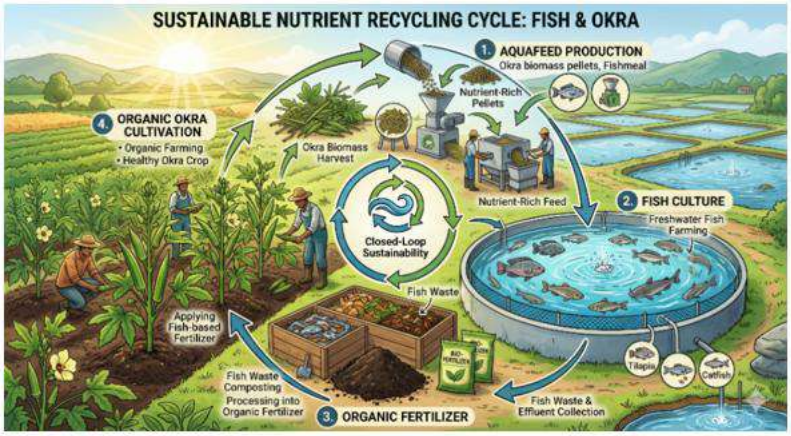
A key component of the circular system is the reutilization of okra biomass in feed technology, which helps in converting agricultural residues into valuable inputs for aquaculture.

- **Availability of Okra Residues:** Okra cultivation generates residues such as leaves, stems, and over-mature or rejected pods, which can be effectively utilized in feed formulations instead of being discarded as waste.
- **Nutritional Role in Aquafeeds:** Okra biomass contains moderate levels of protein, along with fibre and bioactive compounds, which can contribute to fish nutrition and support growth when included appropriately in feed.
- **Okra Mucilage as a Natural Feed Binder:** Okra mucilage acts as a natural binding agent in pellet production and improves feed stability in water, thereby reducing dependence on synthetic additives and enhancing the sustainability of aquafeed production.

7. Circular Bioeconomy Model: From Fish Waste to Organic Okra and Back to Feed

The integration of fish waste recycling, organic okra cultivation, and feed production creates a closed-loop system.

7.1 System Dynamics



Source: AI generated with the contents referring to articles

1. **Aquafeed Production:** Raw okra biomass and fish waste are processed to create nutrient-rich fish feed pellets.
2. **Fish Culture:** This aquafeed is used to farm freshwater fish (such as Tilapia and Catfish) in tank systems.
3. **Organic Fertilizer:** Waste generated by the fish is harvested and converted into organic fertilizer, initiating the land-based stage.
4. **Organic Okra Cultivation:** The organic fertilizer is applied to nutrient-rich soil to cultivate healthy okra crops without synthetic chemicals.

Okra Biomass: Harvested okra plants provide produce, while the resulting leafy biomass is collected to serve as a key ingredient for the next cycle of aquafeed production.

7.2 System Efficiency and Sustainability

This circular model maximizes resource utilization by efficiently recycling fish waste into agricultural inputs, minimizes waste generation, and significantly reduces environmental impact, thereby promoting sustainable farming practices.

7.3 Socio-economic Implications

The system enhances farmer income through cost reduction and value addition, promotes diversified farming practices, and supports rural livelihoods by creating sustainable and integrated production opportunities.

8. Practical Applications and Future Scope

The circular bioeconomy model can be applied in smallholder farms, commercial aquaculture–agriculture systems, and urban farming setups, promoting efficient resource use and sustainability. Future research should focus on improving nutrient recycling methods, evaluating the efficiency of okra-based feed, and developing scalable models suitable for wider adoption.

9. Conclusion

The circular integration of fish waste utilization, organic okra cultivation, and feed technology represents a sustainable pathway for modern agriculture and aquaculture systems. By transforming waste into valuable resources, this approach enhances productivity, reduces environmental impact, and improves economic returns. Okra plays a central role in this system due to its adaptability, nutritional value, and potential for feed applications. The adoption of such circular bioeconomy models is essential for achieving long-term sustainability and resilience in food production systems.

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BUILDING SOIL HEALTH NATURALLY WITH LEGUME-BASED CROPPING MODELS

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Abstract

Legume-based cropping models are increasingly recognized as a sustainable agricultural strategy to enhance soil health by harnessing **biological nitrogen fixation (BNF)** and improving soil physical, chemical, and biological properties. By incorporating legumes in mixed cropping systems, agroecosystems can reduce dependence on synthetic nitrogen fertilizers, improve soil organic carbon (SOC) stability, optimize nutrient cycling, and enhance microbial diversity. This article synthesizes recent scientific evidence supporting the positive impacts of legume-based cropping on soil health and discusses mechanistic pathways driving these benefits.

Introduction

Soil health — defined as the continued capacity of soil to function as a living ecosystem that sustains plants, animals, and humans — is fundamental for resilient agriculture. Conventional monoculture systems often deplete soil nitrogen and organic matter while degrading soil structure and biodiversity. Integrating legumes into cropping systems, either through intercropping, rotations, or green manures, offers a biologically grounded alternative to restore soil fertility and ecosystem function.

Biological Nitrogen Fixation and Nitrogen Cycling

Legumes establish symbiotic relationships with nitrogen-fixing bacteria (rhizobia) in root nodules, allowing them to convert atmospheric N_2 into plant-available nitrogen. This **biological nitrogen fixation (BNF)** increases nitrogen inputs to the system without synthetic fertilizers, enriching soil nitrogen and supporting companion crops in mixed stands. In systems where soybean is intercropped with cereals such as wheat, legume BNF contributions were shown to

increase reliance on atmospheric N_2 fixation and boost nitrogen accumulation compared to monocultures, enhancing nitrogen availability in soil (using isotopic ^15N methods) and promoting sustainable nutrient cycling.

Beyond nitrogen fixation, legume rhizosphere interactions improve nutrient capture and reduce inorganic nitrogen requirements, thereby lowering environmental impacts and fossil-fuel-derived inputs.

Soil Organic Carbon and Soil Structure Enhancement

Long-term legume intercropping studies demonstrate significant improvements in **soil organic carbon (SOC) storage and stability** — critical indicators of soil health and climate resilience. A seven-year field experiment comparing potato–soybean intercropping with monocultures revealed:

- A 7.8 % increase in SOC content under intercropping.
- A 17.8 % increase in mineral-associated organic carbon (MAOC), a stable carbon pool linked to long-term soil carbon sequestration.
- A 22.8 % improvement in overall SOC stability.

These results suggest that legume presence alters microbial community dynamics, stimulating fungal abundance and enzymatic processes that convert labile carbon into more stable forms bound to soil minerals.

Legumes also contribute organic residues (roots, stubble, leaf litter) that improve **soil structure** by enhancing aggregate stability, increasing porosity, and promoting water infiltration — all of which are fundamental to soil resilience and productivity.

Soil Biochemistry, Enzyme Activity, and Nutrient Cycling

Intercropping legumes with non-legumes alters soil enzyme activities and nutrient transformations:

- Legume-derived biological C and N inputs increase hydrolytic enzyme activities linked to carbon and nutrient cycling.
- These enhanced enzymatic pathways promote soil organic matter decomposition and nutrient mineralization, which in turn improve soil fertility and crop nutrient uptake.

These processes support a coordinated loop of carbon and nutrient flow in the soil ecosystem, benefiting both legumes and partner crops like maize by enhancing nutrient availability in nutrient-deficient conditions.

Microbial Diversity and Soil Biological Function

The inclusion of legumes in cropping systems fosters diverse microbial communities by providing a range of root exudates and organic substrates. Microbial community composition shifts toward organisms capable of facilitating carbon transformation and nutrient cycling, reinforcing soil health and nutrient stability. Enhanced microbial diversity is particularly associated with increased fungal abundance, which contributes significantly to soil organic matter persistence and structure.

Complementarity and Synergy in Mixed Cropping Systems

Beyond BNF, legumes exhibit **complementarity with non-legume crops**:

- Root systems exploit different soil niches, optimizing nutrient and water use.
- Mixed systems can enhance phosphorus mobilization and nitrogen capture through rhizosphere processes, further improving soil chemical function.

These complementary interactions reduce soil degradation risks associated with continuous cereal monocropping, build soil resilience, and support diversified agricultural landscapes.

Challenges and Considerations

While legume-based systems generally improve soil health, outcomes can vary based on species combinations, soil conditions, and management practices. Some long-term trials reported **heterogenous effects on subsoil carbon stocks**, hinting at complex dynamics that require tailored agronomic design for sustainable outcomes.

Conclusions and Future Directions

Current scientific evidence confirms that **legume-based cropping models are powerful tools for building soil health naturally** by:

- Enhancing nitrogen inputs through biological fixation
- Increasing soil organic carbon and its stability
- Stimulating beneficial microbial communities
- Improving nutrient cycling and soil structure

As agriculture confronts challenges from climate change and soil degradation, integrating legumes into diversified cropping strategies offers a sustainable pathway to regenerate soils, reduce synthetic inputs, and strengthen agroecosystem resilience.

Future research should continue to evaluate context-specific effects, optimize species combinations, and quantify long-term benefits across diverse climates and soil types.

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INDIA'S GHERKIN INDUSTRY: A SMALL CROP WITH BIG GLOBAL IMPACT

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Introduction

Gherkin (*Cucumis anguria* L. Cucurbitaceae) habitually known as Burr gherkin or Pickle gherkin has been introduced into India in 1989 as a profitable cash crop and is mainly exported to other foreign countries (Venuprasad *et al.*, 2013). Gherkin is grown for its edible vegetable, but it is majorly preferred in the form of pickling. The product has negligible domestic market and the cultivation is exclusively for exports. The preserved/pickled fruits are used in the preparations like sandwiches, pizzas, etc. The crop can be cultivated round the year unlike other major producing countries like Mexico, Hungary and Madagascar, where it can be cultivated only for three months in a year. Further, Gherkin Is a labour-intensive crop and hence, the cost of cultivation is lower in labour surplus country like India compared to Europe and America. For this reason, industries engaged in marketing of gherkin in India.

Importance of gherkin

Gherkin is a favourite lunch substitute in West Sibanda. In Africa, the gherkin have broad medicinal use viz., palmitic acid, stearic acid, oleic, lionlenic and lionlenic acids, were isolated from fruits of *cucumber anguria* L. *Var. longipes*.". It has prime chemical constituents such as cucurbitacin B, cucurbitacin D and cucurbitacin G which are used in conventional treatment of

different diseases (Gill *et al.*, 2014) and cures constipation, indigestion and jaundice (Chadha, 2001). Gherkins are widely used as ingredient of salads as pickles." Gherkin is also an important source of earning foreign exchange that is needed for importing capital goods for the rapidly expanding industrial sector. These tangy, crunchy delights have gained immense popularity in international cuisines, particularly as condiments, toppings, or ingredients in salads, sandwiches, and hamburgers. Pickled cucumbers generally boast higher vitamin and fiber content than their fresh counterparts, albeit with added sugar and sodium, which diminishes their nutritional value. Nevertheless, pickled cucumbers serve as a rich source of antioxidants, are devoid of fat, low in calories, and bolster the body's immunity.

They also aid in regulating blood sugar levels and reinstating the body's electrolyte balance. Gherkins, often referred to as "cucumbers on steroids," are small cucumbers that are harvested before reaching maturity and pickled in vinegar or brine. Moreover, with the escalating prevalence of lifestyle ailments such as obesity, diabetes, stress, and hypertension, individuals are increasingly recognizing the significance of a wholesome diet. Additionally, health-conscious consumers exhibit a proclivity towards pickled cucumbers due to their superior taste compared to raw cucumbers. The health benefits of pickled cucumbers, coupled with heightened consumer consciousness regarding the importance of maintaining a healthy lifestyle, are poised to propel market growth in the forecast period.

Cultivation

Gherkins are grown only in South India where ideal soil type and desirable temperatures of not less than 15°C and not more than 35°C are found mainly in Karnataka, Tamil Nadu and Andhra Pradesh. These conditions which are prevalent throughout the year, render this region ideal to take up three crops of gherkins annually. As true for cucurbitaceous crops, irrigation is a critical requirement in gherkin cultivation. Although the crop Is only of 90 days duration, requirement of frequent irrigation and day-to-day surveillance for a host of pest and disease makes it a labour-intensive one. Karnataka state accounts for almost 60 percent of gherkin production and leads in exporting preserved gherkins with a share of more than 90 per cent in total export. Gherkin cultivation in India is driven largely through contract farming. The crop is ready for harvest in 30-35 days. As the tender immature fruits are meant for canning the price of the produce is decided by the stage of maturity. Fruits are plucked as per company's specifications on size and quality. Smallest fruit (stage 1) which will weigh approximately 4.0g

(250 fruits per kg) will fetch the maximum price followed by stage 2 and stage 3. To maintain the grade the harvesting of fruits should be done every day. A day's break would end up with outsized or overgrown gherkin means loss to farmer. Avoid sharp sun and high temperature while harvesting. For this picking of fruits must be none in the very early morning or late evening. Harvest the fruits by retaining the stalk on the plant. Harvested fruits must be collected under shade. Flower head has to be removed from fruit. Water should not be sprinkled on harvested fruits at any stage. Even if there is surface water during harvest it should be dried by aeration. For collection of fruits jute bags alone have to be used and plastic bags should be totally avoided. Bamboo baskets are compulsorily used to collect fruits after harvesting. Netted bag or a big basket is used temporarily to store the fruits. Fruits which are defective or infested with fruit borer, fruit fly or virus, fruits with flowers, rotten fruits, damaged fruits, bent fruits, fruits with stems, fruits with foreign matter, etc., are removed. The harvested produce should be transported to the factory on the same day before dusk. Leaving the gherkin unprocessed overnight would result in poor quality produce.

Contract farming

While India is a major producer of cucumbers and the top exporter of gherkins, the lack of research and development in crop sciences means that the country continues to be dependent on cucumber seed imports from countries like Holland. Similarly, most processing units are heavily dependent on imports even for machinery. And then, dependence on contract farming, although ensuring steady raw material supplies, has its own share of problems. "Most farmers in India hold very small areas of land. Hence, to achieve uniform quality and timely shipment of export consignments, business houses prefer contract farming. And to effectively communicate and convince farmers to join hands for large scale contract farming, they appoint field staff from the local community. But many times, the field staff join hands with farmers and indulge in malpractice and forge quality and quantity.

Gherkin industry

India has' today emerged as the origin of the finest gherkin cultivation, processing and exporters to the every-growing world requirement. Gherkin cultivation, processing and exports were started in India during the early 1990s with a modestly beginning in Karnataka State (120 thousand MT with the area of 20,000 acres) in South India and later extended to the adjoining states of Tamil Nadu (40,000 MT across 6,700 acres), Andhra Pradesh (25,000 MT over 4,200

acres) and Telengana (20,000 MT across 3,400 acres) now has reached an impressive tonnage of 205 thousand Metric tonnes (2024-2025). The export of processed gherkin is done by about 51 companies located in Karnataka. Tamil Nadu and Andhra Pradesh. Gherkins are grown in contact with small and marginal farmers. Currently there are more than 1, 00,000 small and marginal farmers who are engaged in the production of gherkins. The contract farmers receive all inputs and technical support from the companies and also the farmers are assured guaranteed buy back of crop at pre-declared prices. Initially processed gherkins were exported in bulk packing and since 2001 gherkins are being exported in "Ready-to-eat Jars".

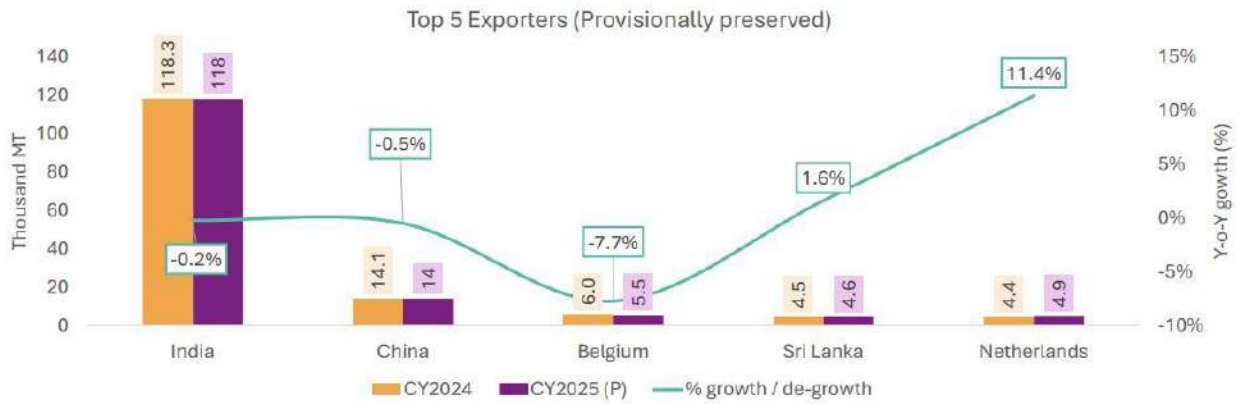
India's Gherkins Export Market

India has emerged as a key player in the global gherkins market, with its exports witnessing a remarkable growth trajectory. According to the Agricultural and Processed Food Products Export Development Authority (APEDA), following directions of the Department of Commerce, Ministry of Commerce & Industry, the Agricultural and Processed Food Products Export Development Authority (APEDA) undertook a series of initiatives in infrastructure development, product promotion in the global market and adherence to food safety management system in processing units. As part of such export promotion measures, it established agri-export zones (AEZs) in Karnataka and Andhra Pradesh and suddenly everything was in place for the country to take the global gherkins market by storm. Another factor which helped the growth of the country's gherkins exports was the fact that farmers too preferred a cash crop like cucumber, because it meant they needn't wait for months to harvest and market their produce. Gherkins are exported under two categories -- cucumbers and gherkins, which are prepared and preserved by vinegar or acetic acid and cucumbers and gherkins, which are provisionally preserved.

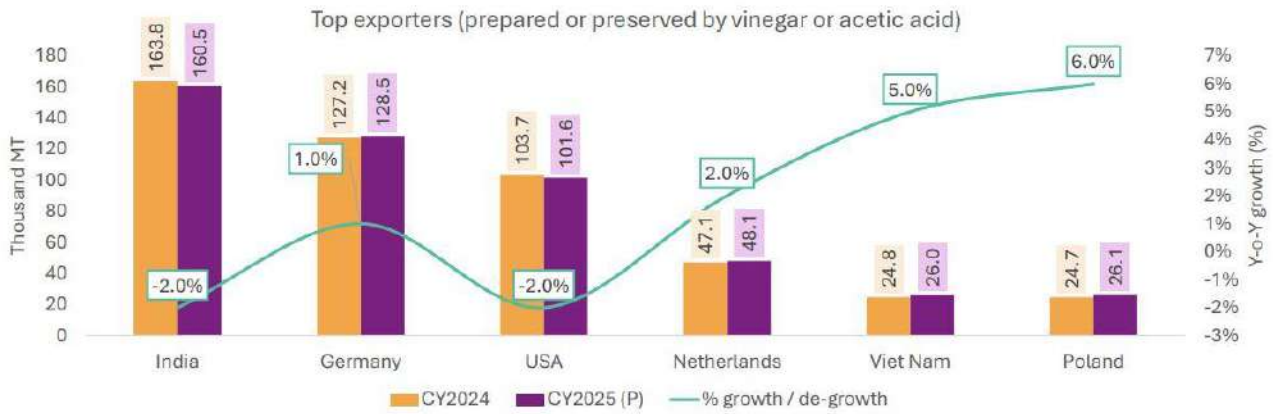
India's Cucumber / Gherkins exports (in US million tons)

S. No.	Product	Export Volume FY 25 (MT)	Exported in FY 25 (USD Mil)
1.	Cucumber and Gherkins (Provisionally preserved and preserved with vinegar or acetic acid	289594.37	306.72

Source: DGCIS



Source: APEDA



Source: APEDA

Export Destinations:

Gherkins is currently exported to more than 20 countries, with major destinations being North America, European countries and Oceanic countries such as USA, France, Germany, Australia, Spain, South Korea, Canada, Japan, Belgium, Russia, China, Sri Lanka and Israel.

Factors driving export growth:

APEDA has played a significant role in promotion of export of processed vegetables and it has been providing financial assistance for development of infrastructure and enhancing quality of processed gherkins, products promotion in the international market and implementation of food safety management systems in the processing units. On an average, a gherkin farmer produces 4 metric tonne per acre per crop and earns about Rs 80,000 with a net

income of Rs 40,000. Gherkin has a 90-day crop and the farmers take two crops annually. Processing plants of international standards have been established here to cater to the requirement of foreign buyers. This ensures all statutory benefits are given to the Employees. The APEDA is also focusing on value addition of gherkins to increase the export value of the product. Apart from its export potential, the gherkin industry plays a key role in the creation of rural employment. In India, cultivation of gherkins is carried out under contract farming by around 90,000 small and marginal farmers with an annual production area of 65,000 acres. Processed gherkins are exported in bulk as industrial raw material and in jars as ready to eat. The bulk production is still occupying a high percentage of the gherkin market. In India there are about 51 major companies producing and exporting gherkins in drums and ready-to-eat consumer packs.

According to APEDA's Agri exchange government website, gherkins hold immense export potential due to their rising demand worldwide, and with India's diverse range of gherkin products, including pickled gherkins, gherkin relishes, and gherkin slices, it is able to cater to various preferences and market requirements. One of the key factors driving India's success in gherkin exports is its favourable agro-climatic conditions. Gherkins thrive in regions with moderate temperatures, abundant sunlight, and well-drained soil—conditions found in several parts of India. Furthermore, the availability of skilled labour, cost-effective production methods, and adherence to stringent quality standards have contributed to India's competitive advantage in the global market. The growth of the gherkins export market in India has had a positive impact on the country's economy and rural communities. Gherkin cultivation and processing provide income-generating opportunities for farmers, contributing to rural livelihoods and the overall agricultural sector. Furthermore, gherkin exports create employment opportunities in processing units, packaging industries, and logistics sectors, supporting India's economic growth and development.

Challenges and Constraints

A challenge impeding market growth is the stringent regulations governing pickled cucumbers and gherkins. Companies are mandated to adhere to regulations and directives issued by diverse governmental bodies. Non-compliance with these regulations could result in additional compliance costs, potentially hindering market growth in the forecast period. Maintaining high-quality standards is crucial for sustaining India's gherkins export market.

APEDA plays a pivotal role in ensuring the quality and safety of gherkins through its regulatory framework. The quality control measures implemented by APEDA, including residue monitoring, traceability systems, and adherence to international food safety standards are some of the best and latest practices that India is following. While India holds a significant position in the gherkins export market, it faces competition from other countries as well. Countries like China, Spain, Turkey, and the Netherlands also have a presence in the global gherkins market. These competitors emphasize their unique qualities, production techniques, and taste profiles to attract international buyers. However, India's favourable agro-climatic conditions, cost-effective production, and adherence to quality standards continue to give it a competitive edge.

Opportunities for growth

The Asia-Pacific region, including countries like Japan, South Korea, and China, is experiencing a rising demand for pickled and processed vegetables, including gherkins. India can capitalize on this trend by expanding its exports to these markets, leveraging its competitive advantage in terms of production capacity and cost-effectiveness. The Middle East and Gulf countries, such as Saudi Arabia, UAE, and Qatar, represent promising markets for gherkin exports due to their large expatriate populations and growing demand for international cuisines. Indian exporters can tap into this market by offering high-quality gherkin products tailored to local tastes and preferences. Africa is another region with untapped potential for gherkin exports from India. Countries like Nigeria, South Africa, and Kenya have emerging urban populations with increasing disposable incomes and a growing interest in convenience foods. Indian exporters can explore opportunities in these markets by supplying processed gherkin products suitable for retail and foodservice channels. Latin American countries, including Brazil, Mexico, and Chile, offer opportunities for gherkin exports from India. The region's diverse culinary traditions and expanding food processing industry create demand for imported ingredients such as gherkins. Indian exporters can target these markets by providing high-quality gherkin products that meet local regulations and consumer preferences. In addition to traditional gherkin exports, there is untapped potential in value-added gherkin products such as gherkin relish, gherkin pickles, and gherkin-based sauces and condiments. Indian exporters can differentiate themselves in the global market by offering innovative and customized gherkin products that cater to specific consumer needs and culinary trends. With increasing consumer awareness of health and sustainability, there is a growing demand for organic and specialty gherkins in international

markets. Indian exporters can capitalize on this trend by cultivating organic gherkins and offering specialty varieties such as baby gherkins or flavored gherkins to niche markets and premium segments. To fully realize the export potential of gherkins in emerging markets, Indian exporters need to invest in infrastructure development, cold chain logistics, and quality assurance measures. This includes ensuring compliance with international food safety standards, implementing traceability systems, and maintaining product consistency and freshness throughout the supply chain.

Future outlook

The *cucumber and gherkins market* worldwide is predicted to experience a significant increase, with an estimated growth of USD 1.39 billion at a CAGR of 4.5% from 2023 until 2028. The consistent growth of Gherkins export companies in India has propelled the country's position as a leading supplier of high-quality gherkins worldwide. The global demand for pickled and processed vegetables, including gherkins, continues to rise due to changing dietary preferences, urbanization, and the growing popularity of convenience foods. As consumers seek healthier snack options and international flavors, gherkins are becoming increasingly popular in various cuisines worldwide. Gherkins are versatile ingredients used in a wide range of food products, including salads, sandwiches, relishes, and appetizers. The versatility of gherkins makes them attractive to food manufacturers, retailers, and consumers looking for convenient and flavorful options. As a result, the demand for gherkins is expected to remain strong across various food segments. Rapid urbanization, rising disposable incomes, and changing consumer preferences in these regions create a favorable environment for the adoption of gherkin-based products. Indian exporters can leverage their competitive advantages, such as cost-effectiveness and production capacity, to tap into these markets. Overall, the future outlook for gherkin exports from India is positive, driven by increasing global demand, emerging market opportunities, and a focus on value addition and sustainability.

Conclusion

India's gherkins export market has witnessed significant growth in recent years, propelled by factors such as favorable agro-climatic conditions, adherence to quality standards, and increasing global demand. As a key player in the gherkins industry, India has demonstrated its ability to provide high-quality gherkins to international standards. Future implications of the gherkin export market underscore the importance of strategic planning, market intelligence, and

continuous innovation to seize opportunities, address challenges, and sustain growth in a dynamic and competitive global marketplace. By proactively addressing these implications, exporters can position themselves for success and contribute to the continued growth and development of the gherkin export industry.

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ENVIRONMENTAL CHALLENGES IN THE HIMALAYAN REGION: SIGNIFICANCE, IMPACTS, TYPES AND SUSTAINABLE MANAGEMENT STRATEGIES

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Abstract

The Himalayan region is one of the world's most ecologically fragile and climate-sensitive mountain systems, providing nearly two billion people with critical ecosystem services such as freshwater supply, biodiversity conservation and climate regulation. However, the region is increasingly under threat from the combined effects of climate change and human activity. Rising temperatures have accelerated glacier retreat and reduced snow cover, having a significant impact on the Himalayan cryosphere. These changes are disrupting hydrological systems, raising the possibility of glacial lake outburst floods and other water-related hazards. In addition, unpredictable precipitation patterns are intensifying the frequency of floods, droughts and extreme weather events. The region's biodiversity is also under severe stress as a result of habitat degradation, fragmentation and shifting vegetation zones, which force species to migrate to higher altitudes and cause ecological imbalances. Human activities such as deforestation, infrastructure development and hydropower expansion exacerbate land degradation, soil erosion and slope instability, increasing the risk of landslides. Furthermore, unplanned urbanization and mass tourism put additional strain on already vulnerable ecosystems and natural resources. Water availability is becoming more uncertain as a result of drying springs and irregular rainfall patterns, affecting agriculture, food security and rural livelihoods. Climate-induced migration has also emerged as a major socioeconomic concern in many Himalayan regions. Emerging

pollutants like black carbon and microplastics are accelerating environmental degradation. The cumulative impact of these factors increases the Himalayan ecosystem's vulnerability to natural disasters. To address these challenges, we need integrated and long-term approaches that combine scientific research and policy interventions. Ecosystem-based management, climate-resilient infrastructure and sustainable tourism practices are all necessary strategies. Community participation and the incorporation of traditional ecological knowledge can also play an important role in environmental conservation. Long-term sustainability requires improved governance and regional cooperation. As a result, immediate and coordinated efforts are required to protect the Himalayan environment and ensure sustainable development for future generations.

Keywords Climate change, glacier retreat, biodiversity loss, land degradation, natural hazards, sustainable development, ecosystem services, anthropogenic pressure

Introduction

The Himalayan mountain range, which covers eight countries—India, Nepal, Bhutan, China, Pakistan, Afghanistan, Bangladesh and Myanmar—is one of the world's most significant and ecologically diverse regions. The Himalayas, also known as the "Third Pole," have the largest reserves of ice and snow outside of the polar regions and provide critical freshwater to major river systems such as the Ganga, Indus and Brahmaputra. These rivers support nearly two billion people in South Asia by providing agriculture, hydropower, drinking water and economic activities (Chauhan *et al*., 2023). The region is recognized as a global biodiversity hotspot, with ecosystems ranging from subtropical forests to alpine meadows and cold deserts. It supports a wide range of flora and fauna, including many endemic and endangered species. In addition to their ecological importance, the Himalayas have a significant impact on regional and global climate systems by influencing atmospheric circulation patterns, monsoon dynamics and carbon cycling processes (Kumar *et al.*, 2024). Furthermore, mountain communities rely heavily on these ecosystems for their survival, making the region socio economically significant. Despite its importance, the Himalayan ecosystem is extremely vulnerable due to its young geology, steep slopes and high seismic activity. Because of its inherent fragility, it is extremely vulnerable to natural and anthropogenic disturbances.

Rapid population growth, deforestation, infrastructure development, unplanned urbanization and tourism intensification have all contributed to the region's increased

environmental stress in recent decades. These pressures have resulted in land degradation, habitat fragmentation and natural resource depletion (Sharma *et al.* 2025). Climate change has emerged as a dominant driver of environmental change in the Himalayas, with warming rates reported to be higher than the global average. Rising temperatures have accelerated glacier retreat, reduced snow cover and altered precipitation patterns, all of which have had a significant impact on the region's hydrology. These changes are increasing the frequency and severity of natural hazards such as floods, landslides and glacial lake outburst floods (GLOFs), posing serious threats to both ecosystems and human populations (Ahmed, 2025; Rather *et al.*, 2026). Moreover, climate-induced shifts in temperature and moisture regimes are affecting biodiversity and ecosystem functioning. Warming causes species to migrate to higher altitudes, while invasive species spread into new areas, disrupting ecological balance. Changes in vegetation patterns also have an impact on soil stability, water retention and carbon sequestration processes. These ecological transformations have far-reaching consequences for ecosystem services and human well-being (Kattel, 2022).

Water resources in the Himalayas are especially vulnerable to climate change and human activity. While glacier melt initially increases river discharge, long-term declines in ice reserves are expected to reduce water availability, particularly during dry seasons. Additionally, the drying of springs and depletion of groundwater sources are already being reported in many Himalayan regions, affecting drinking water supply and agricultural productivity (Pantha *et al*., 2026). Given the growing environmental challenges, there is an urgent need to better understand the complex interactions between climate change, human activities and mountain systems.

A comprehensive assessment of environmental issues in the Himalayas is required for developing long-term management strategies and increasing resilience. The purpose of this article is to examine the major environmental challenges confronting the Himalayan region, analyze their consequences and propose long-term ecological and socioeconomic sustainability solutions.

Major Significance of The Himalayan Region

1. **Tourism and Economic Development**

The Himalayas are a major tourist destination and have a significant economic impact on India.

- Trekking, mountaineering, skiing, river rafting and ecotourism are popular among both domestic and international tourists.

- Popular destinations include Himachal Pradesh, Uttarakhand, Jammu and Kashmir and Sikkim.
- Wildlife tourism in national parks such as the Great Himalayan National Park promotes conservation and local livelihoods.
- Tourism creates jobs in the hospitality, transportation and local handicrafts sectors. However, unregulated tourism may exceed ecological carrying capacity, resulting in environmental degradation.

Fig. 1 Showing Significance of The Himalayas

2. Water Resources

The Himalayas are frequently referred to as the "Water Tower of Asia."

- Major rivers like the Ganga, Yamuna, Brahmaputra, Indus and Sutlej flow from Himalayan glaciers and snow fields.
- These rivers provide irrigation, drinking water and industrial use to millions of people.
- Seasonal snowmelt maintains perennial river flow, which is essential for agriculture in the Indo-Gangetic plains.
- The retreat of glaciers caused by climate change poses a long-term threat to water security.

3. **Energy Sector**
   - The Himalayan rivers play a vital role in India's energy sector.
   - A significant portion of India's hydropower potential is derived from fast-flowing Himalayan rivers.
   - Important contributors include Nathpa Jhakri, Tehri Dam and Bhakra Nangal
   - Hydropower is a renewable and low-carbon energy source, supporting India's climate goals.
   - River systems also support thermal power indirectly by providing cooling water.
   - However, dam construction can lead to ecological disturbances and displacement issues.

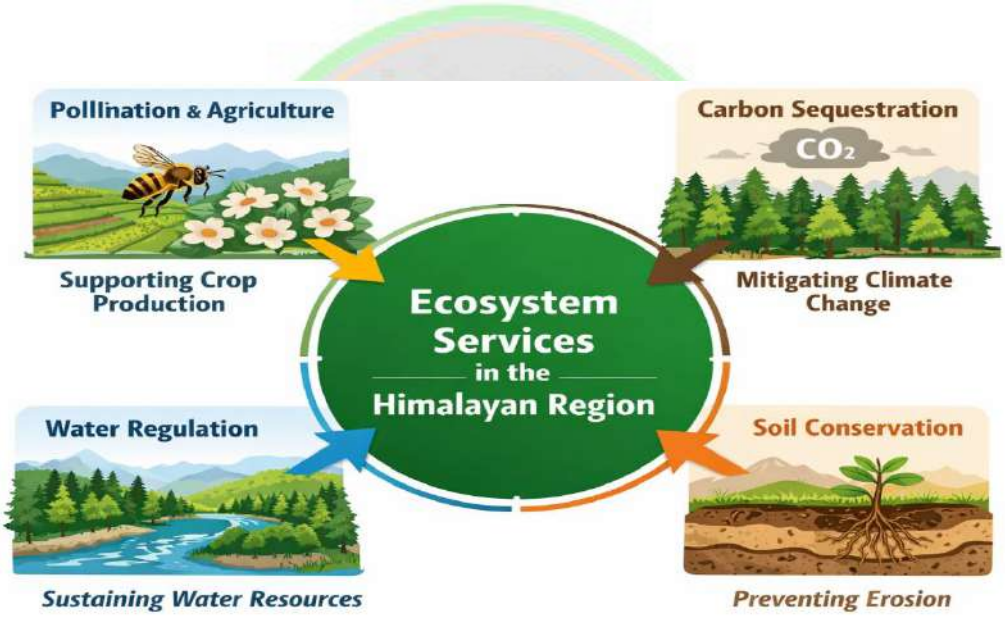

Fig.2

Showing Ecosystem Services in the Himalayan Region

4. **Geopolitical and Strategic Significance**
   - The Himalayas are of immense strategic importance for India.
   - They serve as a natural barrier separating India from its neighbors, including China and Pakistan.
   - Siachen Glacier and Ladakh are two of the region's delicate border regions.
   - By assisting in the distribution of rainfall and obstructing cold winds from Central Asia, the Himalayas have an impact on monsoon patterns.
   - They offer defensive and surveillance strategic vantage points.

- The Himalayas are therefore essential for both climate protection and national security.

5. **Biodiversity and Ecosystem Services**
    - The Himalayas are one of the world's richest biodiversity hotspots.
    - They host diverse ecosystems ranging from tropical forests to alpine meadows.
    - Species such as the snow leopard, red panda, Himalayan monal and medicinal plants are found here.

Types of Environmental Issues in The Himalayan Region

1. **Climate change** is one of the most critical environmental challenges in the Himalayan region, with warming rates exceeding the global average. The formation of glacial lakes has increased, snow cover duration has decreased and glacier retreat has accelerated due to rising temperatures. For instance, glaciers in the Eastern Himalayas (Sikkim and Bhutan) have shown significant shrinkage over recent decades. One recent instance of a Glacial Lake Outburst Flood (GLOF) connected to rapid glacier melt is the South Lhonak Lake outburst in Sikkim in 2023. Similarly, studies in the Gangotri Glacier (Uttarakhand) indicate continuous retreat, threatening long-term water availability in the Ganga basin. River hydrology, agriculture and populations downstream are all directly impacted by these changes (Sharma *et al*., 2026; IPCC, 2021).

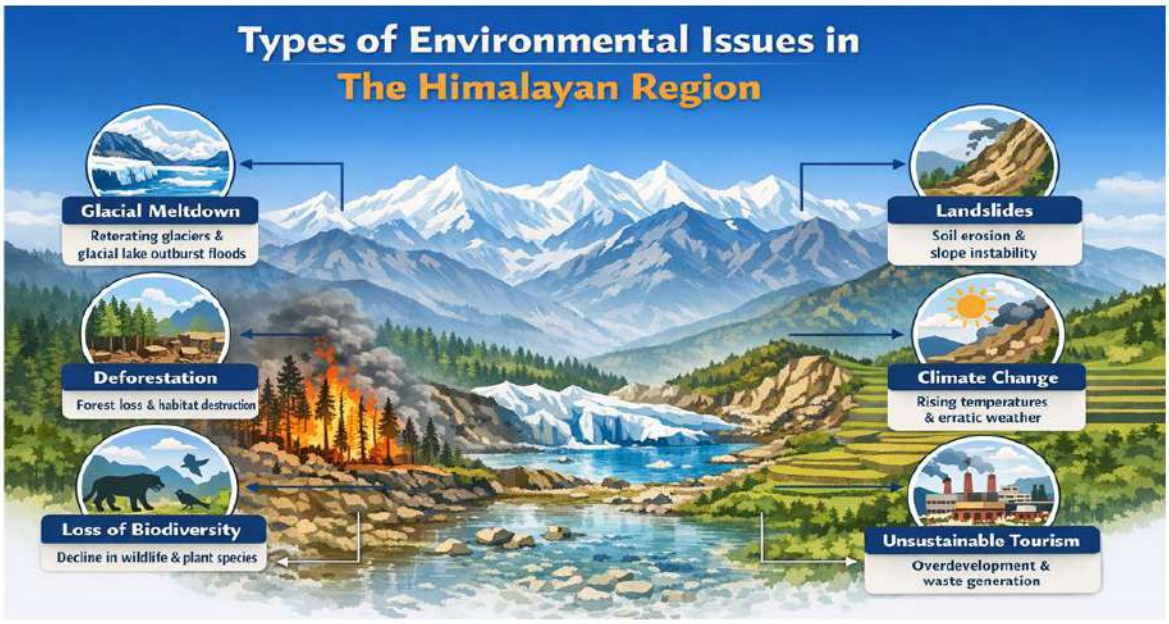

Fig. 3 Showing types of Environmental issues in The Himalayan Region

2. **Land Degradation and Erosion** Land degradation in the Himalayas is primarily caused by deforestation, overgrazing, shifting cultivation, and infrastructure development, such as road building. The region's steep slopes and fragile geology make it highly vulnerable to soil erosion and landslides. Landslides during monsoon seasons are common in Himachal Pradesh due to slope destabilization caused by road widening and hydropower construction. Similarly, in Uttarakhand, unplanned urban development has exacerbated soil erosion and land instability. The 2013 Kedarnath disaster demonstrated how deforestation and slope modification can amplify natural hazards. Soil loss reduces agricultural productivity while increasing river sediment load (Mishra et al.,2022).

3. **Biodiversity Loss** The Himalayas are recognized as a global biodiversity hotspot, but biodiversity is rapidly declining due to habitat destruction, climate change, and human interference. Habitat fragmentation and changing climatic conditions are putting species like the snow leopard, red panda and Himalayan monal at risk. In the Eastern Himalayas, shifting vegetation zones have forced species to migrate to higher altitudes, limiting their survival range. Forest fires in Uttarakhand and Himachal Pradesh have further harmed habitats.(Pandit *et al*., 2014). Furthermore, the spread of invasive species like Lantana camara is displacing native flora, disrupting ecosystem balance. Illegal wildlife trade and rising human-wildlife conflict exacerbate conservation challenges.

4. **Water Resource Degradation** Despite its reputation as the "Water Tower of Asia," the Himalayan region is facing serious water-related challenges. Changes in precipitation patterns, glacier retreat, and over-extraction of groundwater have all contributed to declining water availability. Many traditional springs in mid-hill regions such as Shimla, Himachal Pradesh, and Darjeeling, West Bengal, have dried up, resulting in seasonal water shortages. The 2018 Shimla water crisis is a prime example of how water scarcity harmed tourism and daily life. Furthermore, altered river flow regimes in rivers such as the Teesta and Brahmaputra affect agriculture and hydropower generation. These changes endanger both environmental and socioeconomic sustainability (Yao and Chen, 2025).

5. Pollution and Waste Management Rapid urbanization and increasing tourism have significantly contributed to pollution in the Himalayan region. Hill towns such as **Manali, Shimla, Leh and Nainital** are facing severe solid waste management challenges due to plastic waste, unregulated construction and inadequate sewage treatment systems. For example, during

peak tourist seasons. Rivers like the **Beas and Ganga** are increasingly polluted due to untreated sewage and tourism-related waste. Air pollution is also rising due to vehicular emissions in narrow valleys, leading to localized air quality deterioration (Thakur *et al.*, 2021).

6. **Natural hazards and disasters** The Himalayan region is highly vulnerable to natural disasters due to its tectonic activity and fragile geomorphology. Earthquakes, landslides, flash floods, and cloudbursts are common occurrences. The 2013 Kedarnath floods, the 2021 Chamoli glacier burst, and the recurring cloudbursts in Himachal Pradesh (2023-2024) all demonstrate the growing frequency and intensity of extreme events. Climate change has exacerbated these risks by increasing precipitation variability and glacial instability. These disasters cause loss of life, infrastructure damage and long-term socioeconomic consequences (Sati, 2026).

7. **Unsustainable Tourism and Carrying Capacity Expansion** Tourism is a major economic driver in the Himalayas, but unregulated expansion has resulted in environmental degradation. Popular tourist destinations like Rohtang Pass, Shimla, Mussoorie, and Leh-Ladakh frequently exceed their ecological carrying capacity. This leads to traffic congestion, waste accumulation, water scarcity, and ecosystem disruption. For example, excessive vehicular traffic in Rohtang Pass has exacerbated glacier degradation and air pollution. Similarly, rapid hotel construction in hill towns has put additional strain on land and water resources. Many areas continue to lack sustainable tourism practices.

8. **Interconnectedness of Issues (Synthesis)** These environmental issues are extremely interconnected. Climate change accelerates glacier melt, reducing water availability and increasing disaster risk. Deforestation promotes soil erosion and biodiversity loss. Tourism exacerbates pollution and resource depletion. Addressing Himalayan environmental challenges necessitates an integrated, multidisciplinary approach that includes climate adaptation, sustainable development and ecosystem-based management.

Mitigation and Adaptation Strategies

Mitigation and adaptation strategies are essential for addressing the complex environmental challenges of the Himalayan region. Mitigation measures aim to reduce environmental degradation and greenhouse gas emissions by promoting renewable energy (solar, small hydropower), afforestation and reforestation, pollution reduction and sustainable land management practices.

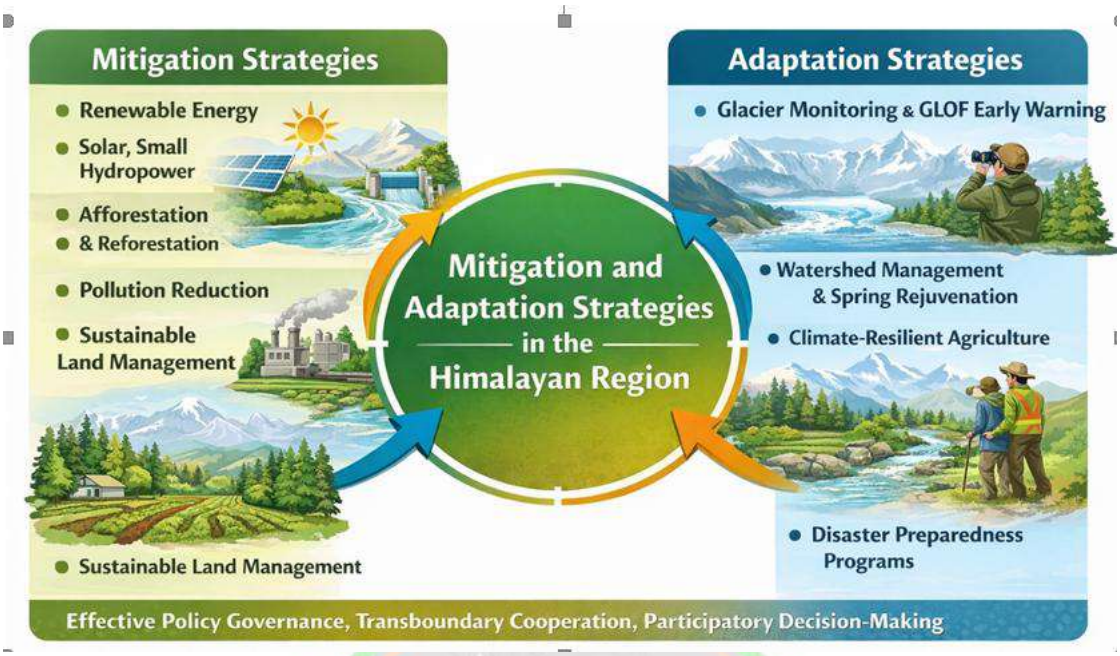

Fig. 4 Showing Mitigation and Adaptaion Strategies

These interventions help to preserve biodiversity, stabilize slopes and increase carbon sequestration. In contrast, adaptation strategies seek to strengthen ecosystems and communities' resilience to changing climatic conditions. Key approaches include glacier monitoring and GLOF early warning systems, watershed management and spring rejuvenation, climate-resilient agriculture and disaster preparedness programs. Community-based adaptation, supported by indigenous knowledge, is critical for ensuring locally appropriate and sustainable solutions.

A comprehensive framework that combines mitigation, adaptation, and effective policy governance including climate action plans, transboundary cooperation, and participatory decision-making is critical for long-term Himalayan development. A multi-sectoral and ecosystem-based approach can help to reduce vulnerability, strengthen resilience and ensure the region's long-term environmental sustainability.

Conclusion

The Himalayan region, a critical ecological and socio-economic lifeline, is increasingly threatened by climate change, land degradation, biodiversity loss, water stress and unsustainable development practices. These challenges are complex and interconnected, amplifying vulnerabilities across both natural ecosystems and human communities. Addressing them requires a balanced integration of mitigation and adaptation strategies, supported by robust policy frameworks and community participation.

Sustainable management of the Himalayas must prioritize ecosystem-based approaches, climate-resilient infrastructure and responsible resource utilization, while incorporating traditional knowledge with modern scientific interventions. Long-term resilience requires a coordinated, multi-sectoral approach at the local, national and transboundary levels.

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SHRIMP TOILETS: A SMART SOLUTION FOR SUSTAINABLE SHRIMP FARMING

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Abstract

Shrimp farming has become one of the most rapidly expanding sectors in aquaculture, contributing significantly to global food security and rural livelihoods. However, the intensification of shrimp culture has led to serious challenges, particularly the accumulation of organic waste in pond systems, which deteriorates water quality and promotes disease outbreaks. The concept of "shrimp toilets," also known as central sludge collection systems, has emerged as an innovative and practical solution to manage pond waste efficiently. This article discusses the origin, design, functioning, and benefits of shrimp toilets in improving pond hygiene and shrimp health. By facilitating the concentration and removal of organic waste, this system reduces toxic gas formation, minimizes disease risks, and enhances production efficiency. The adoption of shrimp toilets represents a significant step toward sustainable and environmentally responsible shrimp farming practices.

Keywords

Shrimp farming, shrimp toilet, sludge management, aquaculture sustainability, pond hygiene, water quality, disease prevention

Introduction

Shrimp aquaculture plays a vital role in the global seafood industry and serves as an important source of income for farmers, especially in countries like India, Bangladesh, and other Southeast Asian nations. With the increasing demand for shrimp, farming practices have become more intensive, often involving high stocking densities and heavy feeding regimes. While these

practices improve production, they also result in the accumulation of organic waste, including uneaten feed, fecal matter, and microbial biomass, at the pond bottom. Over time, this waste settles, particularly in the central region of the pond, creating anaerobic conditions that lead to the formation of toxic gases such as ammonia and hydrogen sulphide. These gases impose stress on shrimp, weaken their immune system, and make them highly susceptible to opportunistic pathogens.

To address these challenges, farmers and researchers have introduced an innovative pond management technique known as the shrimp toilet. This system is designed to collect and remove sludge efficiently from the pond bottom, thereby improving water quality and reducing disease risks. The shrimp toilet has gained popularity due to its simplicity, cost-effectiveness, and significant impact on shrimp health and farm productivity.

Sludge Accumulation and Its Impact on Shrimp Health

In intensive shrimp culture systems, the continuous input of feed and organic matter leads to the rapid accumulation of sludge at the pond bottom. This sludge consists of decomposing organic material that consumes oxygen and creates anaerobic conditions. Under such conditions, harmful gases such as ammonia and hydrogen sulphide are produced, which are toxic to shrimp even at low concentrations. The presence of these gases not only affects shrimp growth but also leads to physiological stress, making them more vulnerable to infections.

Furthermore, sludge accumulation creates a favourable environment for the proliferation of pathogenic microorganisms. Diseases such as Early Mortality Syndrome, Acute Hepatopancreatic Necrosis Disease, *Enterocytozoon Hepatopenaei* infection, and White Fecal Disease are commonly associated with poor pond hygiene and organic waste buildup. These diseases can cause massive economic losses to farmers within a short period, highlighting the importance of effective sludge management in shrimp farming.

Concept and Design of Shrimp Toilets

The shrimp toilet is essentially a centralized waste collection system constructed at the center of the pond. It is designed to concentrate organic waste in a specific area, allowing for easy removal. Typically, about five to seven percent of the total pond area is allocated for the construction of the shrimp toilet. The pond bottom is designed with a gentle slope, usually ranging from 25 to 30 degrees, directing all waste materials toward the central pit.

The central pit, which is about two to three feet deep, acts as a collection point for sludge. The surface of the pond bottom is kept smooth to facilitate the movement of waste particles. Continuous aeration plays a crucial role in this system by creating water currents that push organic waste toward the center. Once accumulated, the sludge can be removed using siphoning methods or pumps such as submersible or floating pumps. This regular removal of sludge prevents its buildup and helps maintain a healthy pond environment.

Recent Innovations in Shrimp Toilet Systems

In recent years, the shrimp toilet concept has been further improved with the introduction of advanced designs such as the use of HDPE or rubber parabola covers. These covers, typically around 2.5 meters in diameter, are placed above the central drain at a height of about two to three feet from the pond bottom. The presence of the parabola enhances the efficiency of sludge collection by creating a stronger suction effect, thereby increasing the area from which waste can be drawn into the central pit.

Additionally, the parabola structure helps prevent the loss of shrimp during sludge removal, which is a common concern in traditional systems. This innovation also reduces the frequency of siphoning, making the system more convenient and cost-effective for farmers. Such improvements demonstrate the evolving nature of shrimp toilet technology and its adaptability to modern aquaculture practices.

Sludge Production and Sustainable Management

Scientific studies indicate that approximately 500 grams of organic waste are generated for every kilogram of shrimp produced. In a typical production system targeting seven tonnes per hectare, this can result in the accumulation of around 3.5 tonnes of sludge. If not managed properly, this large volume of waste can have serious environmental consequences.

It is therefore essential to adopt sustainable sludge management practices. Farmers are advised to allocate a portion of their farm area, usually around five percent, as a sludge pit where collected waste can be stored and treated. Direct discharge of untreated sludge into natural water bodies should be strictly avoided, as it can lead to environmental pollution and the spread of pathogens. Instead, the sludge should be allowed to settle and undergo proper treatment before disposal. Interestingly, treated sludge can also be utilized as an organic fertilizer in agriculture, thereby providing an additional benefit to farmers and promoting resource recycling.

Benefits of Shrimp Toilets in Aquaculture

The implementation of shrimp toilets offers numerous advantages in shrimp farming. By effectively removing organic waste, the system significantly reduces the formation of toxic gases, thereby improving water quality. This leads to better shrimp health, enhanced growth performance, and reduced mortality rates. The system also helps in minimizing the occurrence of major diseases, which are often associated with poor pond hygiene.

Another important benefit is the improvement in feed conversion ratio, as healthier shrimp utilize feed more efficiently. The reduced need for chemical treatments further lowers production costs and minimizes environmental impact. Overall, shrimp toilets contribute to a cleaner, healthier, and more sustainable aquaculture system.

Conclusion

Shrimp toilets represent a simple yet highly effective innovation in modern aquaculture. By addressing the critical issue of sludge accumulation, they play a vital role in improving pond management, enhancing shrimp health, and increasing farm productivity. As shrimp farming continues to intensify, the adoption of sustainable practices such as shrimp toilets becomes increasingly important. This system not only helps farmers achieve better economic returns but also ensures environmental protection and long-term sustainability. With proper design, regular maintenance, and responsible waste management, shrimp toilets can serve as a key component of successful and eco-friendly shrimp farming.

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LASER-BASED DISINFECTION SYSTEMS IN HATCHERIES: A NEXT-GENERATION APPROACH FOR BIOSECURITY AND DISEASE CONTROL

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Abstract

Hatcheries form the backbone of aquaculture and livestock production systems, providing high-quality seed for sustainable farming. However, these facilities are highly vulnerable to microbial contamination, including bacteria, viruses, fungi, and parasites, which can significantly compromise productivity and survival rates. Conventional disinfection methods such as chemical treatments, ultraviolet irradiation, and filtration systems have limitations related to efficiency, environmental impact, and resistance development. In recent years, laser-based disinfection systems have emerged as an innovative and highly precise technology for microbial control. These systems utilize specific wavelengths and energy intensities to inactivate pathogens through photothermal, photochemical, and photomechanical mechanisms. This article explores the principles, design, mechanisms, applications, advantages, challenges, and future potential of laser-based disinfection systems in hatcheries, highlighting their role in improving biosecurity and ensuring sustainable production.

Keywords

Laser disinfection, aquaculture health, microbial inactivation, photothermal effect, UV laser, water treatment

Introduction

Hatcheries are critical units in aquaculture, responsible for the production of larvae, fry, and juveniles under controlled conditions. The success of hatchery operations depends largely on maintaining optimal environmental quality and minimizing pathogen exposure. However,

hatchery systems often face challenges due to high stocking densities, organic load, and continuous water exchange, which create ideal conditions for microbial proliferation (Zhang et al.,2025). Disease outbreaks in hatcheries can lead to massive economic losses, particularly in shrimp and fish farming. Pathogens such as *Vibrio* spp., viral agents, and parasitic organisms can rapidly spread through water systems, affecting entire batches. Traditional disinfection strategies, including chlorination, ozonation, and UV treatment, have been widely used but are associated with limitations such as incomplete pathogen removal, formation of harmful by-products, and reduced efficacy under high organic loads. In this context, laser-based disinfection systems have gained attention as a novel, non-chemical, and highly targeted approach for pathogen control. By harnessing the power of laser light, these systems offer precise and efficient microbial inactivation without compromising water quality or organism health.

Principles of Laser Technology

Laser stands for "Light Amplification by Stimulated Emission of Radiation." Unlike ordinary light, laser light is monochromatic, coherent, and highly directional. These unique properties allow lasers to deliver concentrated energy to specific targets with high precision. Laser systems operate by exciting atoms or molecules in a gain medium, causing them to emit photons at a specific wavelength. The emitted light is amplified through optical feedback and released as a focused beam. Depending on the application, lasers can operate in continuous or pulsed modes, each offering distinct advantages. In disinfection applications, the wavelength and energy of the laser are carefully selected to target microbial structures such as cell walls, membranes, proteins, and nucleic acids. This targeted approach ensures effective pathogen inactivation while minimizing damage to surrounding biological system (Shang et al., 2026)

Mechanisms of Laser-Based Disinfection

Laser-based disinfection relies on multiple mechanisms that act individually or synergistically to inactivate microorganisms. One of the primary mechanisms is the photothermal effect, where laser energy is absorbed by microbial cells and converted into heat. This localized heating can cause protein denaturation, membrane disruption, and eventual cell death. Another important mechanism is the photochemical effect, particularly in the case of ultraviolet (UV) lasers. UV radiation can induce DNA and RNA damage, prevent replication and lead to microbial inactivation. This mechanism is highly effective against a wide range of pathogens, including viruses (Jing et al.,2025). The photomechanical effect involves the generation of shock

waves or mechanical stress within microbial cells due to rapid energy deposition. This can lead to structural damage and cell lysis. Additionally, lasers can generate reactive oxygen species (ROS), which further enhance antimicrobial activity by causing oxidative damage to cellular components.

Types of Lasers Used in Disinfection

- Various types of lasers are used in disinfection systems, each with specific properties and applications. UV lasers are particularly effective due to their ability to directly damage nucleic acids. Visible and near-infrared lasers are often used for photothermal applications.
- Pulsed lasers, such as femtosecond and nanosecond lasers, are capable of delivering high energy in short bursts, making them suitable for precise microbial targeting. Continuous-wave lasers, on the other hand, provide steady energy output and are commonly used in water treatment systems.
- The choice of laser depends on factors such as target pathogens, water quality, system design, and operational requirements.

Design of Laser-Based Disinfection Systems in Hatcheries

Laser-based disinfection systems in hatcheries are typically integrated into water circulation units. The system consists of a laser source, optical components, a treatment chamber, and control systems. Water flows through the treatment chamber, where it is exposed to laser irradiation. The design ensures uniform exposure and optimal energy distribution to maximize disinfection efficiency. Advanced systems may include sensors to monitor water quality parameters such as turbidity, temperature, and microbial load. Automation and control systems allow real-time adjustments based on environmental conditions, ensuring consistent performance. Compact and modular designs make these systems suitable for both small-scale and large-scale hatchery operations.

Applications in Aquaculture Hatcheries

- Laser-based disinfection systems have diverse applications in aquaculture hatcheries. One of the primary uses is water disinfection, where the technology effectively eliminates pathogenic microorganisms without altering water chemistry.
- These systems can also be used for surface sterilization of equipment, tanks, and pipelines, reducing the risk of cross-contamination. In larval rearing units, laser

disinfection helps maintain a pathogen-free environment, improving survival rates and growth performance.

- Additionally, laser systems can be applied to disinfect live feed cultures such as algae and Artemia, which are common sources of contamination in hatcheries.

Advantages Over Conventional Disinfection Methods

- Laser-based disinfection offers several advantages compared to traditional methods. Unlike chemical disinfectants, it does not produce harmful residues or by-products, making it environmentally friendly. The targeted nature of laser treatment ensures high efficiency and minimal impact on non-target organisms (Perini et al.,2021)
- The technology also reduces the risk of microbial resistance, which is a growing concern with chemical treatments. Furthermore, laser systems can operate continuously and require minimal consumables, thereby reducing long-term operational costs.
- Another key advantage is the ability to integrate laser systems with existing hatchery infrastructure, enhancing overall biosecurity without requiring significant modifications.

Impact on Hatchery Productivity and Biosecurity

- The implementation of laser-based disinfection systems can significantly improve hatchery productivity by reducing disease incidence and mortality rates. By maintaining a clean and stable environment, these systems support optimal growth and development of larvae and juveniles.
- Enhanced biosecurity measures also reduce the need for antibiotics and other chemical treatments, promoting sustainable aquaculture practices. This is particularly important in the context of increasing regulatory restrictions on antimicrobial use.

Environmental and Sustainability Aspects

Laser-based disinfection aligns with the principles of sustainable aquaculture by minimizing environmental impact. The absence of chemical residues ensures that discharged water does not harm surrounding ecosystems. Energy efficiency is another important consideration. Advances in laser technology have led to the development of low-power, high-efficiency systems that reduce energy consumption while maintaining high performance.

Challenges and Limitations

- Despite its advantages, laser-based disinfection technology faces several challenges. High initial investment costs may limit adoption, particularly in small-scale hatcheries.

Technical expertise is required for system installation and maintenance.

- Water turbidity and organic matter can affect laser penetration and reduce efficiency. Therefore, pre-treatment processes such as filtration may be necessary.
- Additionally, long-term studies are needed to evaluate the effectiveness and safety of laser systems under different operational conditions.

Integration with Advanced Technologies

The future of laser-based disinfection lies in integration with other advanced technologies. Combining laser systems with sensors, artificial intelligence, and IoT can enable smart hatchery management. Real-time monitoring and automated control can optimize system performance and reduce human intervention. Integration with recirculating aquaculture systems (RAS) can further enhance efficiency and sustainability.

Future Perspectives

As research and development continue, laser-based disinfection systems are expected to become more affordable and widely accessible. Innovations in nanotechnology and photonics may lead to the development of more efficient and versatile systems. The technology has the potential to revolutionize hatchery management by providing a reliable and sustainable solution for disease control. Collaboration between researchers, industry stakeholders, and policymakers will be essential for successful implementation.

Case Studies and Emerging Research

Recent studies have demonstrated the effectiveness of laser-based disinfection in inactivating a wide range of aquatic pathogens. Experimental trials in hatchery settings have shown improved survival rates and reduced disease outbreaks.

Ongoing research is focused on optimizing system design, understanding microbial response mechanisms, and evaluating long-term performance. These studies provide valuable insights into the practical applications of this technology.

Broader Implications for Aquaculture Industry

- The adoption of laser-based disinfection systems can have far-reaching implications for the aquaculture industry. By improving hatchery success rates, the technology contributes to increased production and profitability.
- It also supports global efforts to reduce antibiotic use and promote sustainable practices.

- As consumer demand for safe and environmentally friendly seafood continues to grow, such innovations will play a crucial role in shaping the future of aquaculture.

Conclusion

Laser-based disinfection systems represent a transformative advancement in hatchery biosecurity and disease management. By offering precise, efficient, and environmentally friendly microbial control, these systems address many limitations of conventional methods. Although challenges remain, ongoing research and technological advancements are expected to overcome these barriers. The integration of laser technology into hatchery operations holds great promise for enhancing productivity, sustainability, and resilience in the aquaculture sector.

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VACCINES IN AQUACULTURE: CONCEPT, DEVELOPMENT AND ADVANCES

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Abstract

The rapid expansion of aquaculture has significantly increased the risk of infectious disease outbreaks, posing major challenges to productivity and sustainability. Vaccination has emerged as a highly effective and environmentally safe strategy for disease prevention in aquatic organisms. Vaccines are biological preparations containing antigenic components derived from pathogens that stimulate the immune system to develop protective immunity without causing disease. Over time, aquaculture vaccines have evolved from simple inactivated bacterial formulations to advanced molecular approaches such as DNA vaccines, recombinant vaccines, and vectored vaccines. These innovations have improved vaccine efficacy and reduced reliance on antibiotics, thereby addressing concerns related to antimicrobial resistance. However, challenges such as delivery efficiency, high production costs, and the absence of adaptive immunity in shellfish continue to limit their widespread application. This article provides a comprehensive overview of the history, immunological basis, development process, types, delivery systems, and current challenges associated with vaccines in aquaculture.

Introduction

Aquaculture is one of the fastest-growing sectors in global food production, playing a crucial role in meeting the increasing demand for animal protein. However, disease outbreaks remain a major constraint, often resulting in significant economic losses. Intensified farming practices, including high stocking densities and environmental stress, create favorable conditions for the rapid spread of pathogens.

Traditionally, disease control in aquaculture relied heavily on antibiotics and chemical treatments. While these methods provide short-term solutions, they are associated with serious

drawbacks such as antimicrobial resistance, environmental contamination, and the presence of drug residues in aquatic products. As a result, there has been a shift toward preventive strategies, with vaccination emerging as a key approach.

Vaccination involves the administration of antigenic components of pathogens to stimulate the host immune system and establish immunological memory. In fish, both innate and adaptive immune responses contribute to vaccine-induced protection. However, unlike vertebrates, shellfish lack adaptive immunity, making vaccine development more challenging. Despite these limitations, vaccination has proven to be a highly effective tool for disease prevention in finfish aquaculture.

1. Historical Evolution of Aquaculture Vaccines

The development of vaccines in aquaculture has progressed significantly over the past few decades. Before the 1970s, disease management relied entirely on antibiotics, chemicals, and improved husbandry practices. This approach was reactive and often ineffective in intensive farming systems.

The first major breakthrough occurred in the 1970s with the development of inactivated bacterial vaccines against *Vibrio anguillarum* in salmonids. These vaccines demonstrated that fish could develop protective immunity, marking the beginning of vaccination in aquaculture.

During the 1980s, the expansion of salmon farming in Europe and Japan led to the development of vaccines against *Aeromonas salmonicida* and *Yersinia ruckeri*. The introduction of oil-adjuvanted vaccines significantly improved immune responses and protection levels.

In the 1990s, efforts were made to develop vaccines against viral diseases such as infectious pancreatic necrosis and infectious hematopoietic necrosis. However, conventional vaccines showed limited success due to their inability to induce strong cellular immunity.

The early 2000s saw the emergence of molecular vaccine technologies, particularly DNA vaccines, which provided strong and long-lasting immune responses. In recent years, vaccination strategies have focused on sustainability, species-specific vaccine design, and integration with biosecurity measures. However, vaccine development for shellfish remains limited due to the absence of adaptive immunity.

2. Immunological Basis of Vaccination

Vaccination works by exposing the immune system to harmless forms of pathogen-derived antigens, thereby inducing immunological memory. Once administered, the antigen is

recognized by innate immune cells such as macrophages and dendritic cells, which initiate an immune response.

These cells process the antigen and present it to T lymphocytes through major histocompatibility complex (MHC) molecules. This leads to the activation of helper T cells and cytotoxic T cells. B lymphocytes are also activated, producing specific antibodies against the antigen.

A key outcome of vaccination is the formation of memory cells, including memory B cells and T cells, which persist in immune organs such as the spleen and head kidney. Upon subsequent exposure to the pathogen, these memory cells enable a rapid and enhanced immune response, providing effective protection against disease.

3. Vaccine Development Process

The development of vaccines involves several critical steps. Initially, the causative pathogen must be identified and characterized. This is followed by the selection of suitable antigenic components capable of inducing protective immunity.

Next, an appropriate vaccine type is chosen, considering factors such as safety, stability, and immune response. The antigen is then formulated with adjuvants and stabilizers to enhance its effectiveness.

Preclinical testing is conducted to evaluate safety and immunogenicity under laboratory conditions. Optimization studies are carried out to determine the appropriate dosage, delivery route, and vaccination schedule. Field trials are then performed in aquaculture systems to assess vaccine performance under practical conditions.

Finally, vaccines must undergo regulatory approval to ensure compliance with safety and efficacy standards set by international and national authorities.

4. Types of Vaccines and Recent Advances

DNA vaccines involve the introduction of plasmid DNA encoding antigenic proteins into host cells. These vaccines stimulate both humoral and cellular immune responses. Advances include improved gene design, optimized plasmid vectors, and enhanced delivery techniques such as electroporation and nanoparticle systems.

Recombinant vaccines are produced by expressing pathogen-derived genes in suitable systems such as bacteria or yeast. These vaccines are safer as they do not involve the whole pathogen.

Advances include improved antigen selection, enhanced expression systems, and the use of novel adjuvants and nanoparticle-based formulations.

Vectored vaccines use genetically engineered viral or bacterial vectors to deliver antigenic genes into host cells. These vaccines provide strong immune responses and can express multiple antigens. Recent developments focus on improving vector safety, genetic stability, and immune activation.

5. Vaccine Delivery Systems

- The method of vaccine delivery plays a crucial role in determining its effectiveness. Injection vaccination is the most reliable method, providing strong and long-lasting immunity. However, it is labor-intensive and suitable mainly for larger fish.
- Immersion vaccination is widely used for mass vaccination of small fish, as it involves minimal handling. However, it generally results in weaker and shorter-lasting immunity.
- Oral vaccination is the most convenient method, as vaccines are administered through feed. While it reduces stress, challenges such as antigen degradation and variable immune responses limit its effectiveness.
- Advanced delivery systems, including nanoparticle-based delivery, encapsulation techniques, and electroporation, have been developed to overcome these limitations. These approaches improve antigen stability, enhance uptake, and provide controlled release, although they are often costly and complex

Challenges and Future Perspectives

Despite significant progress, several challenges remain in aquaculture vaccination. The lack of effective vaccines for shellfish is a major limitation due to the absence of adaptive immunity. High production costs and regulatory constraints also hinder the widespread adoption of advanced vaccines.

Additionally, variability in immune responses among different species and environmental conditions complicates vaccine design. Future research should focus on developing cost-effective vaccines, improving delivery systems for mass application, and exploring novel approaches such as immune priming and nanotechnology.

Conclusion

Vaccination has become an essential tool for sustainable disease management in aquaculture, significantly reducing the reliance on antibiotics and improving animal health and

productivity. Advances in vaccine technologies, including DNA, recombinant, and vectored vaccines, have enhanced the effectiveness and scope of vaccination strategies. However, challenges related to delivery, cost, and species-specific limitations continue to restrict their full potential. Addressing these challenges through innovative research and improved technologies will be critical for the future growth and sustainability of the aquaculture industry.

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THE SECRET SOCIETY OF HONEYBEES: HOW A SUPERORGANISM WAS BORN

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Abstract

Honeybee colonies exemplify eusociality, where sterile workers form a superorganism. Evolving from solitary ancestors about 34 million years ago, this system arose via Hamilton's kin selection (rB > C), haplodiploidy, Wilson's group selection, Boomsma's monogamy hypothesis, and repurposed ancient genes. Ecological pressures, behavioural flexibility, and policing enforced castes, boosting pollination vital for Indian agriculture. Amid threats like pesticides and habitat loss, evolutionary insights guide resilient beekeeping - from Darwin's "insuperable difficulty" to modern sociogenomics, revealing cooperation's power.

Introduction

Picture a city of 60,000 workers all working towards one goal: keep the queen alive raise the young and make sure the colony survives. No mayor, no elections no written rules. Instinct that has been developed over tens of millions of years. This is not science fiction. It is what happens every day inside a honeybee hive.

Honeybees are an example of eusociality. The highest level of social organisation in the animal kingdom. How did such an amazing social structure evolve? The answer involves genetics, ecology, game theory and developmental biology.

What Is Eusociality?

Eusociality is a system that has three main features: cooperative care of young, a division of labour where only certain individuals reproduce and overlapping generations - Where parents and offspring live and work together.

In a honeybee colony this plays out in a way. A single queen lays thousands of eggs. Workers are all females. They forage for nectar, build the wax comb, care for larvae, regulate

hive temperature and defend against intruders. Drones exist to mate. The colony functions as one “superorganism" - greater than the sum of its thousands of individual parts.

Eusociality is not just found in bees. It has evolved in ants, wasps, termites, certain shrimps and two mammal species like the naked mole-rat and the Damaraland mole-rat. Nowhere is it more well-known, or more important for agriculture, than in the honeybee.

A Society 34 million Years in the Making:

Honeybees did not always live like this. Their ancestors were bees in the family Apidae and the honeybees’ eusocial lifestyle developed around 34 million years ago during the Eocene epoch. Fossil evidence and molecular studies suggest that the transition began in Asia or Africa as ancestral females began nesting cooperatively under ecological pressure.

The groups we see today are Apini (honeybees) Meliponini (stingless bees) Bombini (bumblebees) and Euglossini (orchid bees). All developed eusocial tendencies, though in different degrees. Apini and Meliponini developed "fixed caste" systems, where a bee’s role is permanent from birth. In contrast, bumblebees and orchid bees show "totipotent castes”. A worker can under the right circumstances transform into a queen and establish her own colony.

Darwin’s Difficulty and Hamilton’s Solution:

When Charles Darwin first studied worker castes he admitted they posed a big problem for his theory. How could natural selection favour individuals that never reproduce?

The answer came a century later from British biologist W. D. Hamilton in 1964. His inclusive fitness theory showed that altruistic behaviour evolves when the genetic benefit to relatives outweighs the reproductive cost. In honeybees this equation is loaded in favour of altruism, because of a system called haplodiploidy - where females develop from fertilised eggs and males from unfertilised ones. Worker bees share around 75% of their genes with their sisters. This is higher than the 50% relatedness they would share with their daughters.

However, Hamiltons kin selection theory has its limitations. In practice, honeybee queens mate with males (polyandry), which reduces average relatedness among workers. Moreover, eusociality has also evolved in species like termites and naked mole-rats, where haplodiploidy plays no role at all.

Thinking Beyond Genes: Wilson, Boomsma and the Group

E. O. Wilson proposed that natural selection acts not on individuals but on entire colonies. A beehive that cooperates efficiently, defending itself, raising young ones, and

exploiting food sources outcompetes fragmented or poorly organised rivals.

Wilson described this as a three-step process: first, the ancestral solitary females began forming nests under pressure from predators and seasonal resource scarcity. Second, traits that made cooperation easier evolve - Shared brood care, pheromone signalling, and overlapping generations. Finally, colony-level selection favoured the full reproductive division of labour we see today.

Jacobus Boomsma offered an insight with his monogamy hypothesis - He argued that the crucial precondition for eusociality was lifetime monogamy in the ancestral lineage. This involves the queen mating with just one male before the colony was established.

Negotiation, Strategy and the "Deals" Inside the Hive

Not all theories focus on genetics. David Queller and Joan Strassmanns bargaining model views the hive as a society of individuals with aligned, but never identical interests. Workers and queens are constantly "negotiating" roles through behaviour and chemistry. The resulting social structure is not pre-programmed by genes, it emerges from repeated interactions where both parties gain more from a stable productive colony than from escalating conflict.

John Maynard Smiths evolutionary game theory adds a backbone to this idea. His concept of a Stable Strategy (ESS) explains why worker policing persists.

Old Genes, New Roles: The Genetic Toolkit

One of the striking revelations of modern genomics is that honeybees did not evolve entirely new genes for their complex social life. Instead, they repurposed genes. A "genetic toolkit" was already present in their solitary ancestors. By changing how and when those genes are switched on or off, they evolved with suitable behaviour to build towards a eusocial “superorganism”.

Ecology, Flexibility and the Shaping of Castes

Mary Jane West-Eberhard’s behavioural ecology approach reminds us that evolution operates on behaviour much as on genes. She argued that cooperative behaviours likely began as facultative responses to ecological conditions. The life-history approach builds on tracing how resource allocation is done across a bee’s lifespan - How much energy goes to survival versus reproduction.

Why It Matters: From Hive to Harvest

Understanding how eusociality evolved is important. For a country like India, where

honeybee pollination underpins the agricultural productivity of hundreds of crops.

The division of labour that evolved over millions of years is precisely what makes honeybee colonies such efficient pollinators. These traits - the products of evolutionary history - are what beekeepers rely on when managing colonies, for crop pollination services.

Insights from the genetic toolkit hypothesis are opening ways in bee breeding. By understanding which gene pathways control caste development, researchers can find markers for disease resistance, queen quality and worker productivity. This helps create scientifically based selective breeding programs.

Conclusion

Bees are in trouble worldwide because of pesticides, habitat loss, pathogens and climate change. Understanding what makes a bee colony strong and able to adapt is very important.The honeybee colony is one of evolutions achievements. It is the result of factors working together: genetic relatedness, ecological pressures, game theory, behavioural flexibility and gene regulation.

Each theory we've explored - from Hamilton's equation to West-Eberhard's flexibility - shows different parts of the same amazing story. No single framework has all the answers. Together they reveal a truth that Charles Darwin understood: cooperation can be a very powerful strategy.Inside every hive that ancient evolutionary agreement plays out every day - Thousands of workers supporting a civilization than our own.

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RHODODENDRON ARBOREUM: A NEW AVENUE FOR FOOD AND PHARMACEUTICAL INNOVATION

Article ID: AG-VO6-I04-97

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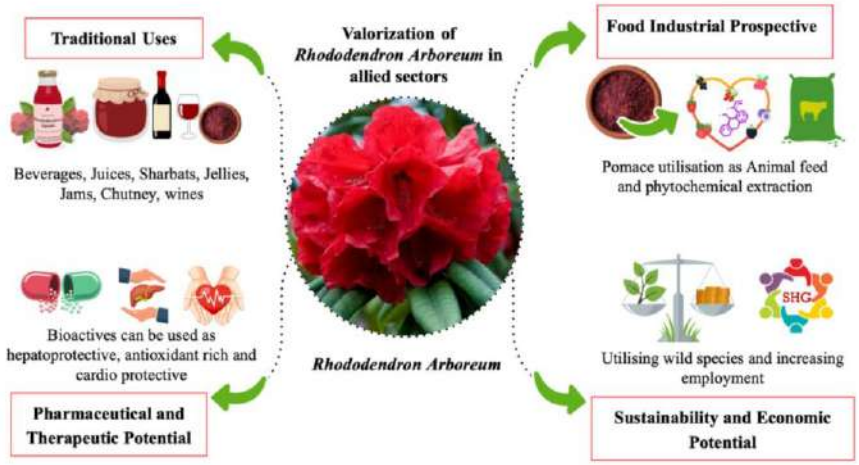
Introduction

Nature offers a vast array of edible flowers that have long been an integral part of culinary traditions across the globe. These blossoms not only enhance the visual appeal, aroma, and flavor of food but also contribute valuable nutritional and therapeutic properties. Flowers such as *Hibiscus rosa-sinensis* (hibiscus), *Rosa* spp. (rose), and *Tagetes erecta* or *Tagetes patula* (marigold) and *Rhododendron arboreum* are commonly incorporated into teas, salads, sweets, and various traditional dishes. Owing to their richness in antioxidants, vitamins, and bioactive compounds, edible flowers are increasingly recognized for their potential as functional ingredients in contemporary food systems. *Rhododendron arboreum*, rich in phytochemicals (steroids, glucoside, ericolin, ursolic acid, tannin, saponins, quercetin, flavone, flavonoid, phenol, glycoside, and catechins) and bioactive compounds, holds great potential for promising applications in both the food and pharmaceutical industries.



Rhododendron: The Nutritional Hub

The genus *Rhododendron* belongs to the *Ericaceae* family, derived from the Greek word Rhodo (Rose) and Dendron (tree). It is addressed by different local names like "Lali gurans" and "Rohitika" in Nepal. This is the national flower of Nepal, the state tree and flower of Nagaland, and Himachal Pradesh, respectively, in India. Within India, it is commonly seen in the mountainous areas of Uttarakhand, Himachal Pradesh, Sikkim, Arunachal Pradesh, and northern West Bengal, flourishing at elevations ranging from approximately 1,500 to 3,600 meters. This plant prefers cool and humid environments, often growing on forested hillsides and mountain slopes. The flowers of *R. arboreum* are especially admired for their vivid beauty, typically blooming between February and April. They are large, funnel-shaped blossoms that are most commonly bright red, though pink and white variants can also be found, influenced by altitude and environmental conditions.

The *Rhododendron* genus is an ethanopharmacological plant, having tremendous health benefits due to a large number of secondary metabolites and phytochemicals responsible for pharmacological activities (Rawat et al. 2020). It contains essential macronutrients such as carbohydrates, proteins, fats, and dietary fibre, along with various minerals and trace elements, which support basic physiological functions and meet dietary needs. In addition, *R. arboreum* is a potent source of bioactives, known for their antioxidant, antimicrobial, anti-inflammatory, and anti-diabetic properties.

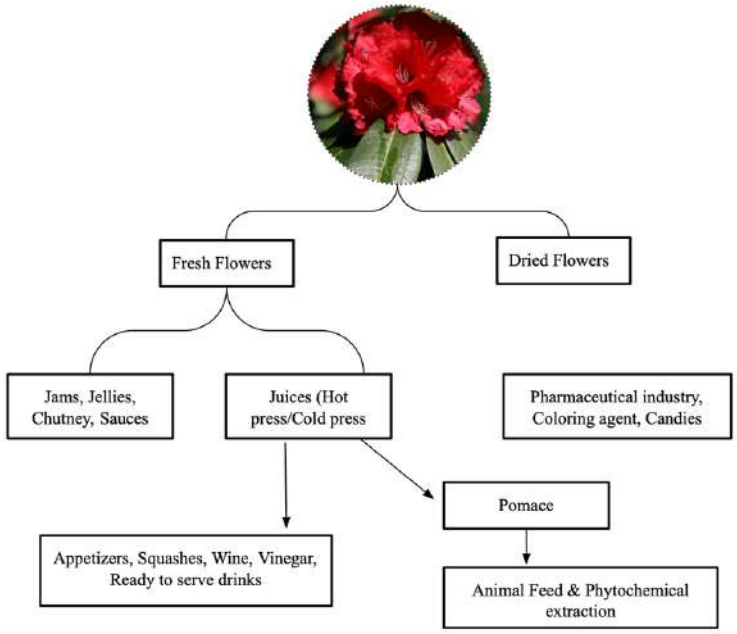
From Folk Use to Innovation

Each part of *R. arboreum* holds significant importance in traditional medicine for its healing properties. Conventionally, the flowers and leaves of this plant were used to cure ailments like fever, headache, blood dysentery, altitude sickness, menstrual disorders, wound healing, and anti-inflammation. Often, the flower of this plant is dried and processed into powder for use. It is used in the preparation of jelly, jam, squash, juice, and a local fermented drink called 'Guranse' (Pinakin et al., 2020). Also, the wood is utilised to make the wooden handles (Khurki), gift boxes, and as a fuel for making cattle sheds. Extracts from its flowers and leaves show antimicrobial effects, as well as mild hepatoprotective, analgesic, and cardioprotective properties, which highlight its pharmaceutical applications, though further clinical scientific validation is needed to confirm dosage, safety, and efficacy.

Such valuable flowers can be efficiently commercialized by incorporating in different products like bread, biscuits, vinegar, juice mix, instant chutney premix, probiotic drink, flavoured milk, and other milk-based products. In addition to its food applications, *R. arboreum* also serves as a natural coloring agent, offering potential for use in the development of innovative products.

Processing and Utilization

R. arboreum petals can be valorised in both fresh and dried forms for various food and nutraceutical applications. Fresh petals are amenable to direct processing into value-added products such as juices, squashes, chutneys, and appetizers. Alternatively, these petals can be harvested and subjected to controlled drying at specific temperatures to preserve bioactive compounds. The resulting dried material can be milled into a fine powder, which enhances its shelf life and enables its incorporation into a wide range of processed foods, including biscuits, breads, pasta, and ready-to-eat (RTE) products. The powder also serves as a natural colorant due to its rich anthocyanin content. Juice extraction from fresh petals can be performed using cold-press or hot-press techniques, each yielding both juice and pomace. The pomace, which is a by-product rich in dietary fiber and residual phytochemicals, can be repurposed as a sustainable livestock feed or further processed for the extraction of sensitive compounds, thereby supporting a zero-waste approach.



Advances in extraction and formulation

In ancient times, rhododendron petals were traditionally handpicked and then sun-dried, allowing for longer storage. When used fresh, the petals were washed and ground into a slurry to prepare chutney, or they were pressed either hot or cold to extract juice. These processes were simple and did not involve any specialized technology. However, with growing awareness of the flower's rich content of bioactive compounds, there is a need to adopt modern techniques to preserve its richness. Green extraction methods, such as microwave-assisted extraction and ultrasonication and enzyme-assisted extraction, offer improved efficiency and higher yields that help to minimize the degradation of heat-sensitive compounds. Thus, there is a need to explore and optimize the extraction process of rhododendron flowers.

Pharmaceutical and Therapeutic Potential

Rhododendron arboreum is rich in a diverse array of phytochemicals, including flavonoids, saponins, triterpenoids, and other compounds, which contribute to its medicinal potential. The bark contains taraxerol and betulinic acid, known for their anti-inflammatory and liver-protective effects, while the leaves are abundant in antioxidants such as arbutin and ursolic acid. Pharmacological studies demonstrate that the plant exhibits strong anti-inflammatory and analgesic effects in animal models, due to the presence of flavonoids like quercetin and hyperin. Moreover, it also protects against liver damage caused by toxins by restoring enzyme balance and reducing oxidative stress. Flowers show promising antidiabetic activity in laboratory studies where compounds like quercetin and rutin play a key role in blood sugar-lowering effects (Dahal and Oli, 2024). While there is a scarcity of detailed animal and human clinical studies on *Rhododendron arboreum*, the presence of various bioactive compounds suggests significant potential for pharmaceutical development. Conducting further scientific investigations, particularly well-designed preclinical and clinical trials, could help confirm its therapeutic benefits and support its integration into natural medicinal products.

Sustainability and Economic Potential

The promotion of sustainable agricultural practices in hill and tribal regions presents a valuable opportunity for income generation among local communities. These areas, rich in biodiversity and traditional knowledge, hold significant potential for the development of agri-entrepreneurship, particularly through the involvement of women's self-help groups (SHGs), which can play a crucial role in driving community-based enterprises. By enhancing cultivation

methods and addressing region-specific challenges such as limited market access, inadequate infrastructure, and climate vulnerabilities, there is considerable scope to strengthen the agricultural value chain. Improved processing, packaging, and marketing strategies can further boost the economic viability of local produce, fostering inclusive growth and long-term sustainability.

Conclusion

Rhododendron arboreum, recognized for its ethnopharmacological significance, has been used in folk medicine since ancient times. Despite its wide range of applications, the plant still remains underutilized primarily due to its limited seasonal availability and lack of commercialization. With proper valorisation, this wild species holds the potential to become a valuable source of livelihood, particularly for communities residing in hilly regions. Over time, the pattern of its use has evolved, shifting from traditional methods to more modern processing techniques. The flower (both fresh and dried form) of *R. arboreum* shows great potential in both the food and pharmaceutical industries in the development of high-value products.

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GROCERIES IN 10 MINUTES, FARM INPUTS IN 4–7 DAYS: A NEED TO BRIDGE THE GAP IN AGRICULTURAL SUPPLY CHAINS

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Introduction

People in urban areas are purchasing commodities in every possible ways, which minimizes their time and physical efforts. They can order and get any commodities including fresh products, groceries, medicines, etc at their doorsteps in just 10 minutes. On the other side, farmers in rural areas could not get their required farm inputs at desired time or whenever needed. Many times, he is supposed to wait for more than a week to get the farm inputs delivered. This causes delay in application of requisite inputs at proper durations, causing extreme loss in farm productivity.

Being an intern in an agri e-commerce platform, I used to get on query frequently, “When will my product gets delivered… Can you make it delivered as soon as possible?” Sometimes, there might be delay due to logistics, misrouting of the inputs, damages due to harsh handling during shipments and sometimes there might be missing products and also mismatched products. The farmers can notice such issues only after receiving the orders. This affects the farmers from applying necessary farm inputs at appropriate durations. The speed of delivery determines the intensity of crop losses. Farming is all about acting at the right time, right place and with the right solution, which can save the crop as well as the farmer’s income.

Quick e-commerce companies in India have initiated innovative systems such as dark stores, micro-warehouses, and optimised logistics networks to deliver products to customers within 10 minutes.

But there is a lot of supply chain gap when it comes to farmers. But why does this gap exist?

Despite the rise of specialized agri-e-commerce platforms, most continue to depend on traditional logistics due to several unique structural challenges in the rural landscape. Unlike urban centers, where high population density makes demand predictable and delivery efficient, the agricultural sector faces a more complex reality:

1. **Dispersed and Diverse Production** - Indian farmers grow a vast array of crops ranging from cereals and pulses to fruits and vegetables, where the production is highly fragmented. Farmers are geographically scattered, making it difficult to consolidate shipments.
2. **Highly Seasonal Demand** - Requirements for inputs such as seeds and fertilizers are not consistent throughout the year; instead, they experience massive spikes during sowing and harvest periods.
3. **Unpredictable Volatility** - Demand can shift instantly due to sudden pest outbreaks or disease, requiring rapid response times that conventional systems struggle to meet.
4. **Regulatory & Safety Constraints** – Logistics are further complicated by strict government controls on fertilizers and pesticides, many of which are volatile or hazardous and require specialized handling.
5. **Infrastructure Gaps** - A critical lack of localized storage and climate-controlled warehousing in rural areas often forces platforms to rely on existing, albeit inefficient, supply chains.
6. **The Hidden Tax** - Beyond the physical hurdles of bad roads and missing warehouses lies a deeper, systemic issue, the "Middleman Maze." In the current agricultural input landscape, a product rarely goes from the factory to the farm. Instead, it passes through a dizzying array of hands such as distributors, wholesalers, sub-dealers, and local agents.

While e-commerce promises to "disintermediate" (cut out the middleman), the logistical challenges often force these platforms to rely on local dealers just to get the goods delivered on time.

Why are there fewer users?

Bringing e-commerce to the farm isn't just about building a better app; it's about reinventing a supply chain that can handle the beautiful, chaotic, and unpredictable reality of the Indian countryside. In villages, a recurring pattern emerges where retailers provide inputs on credit to be settled after harvest. However, this convenience comes at a heavy cost wherein the

farmers are often charged prices well above market rates, yet they have no alternatives due to severe capital constraints. Furthermore, awareness of agri-e-commerce remains low. These platforms struggle to scale into "quick commerce" models because the massive investment required to reach scattered rural areas is often prohibitive. Beyond logistics, there is a significant trust deficit; a rise in cyber fraud has made many farmers wary of transacting with "faceless" online entities.

Perhaps the biggest deal-breaker, however, is time. While a city dweller can wait a few days for a package, a farmer cannot. Most apps quote a 3-to-5-day delivery window, but pests and diseases do not wait. To prevent economic injury to their fields, farmers require one-day delivery. When an app cannot guarantee that speed or maintain consistent stock, farmers are forced to abandon their carts and return to the local middleman to save their livelihood.

How can we overcome and bridge this supply chain gap?

Bridging the gap between the farm and the digital marketplace requires a shift from reactive logistics to predictive intelligence. By blending local infrastructure with cutting-edge technology, we can create a sustainable ecosystem. This can be achieved through a multi-pronged strategy,

1. Modernizing Logistics & Infrastructure - The shift starts with hyperlocal delivery networks. By establishing "dark stores" or small-scale warehouses in rural clusters, platforms can maintain ready stocks of high-demand inputs like fertilizers and pesticides. Utilizing local delivery agents not only ensures one-day delivery to save crops from "economic injury" but also generates vital rural employment opportunities.

2. **Integrating Local Retailers** - Rather than displacing existing shops, agri-e-commerce should integrate them. Local retailers already possess the infrastructure and, most importantly, the trust of the community. By converting these shops into AI-driven micro-fulfilment centres, platforms can achieve massive scalability without the prohibitive costs of building new warehouses from scratch.

3. Predictive Intelligence (AI & Machine Learning) - In this digital era, AI and Machine Learning can transform logistics by analyzing soil types and historical crop patterns. Because pest outbreaks and nutrient needs are often recurring, demand forecasting allows stores to stock exactly what is needed before the crisis hits. This shifts the model from a "response-driven"

approach to a predictive ecosystem, reducing wastage and ensuring high-demand inventory is always accessible.

4. Public- Private Partnerships - A contract-based delivery model offers a powerful solution, where the government handles the procurement and bulk storage of inputs to ensure price stability and eliminating middlemen, while private quick-commerce companies manage the complex "last-mile" delivery.

5. **Awareness among the Rural Population** - Through targeted advertising, introductory discounts, and digital literacy programs, farmers can be incentivized to move away from high-interest traditional debt and toward the transparency of e-commerce.

Conclusion

The transformation of the Indian agricultural supply chain is no longer just a digital luxury, but it is a necessity for national food security. By replacing the 'Middlemen Maze' with AI-driven micro-fulfilment centres and hyperlocal delivery, we aren't just moving products; we are moving the needle on rural prosperity. When a farmer can order a farm input with the same ease as an urbanite orders a meal, we will have finally bridged the gap between the traditional field and the digital future.

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AGRO AI: TRANSFORMING MODERN AGRICULTURE THROUGH ARTIFICIAL INTELLIGENCE

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Introduction

Agriculture remains the backbone of many economies, especially in developing countries like India. However, the sector is currently facing multiple challenges, including climate variability, declining soil fertility, water scarcity, and labor shortages. In this context, **Agro AI (Agricultural Artificial Intelligence)** has emerged as a transformative approach that integrates advanced technologies into farming practices to enhance productivity, efficiency, and sustainability. Agro AI refers to the application of Artificial Intelligence (AI), machine learning, and data analytics in agriculture. It utilizes tools such as sensors, drones, satellite imagery, and mobile-based applications to collect and analyze real-time data related to crops, soil, weather, and pests. This enables farmers to make informed, timely, and precise decisions.

Concept and Working of Agro AI

Agro AI systems function by collecting large volumes of agricultural data from multiple sources and processing those using intelligent algorithms. These systems analyze patterns and provide actionable insights to farmers. For instance, AI-powered tools can detect crop diseases through image recognition, predict weather changes, recommend irrigation schedules, and optimize fertilizer usage.

By integrating technologies such as Internet of Things (IoT), remote sensing, and cloud computing, Agro AI ensures precision farming, where resources are used efficiently with minimal wastage.

Need for Agro AI in the Present Scenario

The growing importance of Agro AI can be attributed to several pressing challenges:

1. **Climate Change:** Erratic rainfall, rising temperatures, and extreme weather events affect crop yields. AI helps in predicting weather patterns and planning accordingly.
2. **Water Scarcity:** Efficient irrigation management through AI reduces water usage while maintaining productivity.
3. **Labor Shortage:** Automation and AI tools reduce dependency on manual labor.
4. **Rising Food Demand:** With increasing population, there is a need to enhance agricultural output sustainably.
5. **Crop Losses:** Early detection of pests and diseases helps minimize losses.

Thus, Agro AI plays a crucial role in ensuring food security, improving farm incomes, and promoting sustainable agriculture.

Key Features of Agro AI Applications

Modern Agri-AI applications provide a wide range of features that simplify farming operations:

- **Disease and Pest Scanner:** Image-based AI tools diagnose plant diseases instantly and recommend treatment.
- **Voice-Based Guidance:** Enables farmers with low literacy levels to access information through voice commands in local languages.
- **Hyper-local Weather Data:** Provides precise weather forecasts tailored to specific farm locations.
- **Market Intelligence:** Offers real-time information on mandi prices and market trends.
- **Satellite and Drone Integration:** Helps monitor crop health, soil moisture, and field conditions remotely.

Top Agro AI Applications in India

Several AI-powered applications are revolutionizing Indian agriculture:

- Bharat-Vistaar: A government-backed digital assistant that provides information on crops, weather, and agricultural schemes in multiple Indian languages.

- Plantix: Known for its advanced disease detection feature using image recognition technology.
- Krishi AI: Offers personalized agricultural advice in regional languages.
- Cropin: Provides cloud-based AI solutions for crop monitoring and analytics.
- Fasal: Uses IoT sensors to monitor soil moisture and microclimatic conditions for smart irrigation.
- Agri AI: Delivers customized farming recommendations using conversational AI.
- MahaVISTAAR-AI: Provides localized agricultural advisories and pest management information.
- SBOF Agrosmart: Focuses on climate resilience, pest control, and market insights.

Benefits of Agro AI

The integration of AI in agriculture offers numerous advantages:

- **Improved Productivity:** Optimizes crop yields through precise decision-making.
- **Resource Efficiency:** Reduces wastage of water, fertilizers, and pesticides.
- **Cost Reduction:** Minimizes input costs and labor dependency.
- **Sustainability:** Promotes environmentally friendly farming practices.
- **Risk Management:** Helps farmers anticipate and mitigate risks related to weather and pests.

Challenges and Limitations

Despite its benefits, Agro AI faces certain challenges:

- Limited digital literacy among farmers
- High initial investment costs
- Poor internet connectivity in rural areas
- Data privacy and accessibility issues

Addressing these challenges is essential for widespread adoption.

Conclusion

Agro AI is revolutionizing the agricultural sector by enabling data-driven and precision-based farming. It empowers farmers with real-time insights, reduces uncertainties, and enhances productivity while ensuring sustainability. As agriculture faces increasing pressure from climate change and population growth, the adoption of Agro AI becomes not just beneficial but essential.

With supportive policies, infrastructure development, and farmer awareness, Agro AI has the potential to transform the future of agriculture in India and beyond.

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ELECTRICAL CONDUCTIVITY TEST AS AN INDICATOR FOR SEED VIGOUR

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Abstract

Determination of seed vigour, a complex physiological quality parameter, is essential for predicting field performance under diverse environmental conditions. The vigour level of seed lots can be assessed using various laboratory techniques. Among these, the electrical conductivity (EC) test is widely used to evaluate the physiological condition of seeds by measuring cell membrane integrity. The conductivity of seed leachate, which reflects the leakage of water-soluble substances such as sugars, amino acids and electrolytes, is inversely related to seed vigour. Higher leachate conductivity indicates greater membrane permeability and lower seed vigour, whereas lower conductivity indicates better membrane integrity and higher vigour.

Keywords: Seed leachate, Electrical conductivity, Cell membrane integrity, Physiological quality

Introduction

A key element in influencing the effectiveness of crop production is seed quality. Higher crop yields, homogeneous seedling establishment and quick germination are all guaranteed by high-quality seeds. Seed vigour is one of the many factors used to assess seed quality. An evaluation of seed quality is essential to comprehending the seed lots' field performance. A standard germination test is used to assess seed germination and seedling growth under favourable conditions in order to determine the planting value of seeds. However, the performance of individual seed lots takes a long time because of the limitations; therefore, a fast

and suitable technique of vigour testing is required, especially for commercial trade purposes (Marcos Filho, 2015).

The germination tests show whether seeds can sprout when conditions are right, but they don't always represent how well seeds behave in the field while under stress. Numerous seed vigour tests have been created to get around this restriction. The Electrical Conductivity (EC) test is one of the most dependable, straightforward and popular techniques (Prado et al., 2019). This test provides an indirect evaluation of the integrity and vigour of the seed membrane by measuring the quantity of electrolytes that seeds leak while soaked in water. For evaluating seed quality and forecasting field performance, the EC test has grown in importance in seed testing labs, the seed industry and academic institutions.

Understanding Seed Vigour

The total of the characteristics of seeds that affect their activity and performance during germination and seedling emergence is referred to as seed vigour. Typically, vigorous seeds exhibit:

• Quick and consistent germination
• Robust development of seedlings
• Increased resilience to environmental stress
• Establishment of higher fields

In laboratory experiments, seeds with low vigour may still exhibit adequate germination percentages, but they frequently perform poorly in the field. As seeds are handled and stored, they naturally deteriorate. Seeds' cellular structure, especially their cell membranes, deteriorate with age. When seeds absorb water, this injury causes an increase in cellular solute leakage. Measuring this leakage is the foundation of the EC test.

Principle of Electrical Conductivity Test

The damaged or deteriorated seeds leak more electrolytes when soaked in distilled water than healthy seeds. During the process of water soaking, the cell membranes rehydrate. If membranes are intact, this leads to minimal leakage; if membranes are damaged, it shows high leakage of electrolytes includes sugars, amino acids, organic acids and mineral ions. The leaked substances increase the electrical conductivity of the soaking solution, which can be measured using a conductivity meter (Fig. 1). The low EC value correlates with the high seed vigour. The high EC value indicates low seed vigour.

Fig.1 Digital electrical conductivity meter

Electrical conductivity method

Electrical conductivity measurement is a biochemical vigour test method. It meets a number of requirements, including objectivity, speed, affordability, repeatability and ease of execution and interpretation. The electrical conductivity test is predicated on the direct correlation between cell membrane integrity and seed vigour. The amount of disarray in the cellular membranes of dried seeds is indicated by the leaching of electrolytes from cellular constituents when the seeds are soaked in water. This, in turn, reveals the physiological quality and vigour of the seeds (Marcos Filho, 2015). Membrane damage occurs during seed deterioration before seed vigour and germination is lost. The electrical conductivity of seed leachate is used to quantify membrane deterioration (Suganthi and Selvaraju, 2017). The amount of water used to soak the seeds, the duration of the immersion, the quantity of seeds soaked, the temperature and the age, integrity and genotype of the seeds all have an impact on the electrical conductivity test's outcomes. The electrical conductivity test for garden peas (Pisum sativum L.) was the first vigour test added to the International Rules for Seed Testing of ISTA in 2001. The International Seed Testing Association (2019) recommendations state that the electrical conductivity test has only been standardised for pea seeds (*Pisum sativum* L.).

Methodology

The electrical conductivity test is often carried out by submerging seeds in water for 24 hours, although new research indicates that shorter immersion times can also be appropriate and evaluate the high viogur and low vigour seed lot (Khajeh-Hosseini, & Rezazadeh, 2011) (Fig. 2 A & B), since different species may have different ideal immersion times. Through dilution, the amount of water used to soak the seeds may potentially have an impact on the electrical

conductivity test findings. Consequently, the impact of the amount of water utilised for seed imbibition must be taken into account while optimising the test for a particular species (Bradford, 2019).

A

B

Fig. 2 Seed leachate for high- and low-vigour seed of groundnut and sesame

The Electrical Conductivity Test Significance

Due to its various benefits in assessing seed quality, the Electrical Conductivity test is frequently employed.

1. Quick Evaluation

EC tests yield results in a day or less, in contrast to field emergence tests, which could take many days or weeks.

2. Sensitive Seed Deterioration Indicator

Even before there is a discernible decrease in germination, the test finds early membrane damage.

3. Easy and Replicable

The procedure can be carried out with modest lab equipment and is really straightforward.

4. Beneficial to the Seed Industry

EC tests are used by seed firms to assess the quality of the seed lot.

5. Forecasts Field Results

Numerous studies demonstrate a robust association between EC

Factors Affecting the EC Test

Several factors influence the accuracy and reliability of the Electrical Conductivity test.

1. Moisture Content of Seeds

Electrolyte leakage may vary depending on the moisture content of the seed.

2. Size of the Seed

Large seeds have higher solutes by nature, which could affect conductivity measurements.

3. The temperature

Electrolyte leakage may rise at higher temperatures.

4. Duration of Soaking

Higher EC levels are typically the outcome of longer soaking times.

5. Damage from Mechanism

Higher values result from cracked or damaged seeds leaking more solutes.

Standardised testing conditions must always be adhered to in order to guarantee accurate results.

Advantages of the Electrical Conductivity Test

The EC test offers several benefits in seed quality assessment:

- Quick and easy technique
- Strong association with seed vigour
- Beneficial for identifying early seed degradation
- Minimal laboratory equipment is needed.

Limitations of the EC Test

Despite its usefulness, the Electrical Conductivity test has some limitations.

1. It works better for crops with large seeds.
2. Variations in seed size can lead to different outcomes.
3. Results from mechanical damage could be deceptive.
4. Different species need to be standardised.

Therefore, EC tests are often used along with other vigour tests such as accelerated ageing and seedling growth tests.

Conclusion

In order to ensure good crop establishment and productivity, seed vigour is essential. By

detecting electrolyte leakage from soaked seeds, the Electrical Conductivity test is a popular and efficient way to assess seed vigour. While damaged seeds show higher leakage and conductivity measurements, healthy seeds with intact membranes release fewer electrolytes, leading to lower conductivity values. The EC test has become a crucial instrument in seed science and seed quality management because of its ease of use, rapidity and dependability. The Electrical Conductivity test offers important insights into seed performance and helps guarantee that only high-vigor seeds reach farmers when it is appropriately standardised and integrated with other seed quality tests. This eventually contributes to improved crop yields and sustainable agriculture.

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DOUBLED HAPLOID TECHNOLOGY FOR RAPID HOMOZYGOSITY IN PLANT BREEDING

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Abstract

Doubled haploid (DH) technology has emerged as a powerful tool in modern plant breeding for the rapid development of completely homozygous lines. Conventional breeding methods require multiple generations of selfing to achieve genetic fixation, whereas DH technology enables the production of fully homozygous lines within a single generation. This review discusses the principles, methods, applications, advantages and recent advances in DH technology. Both in vitro and in vivo techniques such as anther culture, microspore culture, wide hybridization and haploid inducer lines are described. The role of DH technology in hybrid breeding, genetic mapping and stress tolerance improvement is highlighted with relevant crop examples. Contributions from Indian research programs are also included. Despite certain limitations such as genotype dependency and technical constraints, DH technology remains a key strategy for accelerating crop improvement and enhancing breeding efficiency.

Keywords: Doubled haploids, haploid induction, homozygosity, wide hybridization

1. Introduction

The development of genetically stable and high-yielding crop varieties is a primary goal of plant breeding. Conventional breeding methods require repeated selfing over several generations to achieve homozygosity, making the process slow and resource-intensive. Typically, 5–7 generations are required to obtain stable lines, delaying the release of improved cultivars (Acquaah, 2012). Doubled haploid (DH) technology provides an efficient alternative by enabling the production of completely homozygous lines in a single generation. Haploids contain only one set of chromosomes and chromosome doubling results in fully homozygous doubled

haploids. This rapid fixation of alleles enhances selection efficiency and improves breeding accuracy (Forster *et al.,* 2007). The application of DH technology has expanded in major crops such as maize, wheat, rice and barley. It plays an important role in hybrid breeding, genetic mapping and stress tolerance improvement. The integration of DH technology with molecular markers and genome editing has further strengthened its role in modern plant breeding (Zargar *et al.,* 2022).

2. Principle of Doubled Haploid Technology

Doubled haploid technology is based on the production of haploid plants followed by chromosome doubling to restore diploidy. Haploids are derived from gametic cells such as microspores or egg cells. Under controlled conditions, these cells undergo gametophytic embryogenesis to form embryos (Germanà, 2011).

Chromosome doubling is achieved using antimitotic agents such as colchicine or oryzalin, which inhibit spindle formation during cell division. This leads to duplication of chromosomes and the formation of completely homozygous doubled haploid plants (Forster *et al.,* 2007).

The resulting plants are genetically stable and allow direct selection of superior genotypes, eliminating segregation in subsequent generations (Chaikam and Prasanna, 2019).

3. Methods of Doubled Haploid Production

3.1 In Vitro Methods

Anther Culture (Androgenesis):

Anthers containing immature pollen grains are cultured under controlled conditions to induce embryogenesis. This method is widely used in rice, wheat and barley (Germana,2011). However, genotype dependency and albino plant formation are common limitations (Touraev *et al.,* 2001).

Microspore Culture:

Isolated microspores are cultured directly to produce embryos. This method is more efficient and is widely used in *Brassica* species and barley (Ferrie and Caswell, 2011).

3.2 In Vivo Methods

Wide Hybridization (Chromosome Elimination):

Haploids are produced by crossing distantly related species, leading to elimination of one parental genome. The wheat × maize system is a well-known example (Laurie and Bennett, 1988).

Haploid Inducer Lines:

Certain genotypes induce haploid formation during fertilization. This method is widely used in maize breeding (Prasanna *et al.*, 2012; Chaikam and Prasanna, 2019).

3.3 Chromosome Doubling

Chromosome doubling is achieved using colchicine or oryzalin, restoring fertility and producing stable doubled haploid plants (Forster *et al.*, 2007).

4. Advantages of DH Technology

- Rapid development of homozygous lines
- Reduced breeding cycle duration
- Improved selection efficiency
- Elimination of genetic segregation
- Utility in molecular breeding

These advantages significantly enhance breeding efficiency and genetic gain (Forster *et al.*, 2007).

5. Applications in Plant Breeding

- **Hybrid Breeding:** DH lines are used as parental lines in hybrid breeding programs (Prasanna *et al.*, 2012).
- **Genetic Mapping and QTL Analysis**: DH populations are ideal for studying gene action and mapping quantitative traits (Collard *et al.*, 2005).
- **Marker-Assisted Selection:** DH lines enable rapid fixation of desirable alleles using molecular markers (Collard *et al.*, 2005).
- **Stress Resistance Breeding:** DH technology is used to develop stress-tolerant varieties (Zargar *et al.*, 2022).

6. Crop-Based Examples

- **Maize:** Widely used for hybrid breeding (Chaikam and Prasanna, 2019)
- **Wheat:** Haploids via wheat × maize crosses (Laurie and Bennett, 1988)
- **Rice:** Anther culture widely adopted (Germana, 2011)
- **Barley:** Microspore culture highly efficient (Ferrie and Caswell, 2011)

7. Contributions of Indian Research

Indian research institutions such as ICAR and IARI have significantly contributed to DH technology.

- DH-based maize breeding (Gupta *et al.*, 2022)
- Wheat haploid production (Khan *et al.*, 2017)
- Barley androgenesis improvement (Patial *et al.*, 2025)

These efforts have strengthened crop improvement programs in India.

8. Recent Advances

Recent developments include:

- Identification of haploid induction genes (CENH3, MTL) (Kelliher *et al.*, 2017)
- Integration with CRISPR/Cas genome editing (Jacquier *et al.*, 2020)
- Use of molecular markers (Collard *et al.*, 2005)
- Synthetic apomixis (Wang *et al.*, 2019)

9. Limitations

- Genotype dependency
- High cost and technical complexity
- Low efficiency in some crops
- Albino plant regeneration

These limitations restrict large-scale application (Touraev *et al.*, 2001).

10. Future Prospects

Future research aims to improve haploid induction efficiency, develop universal inducer lines and integrate DH technology with genomic selection and artificial intelligence (Chaikam and Prasanna, 2019).

Conclusion

Doubled haploid technology has revolutionized plant breeding by enabling rapid development of homozygous lines and improving selection efficiency. Its integration with modern molecular tools will further enhance crop improvement strategies (Forster *et al.*, 2007; Zargar *et al.*, 2022).

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CRISPR-BASED DISEASE DIAGNOSTICS IN AQUACULTURE: A REVOLUTIONARY TOOL FOR RAPID DETECTION AND HEALTH MANAGEMENT

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Abstract

Aquaculture is one of the fastest-growing food production industries in the world. It plays a vital role in ensuring food security. However, outbreaks of diseases caused by bacteria, viruses, and parasites significantly lower production and lead to financial losses. Effective health management depends on quick and accurate disease diagnosis. Traditional diagnostic methods are slow and often require complex facilities. CRISPR-based diagnostic technology, which is highly sensitive, specific, and offers rapid detection, has emerged as a powerful tool. The mechanism, applications, benefits, and future of CRISPR-based diagnostics in aquaculture are discussed.

Keywords: CRISPR, Disease diagnosis, Rapid detection, Highly sensitive, Powerful tool.

Introduction

Aquaculture significantly contributes to global protein supplies, but disease outbreaks remain a major issue. Fish and shrimp are vulnerable to pathogens such as Vibrio spp., White Spot Syndrome Virus (WSSV), and parasites. Commonly used diagnostic methods include polymerase chain reaction (PCR) and serology. However, these methods can be cumbersome, require laboratory space, and may not be suitable for field use. Recent advancements in molecular biology have led to CRISPR-based diagnostics that can quickly, accurately, and affordably identify aquatic pathogens. These technologies are transforming the management of aquatic animal health.

CRISPR-Based Diagnostics Principle:

CRISPR, also called as Clustered Regularly Interspaced Short Palindromic Repeats, is a natural immune system found in bacteria and archaea. It recognizes and cuts foreign genetic material using RNA-guided CRISPR-associated (Cas) proteins. This method has been adapted for diagnostics to identify specific pathogen DNA or RNA sequences. The method is based on:

- The guide RNA's (gRNA) ability to recognize target nucleic acids
- Activation of the Cas enzyme after the target binds
- In Cas12 and Cas13, collateral cleavage activity produces a visible signal This unique approach allows for rapid and highly sensitive pathogen detection.

CRISPR-Based Diagnostics Mechanism:

A. The Biological Basis of the Natural CRISPR Mechanism:

The CRISPR system operates in three steps:

Step 1: Adaptation (Acquisition of Spacers) - Viral DNA infects bacterial cells. - A fragment is captured and kept in CRISPR DNA as a spacer. - This creates a form of genetic memory.

Step 2: Expression (Formation of crRNA) - RNA is transcribed from CRISPR DNA. - This RNA is converted into crRNA, which directs the Cas protein.

Step 3: Target cleavage, or interference - The crRNA–Cas complex locates matching DNA. - The Cas enzyme cleaves and degrades the target.

The Applied Flow CRISPR Diagnostic Mechanism:

Step 1: Gathering and Preparing Samples - DNA/RNA is isolated from pathogens in samples collected from fish, shrimp, or water.

Step 2: RNA Design Guidance - gRNA is specifically designed for the target pathogen gene.

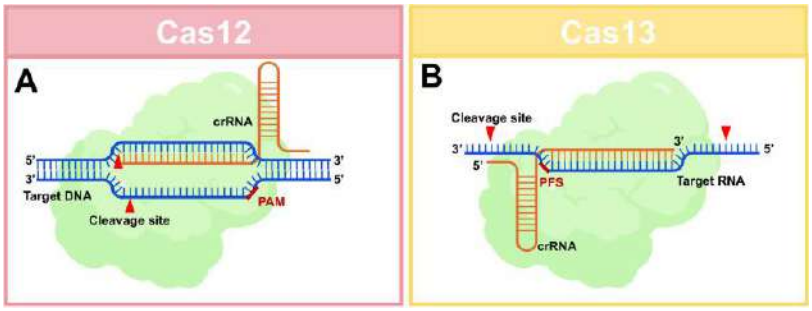
Step 3: Formation of the CRISPR-Cas Complex - The Cas enzyme (Cas12/Cas13) binds to the gRNA.

Step 4: Identification of the Target - The complex scans for and binds to a matching sequence.

Step 5: Cas Enzyme Activation - The Cas enzyme activates upon binding.

Step 6: Collateral Cleavage Activity - The Cas enzyme cuts nearby reporter molecules.

Step 7: Generation of Signals - A colour or fluorescent signal indicates the presence of a pathogen.



(A) Cas12, upon recognising and cleaving its target DNA, is activated and subsequently performs indiscriminate cleavage of any surrounding single-stranded DNA molecules, enabling cascading signal amplification. **(B)** Cas13, following target RNA recognition and cleavage, becomes activated and conducts indiscriminate cleavage of any surrounding single-stranded RNA molecules, facilitating highly sensitive RNA detection.

Aquaculture Applications:

Identification of Viral Diseases:

CRISPR diagnostics can detect viruses, including: - Koi Herpesvirus (KHV) - White Spot Syndrome Virus (WSSV) - Infectious Salmon Anaemia Virus (ISAV). Early detection can prevent large-scale mortality.

Identification of Bacterial Diseases:

Bacterial diseases, such as those caused by Vibrio spp., can be identified quickly without culture methods. This reduces antibiotic misuse and supports timely treatment.

Identification of Parasitic Diseases:

CRISPR techniques enable early detection of parasite infections, improving disease management strategies.

Environmental Monitoring:

CRISPR-based tools allow farmers to identify pathogens in water, enabling preventive measures before outbreaks occur.

CRISPR-Based Diagnostics' Benefits:

High Sensitivity: Detects infections at very low concentrations

High Specificity: Accurately identifies target organisms

Quick Results: Provides results in 30 to 60 minutes

Economical: Requires minimal equipment

Field Applicability: Suitable for on-site testing

User-friendly: Accessible even for non-experts

Challenges and Limitations :

- ✓ Lack of established procedures
- ✓ Risk of contamination
- ✓ Limited availability in commercial markets
- ✓ Regulatory hurdles

Despite these limitations, ongoing research is addressing these challenges.

Comparison with Traditional Approaches:

Conventional Methods for Parameters | Diagnostics for CRISPR:

Time: 30 to 60 minutes | A few hours or days Sensitivity: Moderate to High | Very High Equipment: Advanced | Minimal Field Use: Limited | Excellent Prospects for the Future CRISPR diagnostics have significant potential in aquaculture. Their integration with portable devices and smartphone-based detection systems could enable real-time monitoring.

Future developments:

- ✓ Multiplex detection of multiple infections
- ✓ AI-driven disease forecasting
- ✓ Cost-effective diagnostic tools for farmers

These advancements could improve sustainable fish farming practices and disease monitoring.

Conclusion

CRISPR-based diagnostics represent an innovative approach to managing aquatic animal health. This technology combines high specificity, rapid detection, and ease of use, providing an effective method for early disease diagnosis in aquaculture. CRISPR diagnostics are reliable due to a clear process that includes guide RNA targeting, Cas enzyme activation, and signal generation based on collateral cleavage. With further research and development, this technology is expected to be vital in enhancing the sustainability and productivity of aquaculture.

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FEEDS AND FEEDING OF SMALL RUMINANTS DURING CLIMATE-CHALLENGE SCARCITY CONDITION

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Introduction

Livestock in general and small ruminants (sheep and goat) in particular play an important role in rural economy of India where small, marginal and landless farmers are the main beneficiaries. The sheep and goats either graze on pastures, wastelands, fallow lands etc. or stall fed to meet their nutrient requirements for various physiological state as well as level of production. In view of the climate change, changing land utilization pattern, deforestation, degradation of pastures and rangeland, the gap between availability and requirement of nutrients is increasing. Further, the already scarce feed resources are also being diverted for other purposes. Therefore, under the prevailing circumstances, exploration and evaluation of new feed resources and their efficient utilization should be continual process to overcome with problem of feed scarcity. Newer feed resources- under or unutilized non-conventional feeds including agro-industrial by-products and livestock waste have great role to play by providing useful nutrients to already under nourished livestock population. Importance of these feed resources has been realized for the last four decades. The feeding value, level of incorporation in a particular livestock species and presence or absence of incriminating factor in a newer feed resource are the main criteria for its effective use in sheep and goat ration. Various aspects of utilizing the newer feeds during climate change scarcity are being discussed in detail as under.

Top feed resources

Trees and shrubs provide green biomass of moderate to high digestibility and protein content when other feed reserves are scarce and low in nitrogen. There are several commonly available options for making effective use of shrub and tree foliage in tropics. Probably most of the small ruminants animals are maintained on top feeds than the conventional fodder resources.

Tree leaves are harvested and sun dried at appropriate stage and stored, for use as supplements in addition to grazing during lean summer months when scarcity of feeds becomes a problem for maintaining the small ruminants. However, browsing by the animals on the bushes or freshly lopped trees is nutritionally advantageous as well as economical.

The dry matter content of the top feed ranges from 20 to 40 per cent with 10 to 15 per cent CP on DM basis whereas higher CP value (20 to 23 %) has been found in Subabul (Leucaena leucocephala) leaves. The cultivation of Subabul as a palatable, high-protein browse or cut- and- carry feed component, often used with crop residues or native grasses as the basal roughage. Mainly locally available species are used for cultivation. The ether extract fraction of top feeds is high with low crude fibre content whereas the fibre fraction gets complex and lignified at maturity with concomitant decrease in CP content. The calcium content is generally 2 to 3 times higher than the conventional fodders with low phosphorus content resulting in wide Ca to P ratio. Higher Ca content of top feeds has little advantage without P supplementation. It is important to note that the palatability, digestibility and nutritive value of the tree leaves also decreases with advancing maturity. It is estimated that 300 to 350 million MT dry fallen leaves and grass is available from the forest with nutrient content particularly CP value better than the crop residues like paddy and wheat straws. About 43 million MT of this resource, if processed, can be effectively used in livestock feeding. The ground tree leaves can be incorporated in various feed formulation at appropriate levels for maintenance of sheep and even for growth providing ADG of 180 to 200 g (Karim, 1995).

Prickly pear cactus [Opuntia ficus-indica (L.) Mill.], an excellent natural bio-mass is a fast-growing xerophytes draught resistant plant and well adopted to arid and hot environment. Dry matter yield from opuntia may exceed 2000 kg/hectare on uncultivated wastelands. Prickly pear cactus (Opuntia) is rich in energy and water and poor in protein, has been used in livestock feeding in North America since 19th century (NRC, 1976). It has been used as a drought feed and as forage for cattle feeding. In most of the instances it is still used as emergency feed during drought and scarcity. However, the genus appears in great genetic diversity as it is widely used in human (fruits and green vegetables) and animal diets. The plant is extremely variable in nutritional value depending upon species, variety, and age of the plant, sampling season and plant parts. However, in general Opuntia is high in moisture (85%) and IVDMD (75%) and can be used as source of sustenance during climate change scarcity or drought feeding. The chemical

composition (% DM basis) of Opuntia species having dry matter 12.0, crude protein 10.5, neutral detergent fibre 57.2, acid detergent fibre 25.9, acid detergent lignin 2.4 and gross energy (Mcal/kg) 3.9, categorized it as a good source of moisture (water) and biomass in arid/semi-arid ecology. Research findings on practical Opuntia feeding are: Sheep offered Opuntia species in combination with Cenchrus hay had low feed intake, apparent digestibility of DM, CP and energy, nutritive value, plane of nutrition and N balance.

Laxative effect of cactus can be improved by use of lime as additive to control acidosis if fed ad lib or as sole feed. Its low DCP content can be compensated with 50 g groundnut meal supplementation in a way that the values were similar to cenchrus plus 200 g concentrate supplemented diet (Misra et al. 2006). The opuntia diets could be advantageous, when appropriate N supply is emphasized, as sheep may have similar digestion than those on common diets and may reduce considerably drinking water consumption. 1.0 kg Opuntia (prickly pear cactus) feeding in adult sheep compensated mild water restriction, it may be 1 litre without any significant effect on feed intake. Study on water balance also shows adaptive conservation of water and N in response to water restriction and feeding of moderate N containing prickly pear cactus could serve as potential gut filler and also, by ensuring nutrient supply during summer feed scarce. Thus, Opuntia can be successfully fed to sheep during feed scarcity meeting water and nutrient requirement.

Babul (Prosopis juliflora), a leguminous plant well adapted to semi-arid and arid ecology having multifaceted utility yielding 17 to 140 kg pods having high CP and energy value can replace 30% of concentrate in ruminant feeding.

Dried green leaves of P. juliflora are not palatable to rams feeding even at a very low level, i.e. 100- 150 g per head per day and it also affects feed and nutrient intake and utilization (Chaturvedi and Sahoo, 2012). Babul (Acacia nilotica) pods at the rate 150 g/day with ad libitum cenchrus hay could maintain the pregnant ewes in positive N balance.

Ground Siris (Albezia lebbeck) pods can replace 20 to 40 per cent concentrate for adult sheep. Similarly, cotton straw, cotton seed hulls, groundnut hulls, sunflower straw, sunflower heads, sugarcane bagasse, saw dust, wood pulp waste, forest dry grass and leaves have been used in small ruminant feeding at appropriate level of incorporation.

Agroindustrial by-products

Fibrous agro-industrial by-products are usually regarded as being of limited nutritional

value and low to very low digestibility, supporting low intake by the animal (Egan, 1989). The products of digestion are considered to be poorly balanced for all productive purposed. The extent to which supplements result in improved efficiency of overall feed use depends on changes in the rates of fermentation of fibrous carbohydrates, synthesis of microbial protein, degradation of dietary protein and outflow of particulate matter from the rumen. The tactics in supplying supplements are all related to timing, so as to best modify these rates, which both determine and are determined by the level of intake.

A large quantity of other agro-industrial by products viz. banana leaves, pineapple waste, maize cobs, groundnut hulls, cashew bran, neem seed cake and karanja cakes are used as non-conventional feed resources in livestock feeding. Large quantity of sugar cane bagasse is becoming available from sugar industries. Steam treatment of sugarcane bagasse with or without addition of molasses and urea has been proved encouraging in terms of increasing feed intake and digestibility. Since the farmers engaged in sheep and goat raising belong to weaker sections of the society, this group of foodstuffs have real importance in meeting their requirements. Waste from the breweries (antibiotics, enzymes, and beverages like wine, beer and distilled spirits). The primary waste from antibiotic industry is spent mycelia (ratio of waste to antibiotic production is about 2.5: 1) is very rich in protein and may find place in livestock feeding. Aquatic plants Some of the common aquatic plants, viz. Myriophyllum, Ceratophyllum, Pontamogeton, Nymphaea, Hydrilla, Salvinia, Ipomoea quatica, Ceratopteris sp., Nelumbium speciosum and Eichhornia crassipes, are found in the lakes of India and other South and Southeast Asian countries. Water hyacinth (Eichhornia crassipes), a prolifically growing weed of terrestrial as well as running water is reported to have 9.2 % DCP and 45.7 % TDN in hay and 4.64 % DCP and 40.3 % TDN in silage. The leaves of Lotus (Nelumbium speciosum) are eaten by the cattle and buffalo. Several species of Ramdana (Nymphaea sp.) with varying shades of flower may be seen in waterlogged areas. India with vast sea line has great potential for the production of large quantities of seaweeds. The algae (55 % DM digestibility) are very rich in CP (30- 70 % with >70 % digestibility), ether extract (6 - 8 %) and low in crude fibre (5- 8 %).

Animal waste There is a good scope for increasing nutritive value of agro-industrial by-products, animal waste and fibrous crop residues by following new feeding system wherein these ingredients are blended into complete feeds. It helps in developing the low-cost feed, ensures better roughage-concentrate ratio, avoids refusal of unpalatable portion of plant residues, and

improves utilization of NPN compounds, enables use of locally available ingredients and by increasing bulk density to facilitate economic transport. Complete feeds containing 35 and 15 per cent wheat straw and hay, respectively supported 450 g daily growth rate in crossbred calves. The vegetable waste is available amply in and around big cities. Good silage can be prepared out of market vegetable waste up to level of 70 per cent mixed with paddy straw and added with molasses and urea up to 10 and 5.3 per cent, respectively.

Incriminating factors in non-conventional feeds. The toxic factors can be classified into three broad groups viz. the substances limiting digestion and metabolism of proteins, reducing solubility and utilization of minerals, increasing requirement of certain vitamins and hormones. The toxic factors having significance in small ruminant feeding are ricin, saponins, tannins, phytate and oxalate, glucosinolates, gossypol, mimosine, cyanogens and certain mycotoxins. Various treatments such as water soaking and washing, urea and alkali treatment, supplementation of chemical compounds have been developed for annulment of these factors. However, in view of socio-economic status of farmers these methods have little significance hence their traditional method of dilution is of practical use.

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AQUAPORINS: GATEKEEPERS OF WATER TRANSPORT IN PLANTS AND BEYOND

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Abstract

Aquaporins are integral membrane proteins that play a crucial role in regulating water transport across biological membranes, maintaining cellular water balance and structural integrity. In plants, efficient water movement from roots to leaves is essential for growth, metabolism, and physiological processes such as cell elongation, stomatal movement, and transpiration. Aquaporins, belonging to the membrane intrinsic protein (MIP) family, are characterized by a conserved structure with six transmembrane helices and NPA motifs forming selective water channels. Functional studies using systems like Xenopus oocytes and proteoliposomes have revealed their specificity for water and, in some cases, small solutes like glycerol and urea. Their expression is tightly regulated at transcriptional and post-translational levels, including phosphorylation mechanisms. Environmental factors and inhibitors such as mercury influence aquaporin activity, although effects are often linked to broader metabolic disruptions. Overall, aquaporins are evolutionarily conserved proteins essential for water homeostasis, plant development, and stress adaptation across diverse biological systems.

Key words: Aquaporins, Water transport, Membrane intrinsic proteins (MIPs), Plant physiology, Osmotic regulation, Water homeostasis

Introduction

Water is essential for maintaining plant metabolism and structure, requiring tight regulation of water balance. The main pathway of water movement to the leaf surface begins in the roots. Before fulfilling its functions and eventually evaporating into the atmosphere, water must cross several membranes. Earlier, it was believed that water diffused directly through lipid

bilayers, but the discovery of protein-based water channels, known as aquaporins, changed this understanding. These membrane-intrinsic pores facilitate water movement along osmotic gradients. In plant cells, aquaporins are found in both the plasma membrane and the tonoplast, where they regulate membrane water permeability and control water movement into and out of the cytosol and vacuole. Individual cells maintain their water status by adjusting ion concentrations and metabolic osmolytes, with aquaporins contributing to changes in turgor pressure and cell size. Aquaporins enable rapid water transport when simple diffusion is insufficient, particularly during processes such as cell expansion, elongation, stomatal movement, and other hydronastic responses. They ensure efficient water flow across membranes and are essential for certain specialized functions in plants and animals. Water also moves through the apoplast, including vascular and non-vascular tissues, without crossing membranes. Evolutionarily, aquaporins are ancient proteins present from bacteria to higher plants, highlighting their fundamental role in managing osmotic stress.

Aquaporins

Aquaporins are integral membrane proteins that facilitate the selective transport of water across biological membranes, playing a key role in maintaining cellular and tissue water balance. Discovered in the early 1990s, they have been widely studied for their importance in water homeostasis across different organisms. These proteins are highly specific to water molecules, excluding ions and other solutes, and possess a characteristic structure of six transmembrane helices forming a pore for water movement. Various isoforms of aquaporins exist with tissue-specific distribution, supporting diverse physiological functions. In the kidneys, they regulate water reabsorption, enabling efficient urine concentration and dilution. In plants, aquaporins are involved in water uptake from the soil and transpiration, influencing overall water balance. Beyond these roles, aquaporins help maintain cell volume, regulate cerebrospinal fluid production in the brain, and assist fluid transport in the eyes. Dysfunction of aquaporins is linked to disorders such as nephrogenic diabetes insipidus and certain cataracts.

Their discovery has advanced medicine and biotechnology, offering potential applications in drug delivery and water filtration technologies. Ongoing research continues to reveal their structural and functional complexity, opening avenues for therapeutic interventions and improved water management in agriculture and industry.

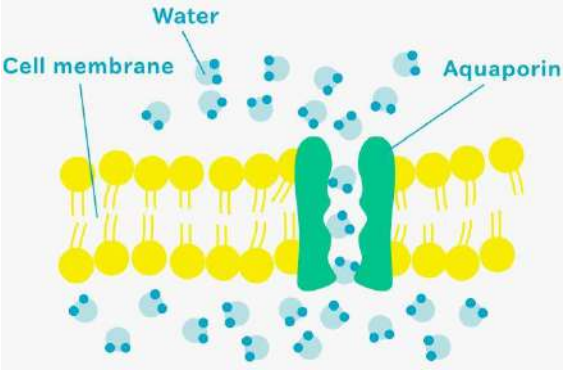

Fig. 1. Aquaporins

The superfamily of membrane intrinsic proteins (MIPs)

Amino acid sequence comparisons of the corresponding plant and animal proteins reveal that they are evolutionarily related and belong to the MIP family. The first member of the MIP family was a highly abundant protein localized in the bovine lens fiber cell membrane. Since then, numerous MIPs in various species have been characterized. With regard to sequence homology, five sub- families can be distinguished:

1) Animal aquaporins,
2) Aquaglyceroporins,
3) Plant aquaporins of the plasma membrane,
4) Tonoplast aquaporins,
5) Nodulin-like membrane proteins.

All members of these families facilitate water transport, except the bacterial glycerol facilitator GlpF, which is highly homologous to the aquaglyceroporins

Structure of Aquaporins

The majority of members of this highly conserved group of membrane proteins have a molecular mass between 26 and 29 kDa and contain the two characteristics, highly conserved amino acid motifs asparagine–proline–alanine. The complete protein consists of six membrane-spanning a helices, linked by loops. Since the first three membrane helices and loops resemble the other half of the MIP, an intragenic duplication has been suggested. This leads to a tandem conformation of three a helix, each half including one in a loop that is slightly more hydrophobic. The in vivo conformation of the peptide results in an overlapping of the NPA regions inside the membrane. This structure has been described as ‘the hourglass model’ and is suggested to form a pore complex of about 3 A° diameter for the passage of water molecules.

Although there are reports demonstrating that a single aquaporin is functional, they have been found to form tetramers, dimers or, in the case of the glycerol facilitator GlpF, just monomers in the native membrane.

Functional analysis

The first aquaporin, AQP1, was functionally analyzed using Xenopus oocytes expressing AQP1-cRNA. This system has been widely applied to both animal and plant membrane proteins, with adaptations for studying water permeability. After injecting cRNA encoding a putative aquaporin, the oocytes were incubated to allow protein synthesis and integration into the plasma membrane. Membrane water permeability was then estimated by measuring the rate of cell swelling under hypo-osmotic conditions, compared to water-injected controls.

Following this method, several plant aquaporins, including tonoplast intrinsic proteins (TIPs) and plasma membrane intrinsic proteins (PIPs), were identified. More recently, additional assay systems such as functional expression in yeast and reconstitution of purified proteins into proteoliposomes have been developed. These approaches have enabled detailed analysis of plant MIPs as facilitators of water and solute transport.

Some aquaporins, such as gTIP and aTIP, are highly specific for water, similar to most animal aquaporins. However, others also transport small solutes like glycerol and urea. For example, tobacco NtAQP1 facilitates both glycerol and urea transport. The soybean aquaporin NOD26 transports glycerol and formamide, but not urea, and is localized in root nodule symbiosome membranes, suggesting a role in osmoregulation during legume–rhizobia symbiosis.

Recent studies indicate that human AQP1 may facilitate CO_2 transport. However, as these findings are based on heterologous systems, further research is needed to confirm similar roles in plant aquaporins.

Regulation of aquaporins

Studies on aquaporin expression reveal wide variation among different cell types. High levels of promoter activity, mRNA, or aquaporin proteins are commonly observed during cell elongation and in tissues such as guard cells and vascular elements of roots, stems, and leaves. The tissue-specific expression of individual aquaporins is often regulated by developmental factors, likely reflecting the changing water requirements during organ growth and tissue specialization. In elongating cells, high membrane water permeability is beneficial for growth,

but it also poses a risk of excessive water loss. Therefore, aquaporin activity is tightly controlled. In addition to transcriptional regulation, aquaporin permeability may be adjusted through post-translational mechanisms, such as switching between active and inactive states. Phosphorylation and dephosphorylation play a key role in this process, supported by the presence of multiple phosphorylation sites in many aquaporins. Examples include aTIP from kidney bean and PM28 from spinach, both of which show increased water permeability when expressed in oocytes under conditions promoting phosphorylation. These proteins differ in the location of their phosphorylation sites, with Ser274 in PM28 confirmed to be phosphorylated in vivo. Although attempts have been made to relate specific amino acid residues to functional changes, clear conclusions are still lacking. Nevertheless, significant changes in aquaporin gene activity across physiological and developmental stages highlight transcriptional regulation as a major and effective control mechanism.

Effect of mercurial reagents on aquaporin function

In the last century, mercury compounds were widely used to study plant metabolism and transport processes. As early as 1884, Haberlandt showed that applying mercury chloride to the cut end of a detached twig inhibited water transport, as indicated by the cessation of guttation. This suggested that mercury interferes with mechanisms involved in water movement. In recent years, improved techniques have enhanced the study of heavy metal effects on plant physiology, particularly on water transport.

Mercury is believed to act by binding to specific cysteine residues in proteins. This interaction, especially with sulfur groups, can block channel proteins and hinder the movement of water or solutes. In aquaporins sensitive to mercury, this inhibition can be reversed using β-mercaptoethanol. Systems such as Xenopus oocytes and proteoliposomes are commonly used to analyze mercury sensitivity. However, not all aquaporins respond to mercury; for example, RD28 and NtAQP1 are known to be insensitive.

Site-directed mutagenesis has helped identify cysteine residues involved in mercury sensitivity. Yet, the presence or absence of these residues does not always determine sensitivity, suggesting that other sequence elements or structural features also play a role. Differences in protein conformation, influenced by mercury binding, may explain variations among aquaporins.

At the whole-plant level, mercury can significantly reduce water transport. When applied to roots, it can decrease hydraulic conductivity by 60–90%. However, its effects are not limited

to aquaporins; mercury also disrupts membrane potential and general metabolism. Similar reductions in water transport occur under anaerobic conditions, and combined treatments show no additional effect. This indicates that normal metabolic activity is essential for aquaporin function, making it difficult to distinguish between direct inhibition and indirect metabolic effects of mercury.

Conclusion

In conclusion, aquaporins play a vital role in cellular water transport, maintaining proper water balance and cellular integrity. Their unique structure and selective permeability highlight their importance in regulating water movement across membranes. Aquaporins contribute to a wide range of physiological processes, including kidney function in animals and water uptake in plants, demonstrating their significance across different organisms. Their adaptability reflects strong evolutionary importance. The regulation of aquaporin activity allows cells to respond effectively to environmental changes and internal needs. Their interaction with other cellular components shows their integration into complex biological systems. Understanding aquaporins offers valuable insights for developing treatments for water imbalance and cellular stress. Overall, aquaporins are essential for the survival, function, and stability of living organisms.

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ENTOMOPHAGY AS A TRANSFORMATIVE INNOVATION IN FUTURE FOOD SYSTEMS

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Abstract

Entomophagy, the consumption of insects, is emerging as a sustainable solution to global food security challenges driven by population growth, climate change, and resource limitations. Edible insects offer high-quality protein, essential nutrients, and efficient feed conversion with minimal environmental impact. Their integration into food systems supports circular economy principles through waste recycling and resource efficiency. Traditional practices across cultures highlight their nutritional and ecological value, while modern innovations in insect farming and processing enhance scalability and consumer acceptance. Despite challenges such as regulatory barriers and cultural resistance, entomophagy holds significant potential as a climate-resilient, eco-friendly, and economically viable alternative protein source for future food systems.

Keywords: Entomophagy, edible insects, sustainable protein, food security, climate resilience,

1. Introduction

The accelerating growth of the global population, coupled with climate instability and resource depletion, has intensified pressure on existing food production systems (Van Huis *et al.*, 2013). Conventional animal agriculture, while nutritionally valuable, is increasingly constrained by its environmental footprint, high input requirements, and vulnerability to climate-induced disruptions. Consequently, global attention has shifted toward alternative protein systems that are nutritionally adequate, environmentally efficient, and economically viable. Within this context, "entomophagy" the human consumption of insects has emerged as a scientifically supported and ecologically sound strategy for strengthening future food systems (Van Huis *et al.*, 2021).

The scope of entomophagy extends well beyond its role as a dietary practice and encompasses ecological sustainability, economic development, and technological innovation. Insect-based systems contribute simultaneously to food production, waste reduction, and nutrient recycling. Their integration into agri-food systems aligns strongly with circular economy principles, positioning edible insects as multifunctional biological resources rather than niche food items (Gonçalves *et al.*, 2022).

2. Origin and Evolution

Historical evidence indicates that insect consumption was an intentional and nutritionally strategic behavior among early human populations. Rather than being a response to food scarcity, entomophagy represented an efficient utilization of abundant and renewable biological resources. Over time, these practices became embedded within cultural traditions and ecological knowledge systems, reflecting localized adaptation to environmental conditions. The decline of insect consumption in industrialized regions was driven largely by socio-cultural shifts rather than by nutritional limitations (Imathiu, 2020).

3. Biodiversity and Taxonomic Aspects

Entomophagy encompasses an exceptionally rich component of global biodiversity, reflecting the immense taxonomic diversity of insects exploited as food by human populations. To date, more than 2,000 insect species have been documented as edible worldwide, spanning over 25 taxonomic orders (Van Huis *et al.*, 2013).. This diversity is unevenly distributed across insect groups, with certain orders contributing disproportionately to human diets due to their abundance, nutritional value, ease of collection, and cultural acceptance. The taxonomic composition of edible insects is shaped by ecological availability, evolutionary traits, and long-standing human–insect interactions (Zhou *et al.*, 2022).

4. Geographic–Taxonomic Link

The taxonomic composition of entomophagous insects varies geographically. In Africa, Lepidopteran larvae and termites dominate traditional diets, whereas Orthopterans and beetles are more prominent in Asia and Latin America. In Northeast India, consumption spans Coleoptera, Hemiptera, and Orthoptera, reflecting the region's high insect biodiversity and strong indigenous food traditions (Imathiu, 2020).

4.1. Coleoptera (beetles) represent the most diverse group of edible insects, contributing nearly one-third of recorded species. Both larvae and adults are consumed, with larvae preferred for

their high lipid content and soft texture. They are widely consumed across Africa, Asia, and Latin America due to their abundance and adaptability.

4.2. Lepidoptera are mainly consumed in the larval stage (caterpillars), valued for high protein and energy content, especially in African and Asian regions. Their lower chitin content improves digestibility.

4.3. Orthoptera, including grasshoppers, locusts, and crickets, are globally recognized edible insects. They are rich in protein, easy to rear, and widely used in commercial farming.

4.4.Hymenoptera, such as ants and bees, are consumed as larvae and pupae and are valued for their nutritional and cultural importance.

Other groups like termites, flies, and dragonflies also contribute regionally. Overall, their dominance reflects high reproductive capacity, ecological adaptability, and efficiency, making them important for sustainable food systems.

5. Composition and Nutritional values

Edible insects possess a rich nutritional profile, providing high-quality protein, healthy lipids, and essential micronutrients. Their composition varies with species, developmental stage, and processing methods such as drying, boiling, or frying. Overall, they serve as an important and sustainable source of proteins, fats, vitamins, and minerals for human nutrition (Ojha *et al*., 2021).

Nutrient / Component	Reported Content / Range	Biological & Health Role	Key Notes	Key References
Proteins	35–60%; up to 70–76% in some Orthoptera	Growth, tissue repair, enzyme and hormone synthesis	High biological value; comparable to meat and eggs	Van Huis *et al.*, 2013; Ordoñez-Araque *et al.*, 2022; Van Huis *et al.*, 2021
Essential amino acids	46–96% of total amino acids	Muscle maintenance, metabolic regulation	Rich in leucine, lysine, valine, threonine	Zhou *et al.*, 2022; Van Huis *et al.*, 2021
Protein digestibility	77–98% (after processing)	Improved nutrient bioavailability	Enhanced by defatting and removal of exoskeleton	Ojha *et al.*, 2021; *Zhou et al.*, 2022
Lipids (total fat)	<5% to >50%	Energy source; cell membrane integrity	Higher in larvae than adults; females > males	Gonçalves *et al.*, 2022; Ordoñez-Araque *et al.*, 2022
Unsaturated fatty acids (ω-3, ω-6)	High linoleic and α-linolenic acids	Cardiovascular health; anti-inflammatory effects	Susceptible to oxidation during processing	Van Huis *et al.*, 2013; Devi *et al.*, 2024
Triglycerides	~80% of total lipid fraction	Energy storage	Major lipid class in insects	Gonçalves *et al.*, 2022; Ojha *et al.*, 2021
Phospholipids and sterols	~20% of lipid fraction	Cell membrane structure; hormone synthesis	Includes cholesterol in small amounts	Gonçalves *et al.*, 2022

Nutrient / Component	Reported Content / Range	Biological & Health Role	Key Notes	Key References
Carbohydrates (total)	Low	Minor energy contribution	Mainly structural carbohydrates	Van Huis *et al.*, 2013
Chitin (dietary fibre)	2.7–49.8 mg/kg FW; 11.6–137.2 mg/kg DW	Gut health; prebiotic activity	Poor digestibility in Western populations	Ojha *et al.*, 2021; Magara *et al.*, 2021
Glycogen	Variable	Energy reserve	Important during metamorphosis	Van Huis *et al.*, 2013
Energy value	200–700 kcal/100 g	Caloric contribution	Larvae more energy-dense than adults	Orkusz, 2021; Ordoñez-Araque *et al.*, 2022
Vitamin B1 (Thiamine)	0.1–4 mg/100 g	Carbohydrate metabolism	Comparable to cereals and meat	Zhou *et al.*, 2022
Vitamin B2 (Riboflavin)	0.11–8.9 mg/100 g	Cellular respiration	Species-dependent	Zhou *et al.*, 2022
Vitamin B12	Up to 5.4 µg/100 g	Nervous system function; erythropoiesis	High in *Acheta domesticus*	Ordoñez-Araque *et al.*, 2022
Vitamin E (Tocopherol)	~9.65 mg/100 g	Antioxidant protection	Reported in silkworm powder	Jantzen da Silva Lucas *et al.*, 2020
Iron (Fe)	31–77 mg/100 g	Prevention of anemia	Higher than beef in some species	Van Huis *et al.*, 2013; Mwangi *et al.*, 2018

Nutrient / Component	Reported Content / Range	Biological & Health Role	Key Notes	Key References
Zinc (Zn)	Up to 26.5 mg/100 g	Immune and enzymatic functions	High in palm weevil larvae	Mwangi *et al.*, 2018
Calcium, Mg, P, K, Mn	Moderate to high	Bone health; metabolic regulation	Bioavailability under investigation	Ordoñez-Araque *et al.*, 2022; Ojha *et al.*, 2021
Anti-nutritional factors	Chitin, phytates, oxalates (low levels)	May reduce mineral absorption	Generally within acceptable limits	EFSA Scientific Committee, 2015; Kunatsa *et al.*, 2020
Allergenic proteins	Tropomyosin, arginine kinase	Hypersensitivity reactions	Cross-reactivity with shellfish allergens	Imathiu, 2020; Ribeiro *et al.*, 2021

6. Functional and Health-Promoting Properties of Bioactive Foods

6.1. Beyond Basic Nutrition

Functional foods provide benefits beyond basic nutrition by supplying bioactive compounds such as vitamins, minerals, fiber, antioxidants, and essential fatty acids that support immunity, cardiovascular health, and metabolic balance (Ribeiro et al., 2021).

6.2. Antioxidant and Anti-Inflammatory Potential

Bioactive compounds like polyphenols and carotenoids reduce oxidative stress and inflammation, helping prevent chronic diseases.

6.3. Functional Food Applications

Functional foods include natural sources (fruits, vegetables, grains) and fortified products such as probiotic yogurt, fiber-rich bread, and omega-3 enriched foods.

6.4. Probiotics, Prebiotics, and Gut Health Interactions

Probiotics improve gut microbiota and immunity, while prebiotics promote the growth of beneficial bacteria.

6.5. Allergenicity and Safety Considerations

Some bioactive compounds may cause allergic reactions; thus, safety evaluation and proper formulation are essential.

6.6. Agricultural and Farming Aspects

Insect farming supports food production, pest control, pollination, and provides products like silk, dyes, and pharmaceuticals.

Examples : Insect that majorly used for food purpose

- Pacific beetle cockroach (*Diploptera apunctata*)
- House cricket (*Acheta domesticus*)
- Red palm weevil (*Rhynchophorus ferrugineus*)

Examples : : Insect that majorly used for pets feed

- Adult house crickets (*Acheta domesticus*)
- Black sodierfly larvae (*Hermetia illucens*)

6.8. Top 5 insect farming companies in other countries

Sl.no	Name of company	Location	Year
1	Entocycle	United kingdom	2014
2	YNSECT	France	2011
3	BETA BUGS LIMITED	United kingdom	2017
4	Cricketone	Vietnam	2016
5	Next protein	France	2015

6.9. Top 5 Indian insect farming companies in other countries

Sl. No.	Name of company	Location	Year
1	Loopworm	Bengaluru	2019
2	Freshrooms lifesciences	Chennai	2008
3	Humble bee	Bengaluru	2023
4	Kovai BSF	Coimbatore	2018
5	Insectifll	Bengaluru	2019

7. Circular insect farming:

An innovative approach that aligns with the principles of a circular economy.

It involves using organic waste streams to rear insects, which can then be processed into valuable products like protein rich feed, biofertilizers, and even biofuels (Gonçalves *et al.*, 2022). Helps in Waste Reduction, Nutrient Recycling, Sustainable Feed and Resource Efficiency.

7.1. Production techniques of insect farming

7.1.1. Traditional method

In traditional method using large area raising greenhouses and it is most cost effective produce large quantities of insects.

7.1.2. Modern method

Vertical insect farming- uses trays and other vertical structures to maximize space efficiency. Require less land and cost effective then traditional method .

7.2. Environmental and Ecological Aspects

Insect farming is a sustainable protein system that requires less land and resources while converting organic waste into valuable protein and biofertilizers, supporting nutrient recycling and climate-resilient production.

7.3. Processing and Value Addition of Edible Insects

Processing ensures safety and acceptability through steps like harvesting, cleaning, and preservation methods such as drying, roasting, and grinding, improving shelf life and nutritional quality.

7.4. Food Safety and Quality Considerations

Food safety concerns include microbial, chemical, and allergenic risks, which can be minimized through controlled rearing, proper processing, hygiene, and adherence to standard practices.

8. Challenges and Constraints

Consumer resistance, Regulatory barriers, Scaling-up difficulties, Standardization issues, Research gaps, Safety issues (EFSA Scientific Committee, 2015).

9. Conservation & Biodiversity Risk Angle

Increasing demand for edible insects raises important biodiversity and conservation concerns, particularly where harvesting relies heavily on wild populations. Unsustainable collection practices may threaten local insect diversity and disrupt ecosystem services such as pollination and nutrient cycling. Consequently, taxonomic knowledge is essential for identifying

species suitable for domestication and for developing management strategies that balance food security with biodiversity conservation (Van Huis *et al.*, 2021).

10. Future Prospects

The successful mainstreaming of entomophagy will depend on coordinated advancements across science, policy, and society. Research efforts must focus on improving production efficiency, ensuring food safety, and understanding long-term health impacts. Simultaneously, policy frameworks and consumer education initiatives are essential for fostering acceptance and facilitating large-scale adoption. Together, these efforts position entomophagy as a viable contributor to sustainable global food security.

11. Conclusion

Entomophagy offers a sustainable and nutrient-rich alternative to conventional animal protein, with significant benefits for food security and environmental conservation. With continued research, supportive policies, and improved consumer acceptance, edible insects can play a meaningful role in future resilient food systems.

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ECO-FRIENDLY MANAGEMENT OF ROOT-KNOT NEMATODE IN TOMATO USING A-TERTHIENYL NANOFIBRE FORMULATION: A DUAL APPROACH FOR GROWTH ENHANCEMENT AND PEST SUPPRESSION

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Abstract

The present study evaluates the bioefficacy of α-terthienyl infused nanofibre formulation in managing root-knot nematode (*Meloidogyne incognita*) and enhancing plant growth in tomato under pot culture conditions. Different concentrations (3, 5, 10, and 15 ppm) of the nanofibre matrix were tested alongside marigold root extract, chemical control (carbofuran), and an untreated control. Among the treatments, 10 ppm concentration exhibited superior performance, significantly improving plant growth parameters such as shoot length (42.26 cm), shoot weight (31.95 g), root length (17.53 cm), and root weight. Simultaneously, it effectively suppressed nematode population, reducing soil juvenile count to 118, minimizing gall formation (2 galls/5 g roots), and achieving the lowest reproduction factor (0.12). The study demonstrates that α-terthienyl nanofibre formulation offers a sustainable and efficient alternative to chemical nematicides, providing dual benefits of plant growth promotion and nematode control.

Introduction

Tomato is an economically important vegetable crop widely cultivated across tropical and subtropical regions. However, its productivity is severely affected by plant parasitic nematodes, particularly *Meloidogyne incognita*, which causes root-knot disease leading to significant yield losses. Conventional management strategies rely heavily on chemical nematicides, which pose environmental and health concerns. Therefore, there is a growing need for eco-friendly and sustainable alternatives (Kavitha *et al*.,2025).

Plant-derived compounds such as α-terthienyl, obtained from *Tagetes erecta*, have shown promising nematicidal properties. Recent advancements in nanotechnology have enabled the development of nanofibre-based delivery systems that enhance the stability, controlled release, and efficacy of bioactive compounds. Incorporating α-terthienyl into nanofibre matrices may improve its bioavailability and provide prolonged protection against nematodes while promoting plant growth (Rawal *et al*.,2020)

This study aims to evaluate the effectiveness of α-terthienyl infused nanofibre formulation in improving plant growth and suppressing nematode populations in tomato under controlled pot culture conditions.

Materials and Methods

Pot culture study

The bioefficacy of alpha-terthienyl loaded nanofibre evaluated by pot culture study. The seedlings of tomato variety PKM 1 were raised in experimental 3 kg pot size. The nematode was inoculated in fifteen days old tomato seedlings. After 30 days of nematode inoculum, alpha-terthienyl infused nanofibre matrix infused into the pot culture at different concentrations. The nanofibre matrix is applied after 20 days of nematode inoculum. The experiment was designed with precised treatment in Completely Randomized Block Design (CRD) with three replications.

Treatments

T1 – *T. erecta* root extract @ 5 ml/plant

T2- Alpha-terthienyl infused nanofibre matrix @ 3 ppm

T3 – Alpha-terthienyl infused nanofibre matrix @ 5ppm

T4– Alpha-terthienyl infused nanofibre matrix @ 10ppm

T5 -Alpha-terthienyl infused nanofibre matrix @ 15ppm

T6 – Carbofuran3G @ 1 g /plant

T7 – Untreated control.

Evaluation of plant growth parameters of alpha-terthienyl nanofibre matrix under pot culture conditions

Shoot length

The application of alpha-terthienyl infused nanofibre on plants resulted in a general increase of shoot length. The concentration of 10 ppm exhibited the most remarkable

performance, showcasing an elongation of 42.26 cm in comparison to the control's 26.89 cm. Following this, the 15ppm treatment displayed an increase of 41.10 cm, trailed by the 5 ppm treatment, which exhibited an elongation of 40.57 cm. The lowest treatment with inoculation of infused nanofibre was 3 ppm, which resulted in an increase of shoot length of 38.28 cm. However, the marigold root extract treatment exhibited the lowest performance, with a meager shoot length of 36.23 cm (Table 1 -; Fig- 1).

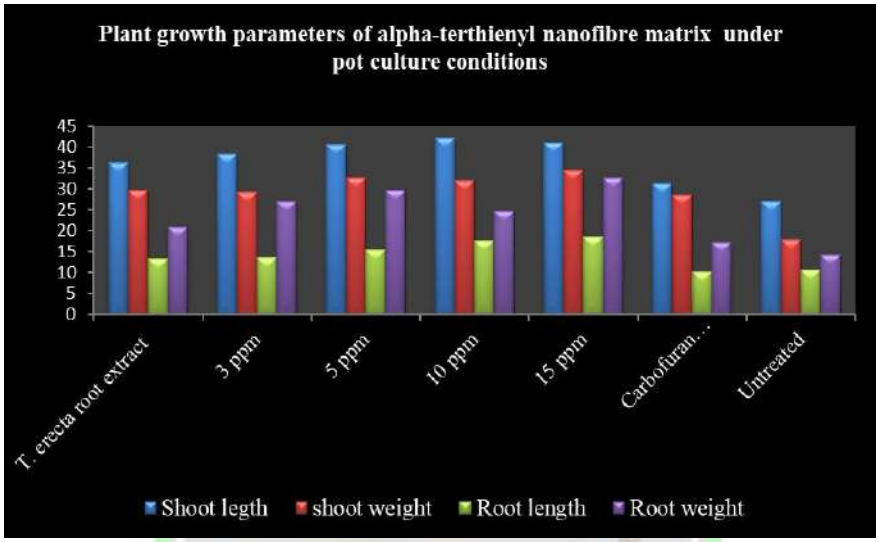

Figure -1 Evaluation of plant growth parameters of alpha-terthienyl nanofibre matrix under pot culture conditions

Shoot weight

The shoot exhibited a weight that was statistically superior compared to other concentrations, and this was observed at 10 ppm, with a weight of 34.46 g. This was followed by 31.95 ppm, which had a weight of 31.95 g. The nanofibre treatment showed a minimal increase in weight at 3 ppm, with a weight of 29.23 g, while the root extract of marigold had a weight of 29.78 g. It is evident that the results showcase a remarkable difference in weight, highlighting the importance of concentration and treatment in determining shoot weight (Table 1; Fig 1).

Root length

The table furnishes the root length per plant observed at the time of harvest under various treatments. The zenith root length of 18.46cm was documented at 10 ppm concentration, while the subsequent treatment was the administration of nanofibre 15 ppm, exhibiting 17.53 cm. The slightest elongation in root length was witnessed at 3 ppm and manifested as 13.56cm, whereas the root extract of marigold displayed a 13.39 cm elongation (Table;1 ,Fig 1).

Root weight

The estimation of growth parameters can also consider the weight of roots. The highest weight recorded in the experiment was approximately 32.68 g at 10 ppm, whereas the lowest weight observed was 26.85g at 3 ppm. The remaining treatments exhibited results of 29.76 g at 5ppm and 26.85 g at 3 ppm (Table -1; Fig - 1).

Table 1. Evaluation of plant growth parameters of α-terthienyl nanofibre matrix under pot culture conditions

Treatments	Mean of three replications			
	Shoot length(cm)	Shoot weight(g)	Root length (cm)	Root weight (g)
T1- *T. erecta* root extract @ 5 ml/plant	36.23^{f} (6.01)	29.78 ^{d} (5.45)	13.39^{e} (3.65)	20.89 ^{e} (4.57)
T2- Alpha-terthienyl infused nanofibre matrix @3 ppm	38.28^{e} (6.18)	29.23^{e} (5.40)	13.56^{d} (3.68)	26.85 ^{c} (5.18)
T3- Alpha-terthienyl infused nanofibre matrix @5 ppm	40.57^{d} (6.36)	32.60^{b} (5.70)	15.46^{c} (3.93)	29.76 ^{b} (5.45)
T4- Alpha-terthienyl infused nanofibre matrix @10 ppm	42.26 ^{b} (6.50)	31.95^{c} (5.65)	17.53^{b} (4.18)	24.74 ^{d} (4.97)
T5 – Alpha-terthienyl infused nanofibre matrix @15 ppm	41.10^{c} (6.41)	34.46 ^{a} (5.87)	18.46 ^{a} (4.29)	32.68 ^{a} (5.71)
T6-Carbofuran 3G@1g /Plant	31.35 ^{a} (5.59)	28.56 ^{f} (5.34)	10.09 ^{g} (3.17)	17.12 ^{f} (4.13)
T7- Untreated control	26.89 ^{g} (5.18)	17.8 ^{g} (4.21)	10.65^{f} (3.26)	14.26 ^{g} (3.77)
SEd	0.076	0.045	0.03	0.039
C.D	0.167	0.098	0.06	0.085

(Figures in parentheses are square root transformed values.The columns followed by alphabets are significantly differ from each other at1% level by DMRT)

Nematode parameters under pot culture conditions

Nematode population in soil and root

The soil sample of 200cc was obtained from the root zone of tomato plants grown in pot culture under glasshouse conditions. The pot were initially inoculated with 1000 J2. Nematodes were extracted from the sample using Cobb's sieving and decanting technique. The resulting nematode suspension was quantified via Tally counter. The untreated control had a greater population of second stage juveniles (3950) compared to soil incorporation of marigold root extract @1180. A marked reduction in population was noted at 10 ppm 118, followed by 15 ppm with 150 and then 5 ppm with 352. The lowest population reduction was produced by 3 ppm concentration with 468 (Table 2 -, Plate 1, Figure - 2).

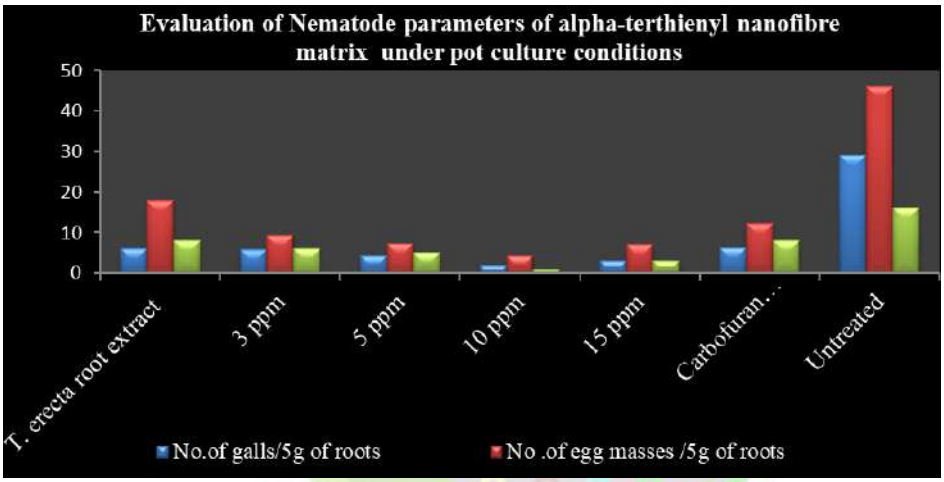

Figure -2 Evaluation of Nematode parameters of alpha-terthienyl nanofibre matrix under pot culture conditions

Adult females in root

The study observed a range of mean numbers of white females in a 5g root sample under various treatments. A comparison of the treatments revealed that the highest population of females was observed in the untreated control group, with a count of 16. This was followed by the incorporation of α-terthienyl-infused nanofibre formulation in the soil, where the best treatment was found to be at a concentration of 10 ppm, resulting in a count of 1 females. The next most effective treatments were at concentrations of 15 ppm (5 females) and 5 ppm (6 females), respectively. The least population was observed at a concentration of 3 ppm, where only 8 females were observed, representing a 50% reduction in comparison to the control group (Table -2, Plate- 1,Fig -2).

Gall index

The calculation of the gall index involves tallying the number of galls in 5 grams of soil. Intriguingly, the introduction of nanofibres at a concentration of 10 ppm resulted in the emergence of 2 galls. This was followed by the implementation of 15 ppm which yielded 3.0 galls. Prior to this, the application of 5 ppm yielded 4.32 galls. Finally, the addition of 3 ppm caused the production of 5.75 galls (Table 2; Fig -2).

Table 12. Evaluation of Nematode parameters of α-terthienyl nanofibre matrix under pot culture conditions

Treatments	Nematode populations in roots (Mean of three replications)		
	No. of galls/ 5g of roots	No. of egg masses/ 5g of roots	No. of females / 5g of roots
T1- *T. erecta* root extract @ 5 ml/plant	6.00[c] (2.44)	17.9 [b] (4.23)	8.00 [b] (2.82)
T2- Alpha-terthienyl infused nanofibre matrix @3 ppm	5.75 [d] (2.39)	9.26 [d] (3.04)	6.00[c] (2.44)
T3- Alpha-terthienyl infused nanofibre matrix @5 ppm	4.32 [e] (2.07)	7.24 [e] (2.69)	5.00[d] (2.23)
T4- Alpha-terthienyl infused nanofibre matrix @10 ppm	2.00 [g] (1.41)	4.28 [g] (2.06)	1.00[f] (1.00)
T5 – Alpha-terthienyl infused nanofibre matrix @15 ppm	3.00 [f] (1.73)	6.98 [f] (2.64)	3.00 [e] (1.73)
T6-Carbofuran 3G@1g /Plant	6.23[b] (2.49)	12.3 [c] (3.50)	8.00 [b] (2.82)
T7- Untreated control	29.1 [a] (5.39)	46.05 [a] (6.78)	16.00 [a] (4.00)
SEd	0.02	0.02	0.02
C.D	0.05	0.06	0.04

(Figures in parentheses are square root transformed values.The columns followed by alphabets are significantly differ from each other at1% level by DMRT)

Table 3. Evaluation of Nematode populations of α-terthienyl nanofibre matrix under pot culture conditions

Treatment	P_f	P_i	P_f / P_i
T1- *T. erecta* root extract @ 5 ml/plant	790	1000	0.79
T2- Alpha-terthienyl infused nanofibre matrix @3 ppm	468	1000	0.46
T3- Alpha-terthienyl infused nanofibre matrix @5 ppm	352	1000	0.35
T4- Alpha-terthienyl infused nanofibre matrix @10 ppm	120	1000	0.12
T5 – Alpha-terthienyl infused nanofibre matrix @15 ppm	150	1000	0.15
T6-Carbofuran 3G@1g /Plant	1250	1000	1.25
T7- Untreated control	3967	1000	3.96

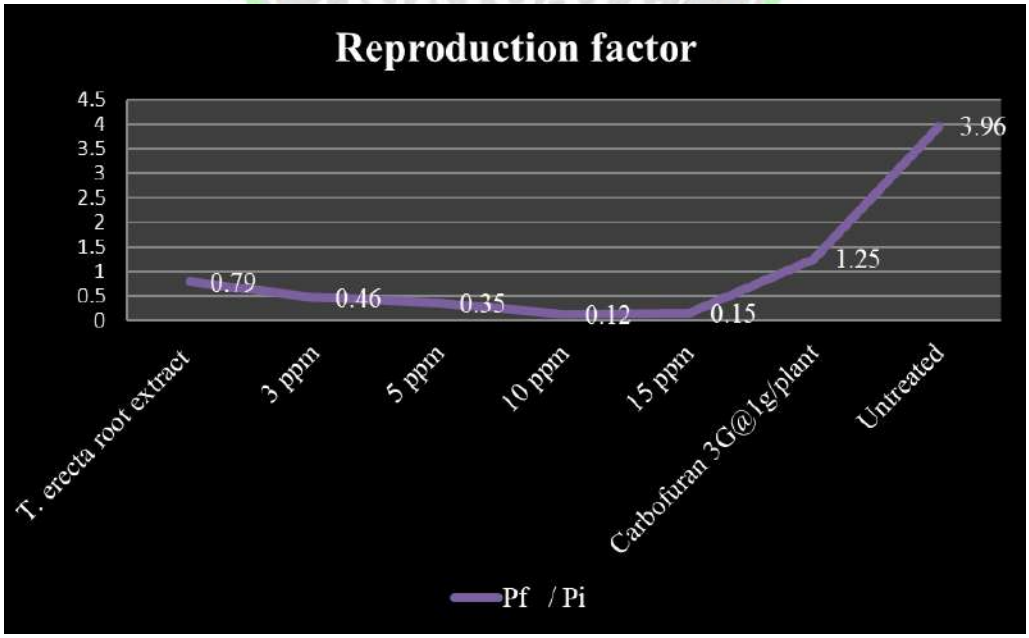

Fig. 3. Evaluation of Nematode populations of alpha-terthienyl nanofibre matrix under pot culture conditions

Reproduction factor

According to the results of reproduction factor (Rf) of *M. incognita*, the concentration of nanofibre formulation @ 10ppm has shown less reproduction factor i.e., 0.12 (Table-3, , Figure - 3).

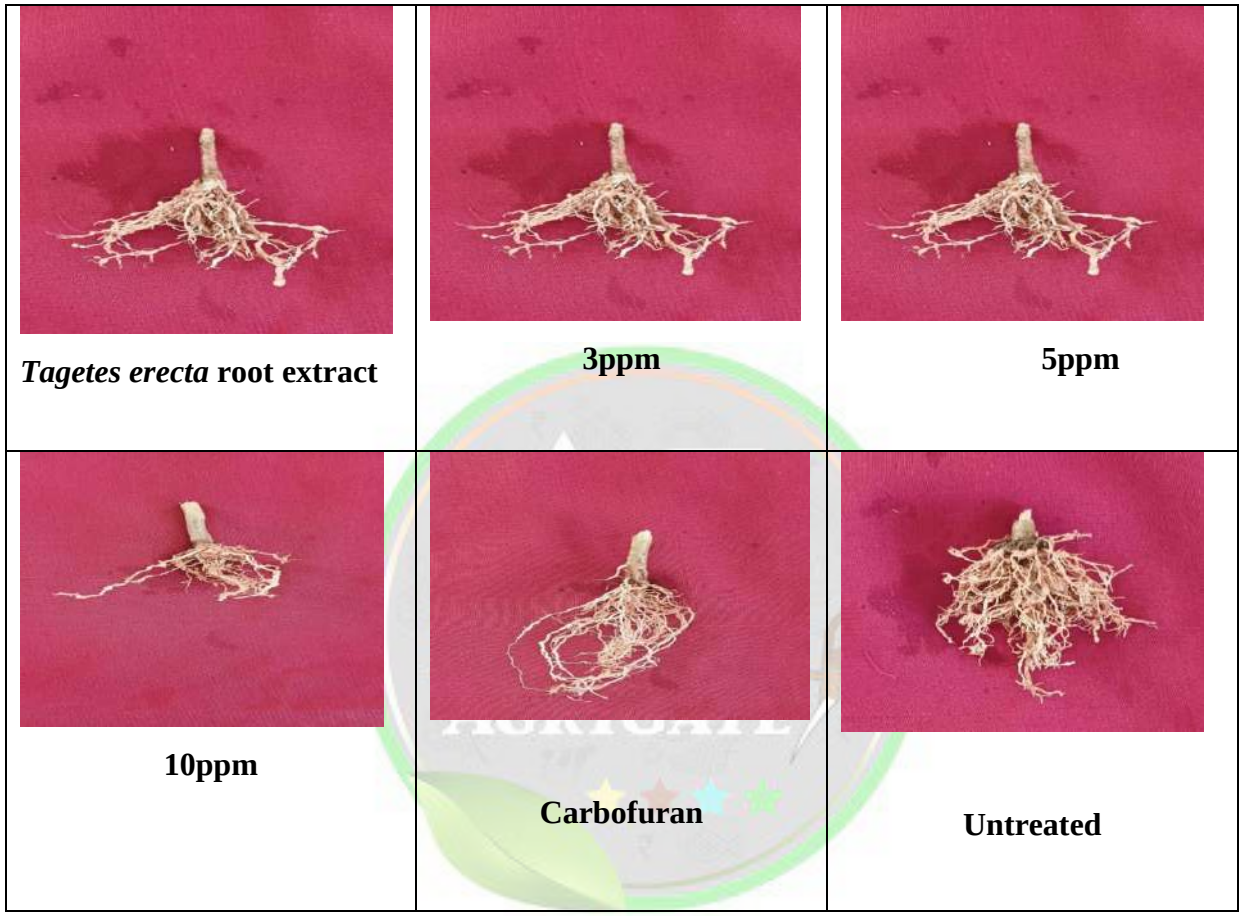

Plate -1 Evaluation of Nematode populations of alpha-terthienyl nanofibre matrix under pot culture conditions

Discussion

Based on the experimental results presented, the alpha-terthienyl infused nanofibre formulation demonstrated exceptional efficacy as a dual-purpose agricultural treatment, simultaneously promoting plant growth and controlling nematode populations. The 10 ppm concentration emerged as the optimal treatment level, achieving remarkable results across all measured parameters - enhancing shoot length by 57% (42.26 cm vs 26.89 cm control), increasing shoot weight to 34.46 g, maximizing root development (18.46 cm length, 32.68 g weight), while dramatically reducing nematode populations from 3950 in untreated controls to

just 118. This concentration also minimized root-knot nematode reproduction with a reproduction factor of only 0.12 and reduced adult female populations from 16 to just 1 per 5g root sample. The dose-response relationship observed across treatments (3, 5, 10, and 15 ppm) indicates that while higher concentrations maintained effectiveness, the 10 ppm level achieved the optimal balance between growth promotion and nematode suppression, suggesting this nanotechnology-based approach offers a promising sustainable solution for integrated pest management in tomato cultivation that addresses both plant nutrition and pest control simultaneously (Daoush *et al.*, 2023)

Conclusion

The results clearly indicate that α-terthienyl infused nanofibre formulation is an effective and environmentally sustainable approach for managing root-knot nematodes in tomato. Among the tested concentrations, 10 ppm proved to be the most efficient, significantly enhancing plant growth parameters while drastically reducing nematode population, gall formation, and reproduction factor. Compared to chemical control, the nanofibre formulation demonstrated superior performance with reduced ecological risk. Although higher concentrations maintained effectiveness, the 10 ppm level provided the optimal balance between efficacy and resource use. This study highlights the potential of nanotechnology-based botanical formulations in integrated pest management. Future research should focus on field-level validation, long-term environmental impact, and large-scale application strategies to promote adoption in sustainable agriculture.

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FRP BOAT CONSTRUCTION: MATERIALS, PROCESSES AND PERFORMANCE

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Abstract

Fishing communities around the world depend on reliable, sea-worthy vessels, and in recent decades, Fibre Reinforced Plastic (FRP) has become the preferred material, replacing traditional timber and metal boats. This article examines the lifecycle of FRP fishing boat construction, covering key materials such as glass fibre reinforcements (CSM and woven roving), polyester, vinyl ester and epoxy resins, gelcoat, and core materials like balsa and PVC foam. The construction process follows a systematic sequence including Mold preparation, application of release agents, gelcoat layering, fibre lamination, internal reinforcement, curing, trimming, and final assembly, typically completed within four to seven days. The study highlights major advantages of FRP boats, such as corrosion resistance, high strength-to-weight ratio, and good surface finish, while also addressing limitations like high initial costs, chemical hazards, osmotic blistering, and disposal issues. Maintenance and repair practices are also discussed to improve vessel lifespan, concluding that FRP remains a practical and cost-effective material when properly managed.

Introduction

Fibre Reinforced Plastic, universally known in the maritime industry as FRP, has fundamentally transformed the way fishing boats are designed, built, and operated around the world. Composed of a polymer matrix (typically polyester or epoxy resin) reinforced with glass

fibres, FRP is a composite material that delivers an exceptional combination of strength, light weight, corrosion resistance, and longevity.

The global fishing industry, encompassing coastal artisanal fishers as well as large commercial fleets, has embraced FRP boats as the standard platform for their work. This shift was driven by two fundamental economic forces that is the escalating cost and declining availability of good boatbuilding timber, and the relative ease with which FRP boats could be manufactured at scale with less-skilled labour compared to traditional wooden boatbuilding. In South Asia, for example, FRP boatbuilding was introduced in the 1960s, gained rapid popularity through the 1970s and 1980s, and today dominates the construction of new fishing craft in countries such as India, Sri Lanka, and Bangladesh.

❖ **Materials Used in FRP Boat Construction**

1. Glass Fibre Reinforcement

The reinforcement is the structural backbone of the FRP laminate. Glass fibre is by far the most widely used reinforcement in fishing boat construction due to its relatively low cost, good tensile strength, and compatibility with polyester resins. Glass is processed into fine filaments that are then woven, chopped, or otherwise arranged into various product forms:

•**Chopped Strand Mat (CSM):** Short, randomly oriented glass fibres bonded together with a binder. CSM is easy to apply into curved moulds, provides good inter-laminar bonding, and is often used as the first laminating layer behind the gelcoat.

•**Woven Roving (WR):** Bundles of continuous glass filaments woven into a heavy fabric. Woven roving delivers significantly higher strength than CSM and is used in the structural layers of the hull laminate, commonly alternated with CSM layers.

•**S-Glass**: A higher-performance glass offering approximately 25-40% greater tensile strength than E-glass. It is used in applications where weight saving and extra strength are prioritised, though at higher cost**.**

2. Resins-

The resin acts as the matrix, binding the fibres together, transferring loads between them, and protecting them from the marine environment. The most common resins in fishing boat construction are:

- **Unsaturated Polyester Resin**: The workhorse of the industry. Polyester is affordable, easy to work with, cures rapidly with a catalyst (typically MEKP) and an accelerator,

and produces adequate mechanical properties for most fishing boat applications. However, polyester is somewhat susceptible to moisture absorption over time.

- **Vinyl Ester Resin**: A modified form of polyester with improved resistance to water permeation and chemical attack. Vinyl ester is commonly used as a barrier layer immediately behind the gelcoat to reduce osmotic blistering risk.
- **Epoxy Resin**: Offers the best mechanical properties and the lowest moisture permeability of the three resin types. Epoxy systems are used in high-performance and structural-repair applications but are significantly more expensive than polyester.

3. Gelcoat

Gelcoat is a pigmented, resin-rich coating applied to the mould surface as the very first layer of the laminate. It forms the exterior surface of the finished boat, providing a smooth, glossy, weatherproof finish. Gelcoat is typically 0.4-0.6 mm thick and is formulated with additives to resist UV degradation, surface abrasion, and limited water permeation. The choice and quality of gelcoat significantly influence the long-term appearance and durability of the hull.

4. Core Materials

For larger vessels and areas where stiffness is the primary requirement, sandwich construction employs a lightweight core material laminated between two FRP skins. Common core materials include end-grain balsa wood (excellent stiffness-to-weight ratio, widely used in decks), PVC foam (good moisture resistance), and polyurethane foam (available in fire-retardant grades suitable for buoyancy compartments). The sandwich structure acts analogously to an I-beam, with the skins carrying bending stresses and the core providing shear resistance.

❖ **Construction Procedure**

The construction of an FRP fishing boat is a methodical, staged process. Thorough planning before the first material is laid is essential: the design must be finalised, the mould built, and the correct environmental conditions established in the workshop. The fundamental tool of FRP production is the female mould, and the quality of everything that follows depends on its accuracy.:

1. **Preparing the Mold**

The first and most critical step in constructing an FRP fishing boat is preparing the Mold. Two types of Molds are used the Deck Mold (also called the Male Mold, forming the upper part) and the Hull Mold (also called the Female Mold, forming the lower part). These molds define the

shape and size of the final boat, which comes in different standard sizes along like 29 ft, 32 ft, and 34 ft in length.

2. **Applying Wax and PVA Release Agents**

Once the mold is ready, a layer of wax is applied across its entire surface in three coats. This wax acts as a release agent, preventing the fibre mat from sticking permanently to the mold. After waxing, a PVA solution (a gel mixed with water) is also applied for the same purpose, ensuring the finished boat can be cleanly separated from the mold once it has cured and hardened.

3. **Gel Coat and Pigment Application**

After the release agents are in place, a gel coat is applied over the wax. The gel coat serves multiple functions it provides a smooth, glossy outer finish and also acts as a binding base for the fibre layers that follow. At this stage, pigment is added to give the boat its chosen colour. Fishermen typically select different colors for the bottom, centre, and top sections of the boat. Cobalt is mixed into the gel coat to help speed up the drying process.

4. **Laying the Fibre Glass Layers**

This is the heart of the boat-building process. Fibre glass mat (known as Chopped Strand Mat or CSM), liquid resin, and a catalyst are applied in alternating layers and carefully rolled out to remove air pockets. The deck of the boat is typically built up using six layers in the following order: two layers of CSM, one layer of woven roving (sometimes two, depending on strength requirements), and two more layers of CSM. Chalk powder is used between layers to ensure tight bonding, while the catalyst (Methyl Ketone Peroxide) and an accelerator are used to trigger and speed up the hardening process.

5. **Fixing the Ribs for Structural Strength**

Once the basic shell layers are laid, internal ribs are constructed using the mold and then fixed into the hull structure. Wooden blank structures known locally as *Vanghu kaal* or *Thadakulipalakai* are used to keep the deck properly fitted and to add strength during this stage. It is important to note that these wooden supports are used only in the hull structure and not in the deck portion. Chalk powder, accelerator, and resin (GP resin) are used to bond the ribs firmly in place.

6. **Curing, Trimming, and Final Assembly**

After all the layers and ribs are set, the parts are left to cure and dry for approximately one to two

days. Once fully dried, the boat components are carefully removed from the mold. Any excess material along the edges is trimmed away for a clean finish. Steel GI pipes of ¼ and ¾ inch sizes are then fitted between the ribs to add further structural support. Finally, the hull and deck are

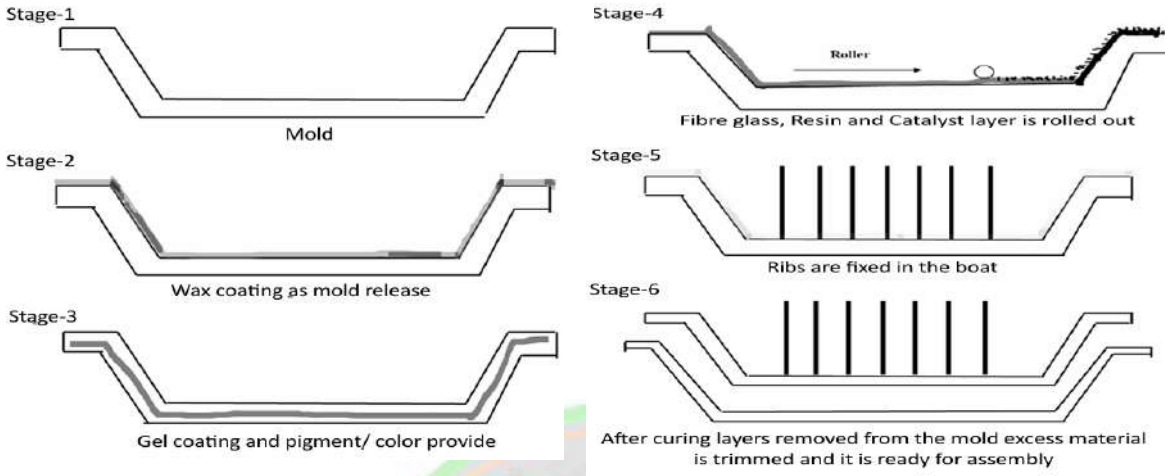

Figure 1 Procedure for Making FRP Boat Construction

Source: Nadu, T. (2021). FRP Fishing Boat Construction in Nagapattinam Coast, Tamil Nadu

joined together using GP resin, chalk powder, catalyst, and accelerator, completing the assembly of the boat and making it ready for use. The diagram above summarizes the full construction flow at a glance, from Mold preparation through to the finished boat. Each stage feeds directly into the next, with the final curing and assembly completing the process in around 4–7 days total per boat.

Figure 4 a. Mould Surface Preparation b. Gelcoat Application c. Mould Lamination d. Mould Framework e. Fixing Surface Finishing f. Final Mould Ready

Source: McVeagh, Jhon, et al. "Training manual on the construction of FRP beach landing boats." (2010).

Benefits of FRP Fishing Boats

1.Corrosion and Rot Resistance-Unlike timber, FRP does not rot, and unlike steel or aluminium, it does not corrode in the marine environment. This is perhaps the single most significant practical advantage for fishing boat operators. The hull requires no anti-corrosion treatments, no caulking, and does not absorb water the way timber planking does.

2.Strength-to-Weight Ratio- FRP delivers excellent structural strength relative to its weight. A well-designed FRP hull is lighter than an equivalent steel hull and often lighter than a comparable timber hull. Reduced hull weight directly translates into improved payload capacity, better fuel efficiency, higher speed, and improved sea-keeping**.**

3.Hull Form Precision and Repeatability- Because every production hull is moulded from the same female mould, FRP construction delivers a level of dimensional accuracy and repeatability that is impossible to achieve with traditional timber boatbuilding. Every boat from a given mould has identical hull lines, ensuring consistent performance characteristics. This is particularly valuable for fishing fleets where operators need predictable, comparable vessels.

Figure 2 a. Lofting & Layout Preparation, b. Frame Cutting & Preparation, c. Frame Assembly on Jig

4.Hydrodynamic Surface Quality –

Figure 3 a. Alignment Checking b. Complete Frame Structure c. Hull Skin Installation Surface Fairing & Putty Work d. Painting & Finishing of Plug

The smooth, fair surface produced by the mould and the polished gelcoat reduces hull resistance as the boat moves through water. A smooth hull requires less engine power to achieve a given speed compared to a rougher surface, contributing directly to fuel savings. Anti-fouling bottom paint applied over the gelcoat below the waterline prevents marine growth that would otherwise increase drag significantly.

5.Design Versatility - By modifying the resin chemistry, fibre type and orientation, and laminate schedule, the designer can tailor the FRP's properties to a wide range of applications. The material can be made heat-resistant, resistant to acids and fuels (important for fish-hold linings and machinery compartments), or optimised for impact resistance in beach-landing vessels.

6.Mass Production Capability - Once the mould investment has been made, FRP boats can be produced efficiently in series. A single well-maintained mould can produce dozens, sometimes hundreds, of hulls over its working life, spreading the tooling cost across many units. Labour requirements per boat are generally lower than for equivalent timber vessels, and the skill threshold for basic laminating operations is more accessible, broadening the pool of available workers for boatyards.

7.Fish-Holding Hygiene - FRP fish holds can be moulded with smooth, impermeable surfaces that are easy to clean, resistant to the acids and oils present in fish, and do not impart taste or odour. These qualities are difficult to achieve with timber. The material can be formulated specifically for contact with food products, making FRP an excellent choice for the fish-holding compartments that are central to a commercial fishing vessel's function and the quality of its catch.

❖ **Disadvantages of FRP Fishing Boats**

High Initial Tooling Investment

The greatest economic barrier to FRP boatbuilding is the cost of producing the plug and female mould before a single production boat can be built. For a typical fishing boat, the plug and hull mould alone represent a very substantial investment in skilled labour and materials. For larger decked vessels requiring separate deck, wheelhouse, and interior moulds, the pre-production investment is even greater. This cost structure heavily favours builders who can spread the tooling cost across a large production run, and disadvantages operators who want to build only one or two boats of a given design.

Environmental and Health Hazards During Construction

The chemicals involved in FRP production, particularly styrene emissions from polyester resins and the peroxide catalysts, are hazardous to workers. Prolonged exposure to styrene vapour can cause respiratory, neurological, and other health problems. Adequate ventilation, appropriate personal protective equipment (respirators, gloves, eye protection), and careful chemical handling are essential.

Osmotic Blistering

One of the most common long-term defects in FRP boats is osmotic blistering — dome-shaped protrusions that form on the underwater hull when water penetrates the gelcoat and reacts with impurities in the laminate, creating internal pressure that distorts and ruptures the surface. While blistering rarely causes immediate structural damage, it reduces the boat's appearance and resale value, and if left untreated can progress to delamination and serious structural compromise, particularly in older polyester-resin hulls kept continuously immersed.

Fire Risk

Polyester and vinyl ester resins used in FRP hulls are flammable and burn readily once ignited, releasing toxic smoke though in practice this is no worse than the risk posed by traditional timber boats. Unlike steel hulls, FRP offers no inherent fire resistance, and while fire-retardant resin formulations and intumescent coatings exist, they are rarely fitted as standard on basic fishing vessels, making careful fuel storage and engine compartment fire prevention especially critical on FRP boats.

Difficult and Costly Structural Repairs

Minor FRP damage is easy to fix, but major issues like fractures, delamination, or osmotic blistering are expensive and require skilled labour and specialized materials. In remote fishing areas, proper repair resources may be unavailable, and poor repairs with incompatible materials can weaken the structure and risk failure at sea.

End-of-Life Disposal

FRP is not biodegradable and is difficult to recycle. Old, decommissioned FRP fishing boats have become a significant waste management challenge in countries with large fleets. Unlike timber boats that decompose naturally or steel boats that can be melted down and recycled, FRP hulls resist almost all forms of environmental degradation and cannot be economically repurposed in most cases.

❖ Maintenance of FRP Fishing Boats

Properly maintained FRP fishing boats can provide decades of reliable service. The material's corrosion resistance reduces some traditional maintenance burdens, but a structured maintenance regime remains essential for safety, performance, and longevity.

1. Regular Cleaning

The hull above the waterline should be washed down with fresh water after every fishing trip to remove salt, fish residues, oil, and biological matter. Salt crystals are mildly abrasive and can dull the gelcoat over time if allowed to accumulate and dry repeatedly. The fish hold and bilge should be similarly flushed and cleaned to prevent the build-up of organic material that creates persistent odours and can degrade the laminate surface over time.

2. Gelcoat Care and Polishing

Gelcoat is the outer protective layer of the hull and needs regular care. Over time, sunlight can cause oxidation, making it look dull and chalky. This can be removed by polishing with a cutting compound, followed by applying wax to restore shine and protection. Regular maintenance not only improves appearance but also extends the life of the hull. It is best to do this at least once a year, or more often in hot, sunny climates.

3. Anti-Fouling Bottom Paint

The underwater hull must be protected against marine fouling: the accumulation of barnacles, algae, and other organisms that increase drag, reduce speed, and raise fuel consumption. Anti-fouling bottom paint is applied annually (or as specified by the paint manufacturer) to the hull below the waterline. The boat must be hauled out, the hull surface inspected for blistering, then new anti-fouling applied over an appropriate primer system.

4. Annual Haul-Out Inspection

An annual haul-out is strongly recommended for all fishing boats spending extended periods afloat. During haul-out, the entire underwater hull should be carefully inspected for:

- ✓ **Osmotic blisters:** Inspect the hull surface immediately after hauling, before blisters shrink. Circle detected blisters with a waterproof marker for assessment.
- ✓ **Impact damage**: Check the keel, bilge keels, and transom corners for cracks, crushing, or delamination resulting from grounding or collision.
- ✓ **Delamination**: Sound the hull by tapping firmly with a rubber mallet or wooden block. A hollow, drum-like sound indicates delamination, where laminate layers have separated.

- ✓ **Through-hull fittings**: Inspect all seacocks, drain plugs, and through-hull fittings for signs of weeping, corrosion of metallic components, or cracking of the surrounding laminate.

❖ **Repairing FRP Fishing Boats**

1. Minor Gelcoat Repairs

Surface scratches, chips, and small impact marks confined to the gelcoat layer and not penetrating to the reinforcement fibres are straightforward to repair. The damaged area is cleaned with acetone to remove contaminants, the edges of the damage are feathered with fine sandpaper, and pigmented gelcoat paste matched to the original colour is applied and allowed to cure. The repair is then wet-sanded progressively through grits from 120 through to 600 and polished to match the surrounding surface. UV-induced colour drift in the original gelcoat means that exact colour matching becomes more difficult as the boat ages.

2. Structural Laminate Repair

Structural damage that penetrates through the gelcoat into the fibre reinforcement requires proper repair. The damaged area must be ground out to remove all loose, cracked, or delaminated material, with the edges scarfed at a 12:1 ratio for effective load distribution. The repair area should be thoroughly dried, as wet laminate results in a weak bond. Epoxy resin is strongly preferred over polyester for its superior adhesion and waterproofing properties on cured laminate. Matching layers of fibre reinforcement are then applied with epoxy, building up to the original thickness while consolidating each layer. Once cured, the surface is faired, primed, and finished with gelcoat or paint to match the surrounding area.

3. Osmotic Blister Repair

Blister repair is a common maintenance task for FRP fishing boats that requires careful and systematic work. The boat is first hauled out, cleaned, and blisters are identified and marked before they shrink. Each blister is then opened carefully to release the acidic fluid, and the damaged area is ground to expose clean laminate. The hull is dried thoroughly in warm, low-humidity conditions, which may take several weeks for severe cases. Once dry, the cavities are filled with epoxy fairing compound, cured, and sanded smooth. The repaired surface is then protected by applying 4–6 coats of epoxy barrier coating to prevent moisture ingress. Finally, anti-fouling paint is applied to protect against marine growth. Epoxy resin is preferred over polyester due to its better waterproofing and strong adhesion, especially in tropical waters.

4. **Delamination Repair**

Delamination is typically identified by the hollow sound produced when sounding the hull. Small, stable delaminations not affecting structural areas may be managed by monitoring without immediate repair. Active delaminations, or those in structurally critical locations, require either injection of epoxy resin into the void (for tight delaminations) or full removal and re-lamination of the affected area. Delaminations in the hull bottom or keel area must be treated promptly as these carry primary structural loads.

Conclusion

FRP (Fiberglass Reinforced Plastic) has transformed fishing boat construction and become the most widely used material due to its strength, durability, corrosion resistance, and suitability for harsh marine conditions. The construction process involves a well-structured sequence of steps, including proper mold preparation, application of release agents and gelcoat, layering of materials like CSM and woven roving, and final assembly, all of which require precision and skilled workmanship to ensure a long-lasting vessel. Although FRP offers many advantages, challenges such as high initial mold costs, health risks from chemical resins, osmotic blistering, and disposal issues must be carefully managed. Despite these limitations, a well-built and properly maintained FRP boat provides a reliable and long-term investment, enhancing the safety, productivity, and livelihoods of fishing communities, especially along coastal regions like Tamil Nad

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Volume: 06 Issue No: 04

CONSTRUCTED WETLANDS: NATURE-BASED SOLUTIONS FOR WASTEWATER TREATMENT AND ENVIRONMENTAL RESTORATION

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Abstract

Constructed wetlands (CWs) are engineered systems designed to replicate the water-purification functions of natural wetlands. Over the past four decades, they have emerged as a cost-effective, energy-efficient, and ecologically sound alternative to conventional wastewater treatment technologies. This essay provides a comprehensive overview of the types, mechanisms, design principles, applications, advantages, limitations, and future prospects of constructed wetlands. Drawing on a broad body of peer-reviewed literature, it argues that constructed wetlands represent a pivotal tool in sustainable water resource management, particularly as global water scarcity and pollution intensify.

Introduction

Water is one of the most essential resources on Earth, yet its availability and quality are increasingly threatened by rapid urbanization, agricultural intensification, industrial development, and climate change. According to the United Nations Environment Programme (UNEP, 2021), approximately 2 billion people lack access to safe drinking water, and an estimated 80% of the world's wastewater is discharged into the environment without adequate treatment. This alarming reality underscores the urgent need for innovative and sustainable water treatment technologies.

Constructed wetlands have gained considerable attention in recent decades as nature-based solutions (NbS) for treating various types of wastewater, including domestic sewage, agricultural runoff, stormwater, and industrial effluents. Unlike conventional treatment plants that rely heavily on mechanical and chemical processes, constructed wetlands harness the combined biological, physical, and chemical processes occurring in soil, water, plants, and microorganisms to remove pollutants.

First developed in Germany in the 1960s by Dr. Kathe Seidel at the Max Planck Institute, constructed wetlands have since evolved into a diverse array of configurations deployed across every continent. Their appeal lies not only in their treatment efficacy but also in their capacity to provide ancillary ecosystem services such as biodiversity support, carbon sequestration, flood mitigation, and recreational opportunities.

Types of Constructed Wetlands

Constructed wetlands are broadly classified according to the flow regime of water and the type of vegetation employed. The three primary configurations are free water surface (FWS) systems, subsurface flow (SSF) systems, and hybrid systems.

Free Water Surface Wetlands

Free water surface (FWS) wetlands, also known as surface flow wetlands, closely resemble natural marshes. In these systems, wastewater flows above a gravel or soil substrate in a shallow basin. Emergent macrophytes such as Phragmites australis (common reed), Typha spp. (cattails), and Scirpus spp. (bulrushes) are typically planted in the substrate. The open water surface allows sunlight penetration, fostering algal growth and natural reaeration. FWS wetlands are particularly suitable for treating secondary or tertiary effluents and stormwater. They are widely used in North America and offer significant wildlife habitat value. However, they require large land areas and may produce odor and mosquito problems if poorly managed.

Subsurface Flow Wetlands

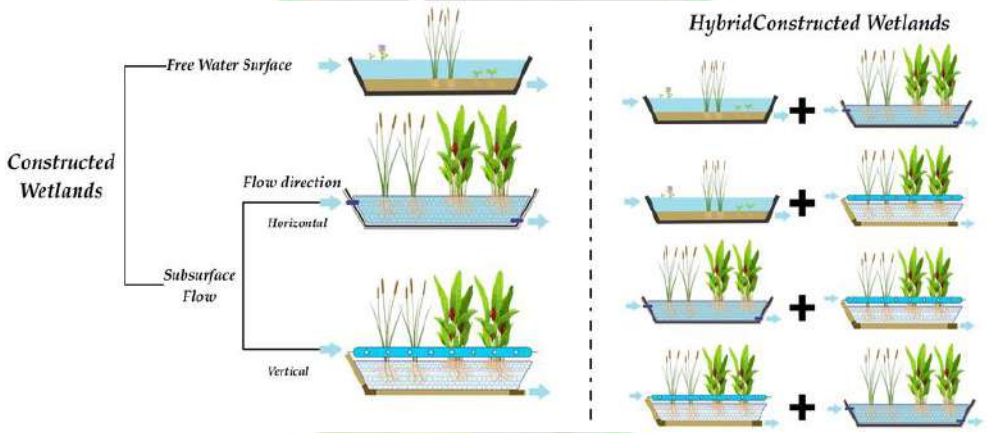
Subsurface flow (SSF) wetlands direct wastewater through a porous medium (gravel, crushed rock, or sand) below the surface. Depending on the direction of water movement, SSF systems are further divided into horizontal flow (HF-SSF) and vertical flow (VF-SSF) types.

In horizontal flow systems, wastewater enters at one end and flows horizontally through the gravel bed to an outlet at the opposite end. The predominantly anaerobic conditions in HF systems favor denitrification and sulfate reduction. Vertical flow systems, by contrast, receive

wastewater intermittently from the surface, which percolates downward through the substrate. This intermittent loading promotes nitrification owing to enhanced oxygen transfer. SSF systems are popular in Europe and developing countries because they present minimal odor and insect nuisance, occupy less land than FWS systems, and function well in colder climates due to insulation by the substrate.

Hybrid Systems

Hybrid constructed wetlands combine two or more CW types in series or parallel to exploit the advantages of each while compensating for individual limitations. A typical hybrid design pairs a VF-SSF system (for nitrification) with an HF-SSF system (for denitrification), achieving more complete nitrogen removal than either unit alone. Hybrid systems represent the current frontier in CW design and are increasingly favored for treating complex effluents and meeting stringent discharge standards.



Treatment Mechanisms

The efficacy of constructed wetlands in removing pollutants rests on a complex interplay of physical, chemical, and biological processes. Understanding these mechanisms is fundamental to optimizing design and performance.

Physical Processes

Physical processes in constructed wetlands include sedimentation, filtration, and adsorption. As wastewater flows through the system at low velocity, suspended solids settle by gravity in a process known as sedimentation. In SSF systems, the gravel or sand matrix acts as a physical filter, trapping particulate matter. Adsorption refers to the binding of pollutants, particularly phosphorus and heavy metals to the surfaces of substrate particles and organic matter.

Chemical Processes

Chemical processes include precipitation, ion exchange, and oxidation-reduction reactions. Phosphorus removal is largely driven by chemical precipitation with calcium, iron, and aluminum ions present in the substrate or water. Redox chemistry governs the transformations of nitrogen, sulfur, and metals: under aerobic conditions, ammonium is oxidized to nitrate (nitrification), while under anaerobic conditions, nitrate is reduced to nitrogen gas (denitrification) or ammonium (dissimilatory nitrate reduction to ammonium, DNRA).

Biological Processes

Biological processes constitute the most dynamic component of constructed wetland function. Microbial communities such as bacteria, archaea, fungi, and algae colonize the rhizosphere (root zone), substrate surfaces, and water column, collectively mediating the decomposition of organic matter, nutrient cycling, and pathogen die-off. Macrophytes play a pivotal dual role: they oxygenate the rhizosphere through radial oxygen loss (ROL), supporting aerobic microbial processes, and they take up nutrients nitrogen, phosphorus, and trace metals—into their biomass. Pathogen removal in constructed wetlands occurs through a combination of sedimentation, filtration, UV irradiation (in FWS systems), predation by protozoa, natural die-off, and antimicrobial exudates from plant roots. Removal efficiencies of 2–4 log units for fecal coliforms have been reported in well-designed systems.

Design Principles and Considerations

The design of a constructed wetland requires careful integration of hydraulic, ecological, and engineering principles to ensure that treatment targets are met efficiently and sustainably.

Hydraulic Design

Hydraulic retention time (HRT), hydraulic loading rate (HLR), and hydraulic conductivity of the substrate are the primary hydraulic design parameters. The HRT, the average time wastewater spends in the system, must be sufficient for treatment processes to occur. Typical HRTs range from 2 to 10 days for SSF systems. The HLR (volume of wastewater per unit wetland area per day) determines the surface area required and must account for evapotranspiration losses.

Substrate Selection

Substrate selection is critical for both hydraulic performance and pollutant removal. Gravel (10–20 mm diameter) is the most commonly used substrate in SSF systems, providing

good hydraulic conductivity and a large surface area for biofilm attachment. Modified substrates including zeolites (for ammonium adsorption), steel slag, and biochar have been incorporated into some designs to enhance specific removal processes.

Plant Selection

Vegetation selection depends on climate, the type of pollutants targeted, and aesthetic or biodiversity objectives. Phragmites australis is the most widely planted species globally due to its high productivity, extensive root system, and tolerance of fluctuating water levels and pollutant loads. Other commonly used species include Typha latifolia, Scirpus lacustris, and Iris pseudacorus. Native species are increasingly preferred over exotic ones to enhance biodiversity and reduce invasive species risks.

Pre-treatment and Post-treatment

Constructed wetlands typically require pre-treatment to remove coarse solids, grit, and high concentrations of suspended matter that could clog the system. Septic tanks, imhoff tanks, ponds, or primary clarifiers serve this purpose. Post-treatment may include disinfection (chlorination, UV, or ozonation) where direct water reuse or discharge to sensitive receiving waters is intended (USEPA, 2000).

Applications of Constructed Wetlands

Constructed wetlands have been applied across a remarkably diverse range of settings and wastewater types, demonstrating their versatility as a treatment technology.

Municipal Wastewater Treatment

Municipal wastewater treatment is the most common application of constructed wetlands globally. Thousands of systems operate in Europe, North America, Australia, and Asia, serving rural communities and small towns where centralized infrastructure is impractical. In Europe alone, more than 50,000 constructed wetlands have been constructed for domestic wastewater treatment. These systems typically achieve BOD_5 removal efficiencies of 70–95% and suspended solids removal of 60–90%.

Agricultural and Livestock Runoff

Agricultural nonpoint source pollution characterized by high concentrations of nitrogen, phosphorus, and pesticides poses significant threats to receiving water bodies. Constructed wetlands positioned at field margins, drainage ditches, or outlet points intercept agricultural runoff and remove nutrients, sediments, and agrochemicals. Studies in Denmark, Sweden, and

the United States have demonstrated nitrogen removal efficiencies of 40–80% in agricultural CW applications.

Stormwater Management

Urban stormwater is a major vector of pollutants including heavy metals, hydrocarbons, pathogens, and nutrients into waterways. Constructed wetlands are increasingly integrated into sustainable urban drainage systems (SUDS) and low-impact development (LID) frameworks. They provide retention, infiltration, and treatment of stormwater while simultaneously offering green infrastructure amenities such as habitat, recreation, and aesthetic enhancement.

Industrial and Mine Wastewater

Constructed wetlands have been applied to treat acid mine drainage (AMD), landfill leachate, food processing effluents, and pulp and paper mill wastewaters. AMD treatment is a particularly challenging application due to the acidic pH and high concentrations of dissolved metals (iron, manganese, zinc, arsenic). Passive treatment wetlands using sulfate-reducing bacteria have demonstrated effective metal removal in several North American mining sites.

Ecological Restoration

Beyond wastewater treatment, constructed wetlands are increasingly designed as ecological restoration tools, re-establishing wetland habitats lost to drainage and land reclamation. The Florida Everglades restoration program, the Rhine delta restoration in the Netherlands, and the Murray-Darling Basin rehabilitation in Australia exemplify large-scale initiatives in which constructed and restored wetlands play a central role in recovering biodiversity, improving water quality, and restoring ecosystem services.

Advantages and Limitations

Advantages

Constructed wetlands offer a cost-effective alternative to conventional treatment systems, with lower construction costs and minimal operation and maintenance requirements due to low energy use and absence of complex machinery. They can achieve treatment at 50–80% of the cost of traditional systems, especially in rural areas. Ecologically, they provide valuable habitats for diverse flora and fauna and contribute to carbon sequestration through plant biomass and peat formation. Socially, constructed wetlands enhance landscape aesthetics, support recreation, and are well-suited for low- and middle-income regions due to their simplicity and low dependence on skilled labor and electricity.

Limitations

Constructed wetlands have notable limitations. A primary constraint is their large land requirement, making them unsuitable for densely populated or land-scarce areas. Their performance can be variable, influenced by seasonal temperature changes, influent fluctuations, hydraulic issues, and substrate clogging. In colder climates, reduced microbial activity and plant growth lower treatment efficiency, while long-term operation may require maintenance such as substrate replacement. Nutrient removal, particularly nitrogen and phosphorus, may be incomplete in single-stage systems. Phosphorus saturation can lead to internal loading, and effective nitrogen removal requires careful balance of aerobic and anaerobic conditions.

Emerging Trends and Future Directions

The field of constructed wetlands is rapidly advancing with innovations in engineering and environmental science. Intensified systems using aeration, recirculation, and intermittent operation significantly enhance treatment efficiency, particularly improving nitrogen removal to levels comparable with conventional systems. Constructed wetlands are also being explored for removing emerging contaminants such as pharmaceuticals, personal care products, endocrine disruptors, and microplastics through processes like sorption, photodegradation, and microbial transformation. Integration with microbial electrochemical technologies, such as microbial fuel cells, enables simultaneous wastewater treatment and bioelectricity generation. Additionally, smart monitoring systems using sensors, IoT, and machine learning are improving performance optimization and system reliability.

Conclusion

Constructed wetlands represent an effective integration of ecological processes and engineering design, offering sustainable treatment of diverse wastewaters while providing ecosystem services such as biodiversity support and carbon sequestration. Their low energy demand and simple operation make them highly relevant under current climate and resource challenges. However, limitations such as large land requirements, performance variability, and incomplete removal of some nutrients and emerging contaminants remain important concerns, highlighting the need for continued innovation in design and process intensification. With advances in hybrid systems, aeration, microbial technologies, and digital monitoring, constructed wetlands are emerging as a key nature-based solution for future sustainable water management.

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PROPULSION SYSTEMS IN FISHING VESSELS: EFFICIENCY AND PERFORMANCE

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Abstract

Marine propulsion systems are the backbone of fishing vessel operations, converting engine power into thrust to enable efficient movement through water. This paper examines the working principles of propulsion systems, including engine power generation, transmission components, reduction gear mechanisms, and propeller operation. It also highlights various propeller types, cavitation phenomena, and the importance of maintenance for optimal efficiency. The study emphasizes how efficient propulsion enhances fuel economy, operational performance, and safety in fishing activities. Understanding these systems is essential for improving vessel productivity and sustainability in modern fisheries.

1. Introduction

Fishing vessels rely heavily on efficient propulsion systems to operate effectively in diverse marine conditions. A propulsion system converts the mechanical energy generated by the engine into thrust, allowing the vessel to move through water. Modern fishing boats use advanced propulsion technologies to improve fuel efficiency, maneuverability, and operational reliability. The system typically consists of an engine, gearbox, shafting arrangement, and propeller. Each component plays a crucial role in transmitting power efficiently while minimizing energy losses. With increasing fuel costs and environmental concerns, optimizing propulsion systems has become essential for sustainable fishing practices. This study provides a

detailed overview of propulsion components, working mechanisms, and their importance in fishing operations.

2. Marine Propulsion Systems

Marine propulsion systems are essential for powering vessels by converting engine energy into thrust to move efficiently through water. These systems vary depending on engine types, such as diesel engines and gas turbines; however, the primary objective remains the same: to transmit power effectively from the engine to the propeller. Efficient power transmission is critical for achieving optimal performance, improved fuel efficiency, and extended machinery life. Any inefficiencies may lead to increased fuel consumption, reduced performance, and higher maintenance costs.

3. Engine Power Generation

Marine engines play a vital role in providing the power necessary to propel ships. These engines primarily come in two types: Diesel engines and Gas Turbines. Diesel engines are commonly used in larger vessels due to their efficiency and durability, while gas turbines are favoured for their higher power-to-weight ratio and speed. Mechanical energy in marine engines is generated through combustion. In diesel engines, the combustion of fuel and air inside the cylinders creates high-pressure gas, which forces the pistons to move. This movement generates mechanical energy, which is then transferred to the crankshaft.

The **crankshaft** is a critical component in the power generation process. It converts the linear motion of the pistons into rotational energy, which is necessary to drive the ship's propeller. This rotational energy, once converted, is transmitted through various systems, ultimately reaching the propeller and enabling the ship to move efficiently through water.

4. Power Transmission Components

Power transmission from the engine to the propeller involves several key components that work in harmony to ensure smooth and efficient operation. The main components in the transmission system such as **gearbox**, **clutch**, and **shafting system**.

Gearbox:

The gearbox plays a crucial role in reducing the high engine RPM to a suitable level for the propeller to operate efficiently. This reduction in speed ensures that the propeller can generate the necessary thrust without overworking the engine or propeller.

Clutch:

The clutch allows for smooth engagement and disengagement between the engine and the propeller. It ensures that power is transmitted only when needed, helping to protect the engine and transmission components from sudden jolts or excessive wear.

Shafting System:

The shafting system transfers the rotational power from the engine, through the gearbox and clutch, to the propeller. It is vital for maintaining alignment and transmitting power efficiently to the propeller.

5. Shafting System and Couplings

The **shafting system** is responsible for transmitting the rotational power generated by the engine to the propeller, playing a vital role in the overall propulsion process. The **main shaft** connects the engine to the propeller, transferring mechanical energy through the entire power transmission system. To maintain proper alignment and power flow, **couplings** are used to connect sections of the shaft. There are two types of couplings:

Flexible Couplings:

These allow for slight misalignments between shaft sections, absorbing vibrations and reducing stress on the system, which helps in minimizing wear and tear.

Rigid Couplings:

These provide a strong, inflexible connection between shaft sections where precise alignment is critical. They ensure maximum power transfer without energy losses due to misalignment.

Shaft bearings:

These are crucial in supporting the entire shafting system. They hold the shaft in place, reduce friction, and allow the shaft to rotate smoothly. Properly maintained bearings prevent misalignment, vibration, and wear, ensuring efficient power transmission and extending the lifespan of the propulsion system.

6. Reduction Gear Mechanism

Reduction Gear Mechanism plays a crucial role in marine propulsion systems by optimizing the speed between the engine and the propeller. Here's how the mechanism works, types of reduction gears, and the benefits of using them in marine engines.

6.1. How the Gearbox Reduces Engine Speed for Optimal Propeller Speed

Marine engines typically operate at high speeds, which are not suitable for direct driving of the propeller. A **reduction gearbox** reduces the engine speed to match the optimal rotational speed required by the propeller for efficient propulsion. This process enhances the thrust generated by the propeller, which increases the ship's overall performance. The gearbox works by employing gears of varying sizes to step down the engine's high RPM to a lower, more efficient RPM for the propeller.

6.2. Types of Reduction Gears Used in Marine Propulsion Systems

There are several types of reduction gears used in marine engines, each with unique characteristics suited for different propulsion requirements:

Single Reduction Gears:

A simple gear arrangement that provides a one-step reduction in engine speed.

Double Reduction Gears:

Used in systems requiring more significant speed reduction. This setup involves two sets of gears to gradually lower the engine speed.

Planetary Reduction Gears:

A more compact and efficient gear arrangement, used in systems where space is a constraint, and higher power transmission is required.

Helical Gears:

These gears are Known for smoother and quieter operation due to the angled gear teeth, these gears are commonly used in marine applications for better efficiency and reduced noise.

6.3. Benefits of Using Reduction Gears in Marine Engines

Reduction gears offer several advantages in marine propulsion systems:

Improved Fuel Efficiency:

By reducing engine speed to match the propeller's optimal RPM, reduction gears enhance the fuel efficiency of the marine engine.

Extended Engine Life:

Operating the engine at a reduced speed prevents excessive wear, which prolongs the lifespan of the engine components.

Enhanced Propeller Performance:

The reduced speed allows the propeller to operate in its most efficient range, providing better thrust and reducing cavitation.

Noise Reduction:

Proper gear selection, especially with helical or planetary gears, ensures quieter operation, which is vital for both passenger comfort and reducing underwater noise pollution.

7. Propeller Operation

Propeller Operation is a fundamental aspect of marine propulsion, directly affecting the vessel's speed, maneuverability, and fuel efficiency. This guide explains how propellers convert rotational energy into thrust, the influence of propeller design on power efficiency, and the types of marine propellers commonly used in the industry.

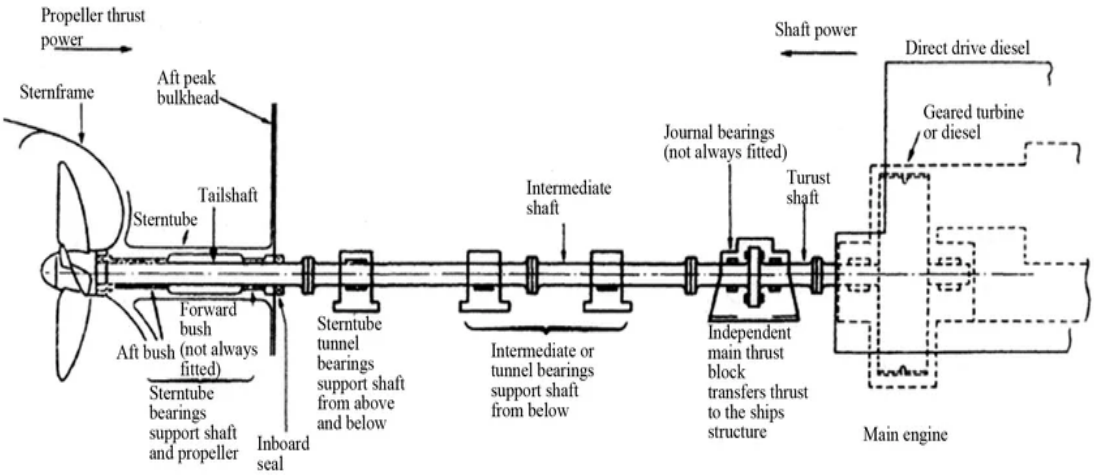

Fig 1. Propeller-Shaft-arrangement

Source: https://www.researchgate.net/figure/Propeller-Shaft-arrangement-6_fig2_321363316

7.1. How the Propeller Converts Rotational Energy into Thrust

A marine propeller functions by converting the **rotational energy** from the engine into **thrust**, propelling the vessel forward. As the propeller blades rotate, they create a difference in pressure between the front and rear sides of the blades. This pressure differential forces water backwards, creating a forward-moving thrust as per Newton's Third Law of Motion (action and reaction). The efficiency of this process depends on the design of the propeller, the number of blades, and the blade angle, which directly affect how much water is displaced and the speed at which the vessel moves.

7.2. Propeller Design and Its Influence on Power Efficiency

The design of a marine propeller plays a crucial role in determining its power efficiency. Several factors influence this:

Blade Shape and Size:

Larger blades can push more water but may cause more drag, while smaller blades reduce drag but may require higher engine RPM to generate the same amount of thrust.

Blade Pitch:

The pitch refers to the angle of the blades, which determines how much water is pushed during each revolution. A higher pitch propeller moves more water with each rotation, making it ideal for faster speeds, while a lower pitch propeller is better for heavy loads.

Based on Number of Blades:

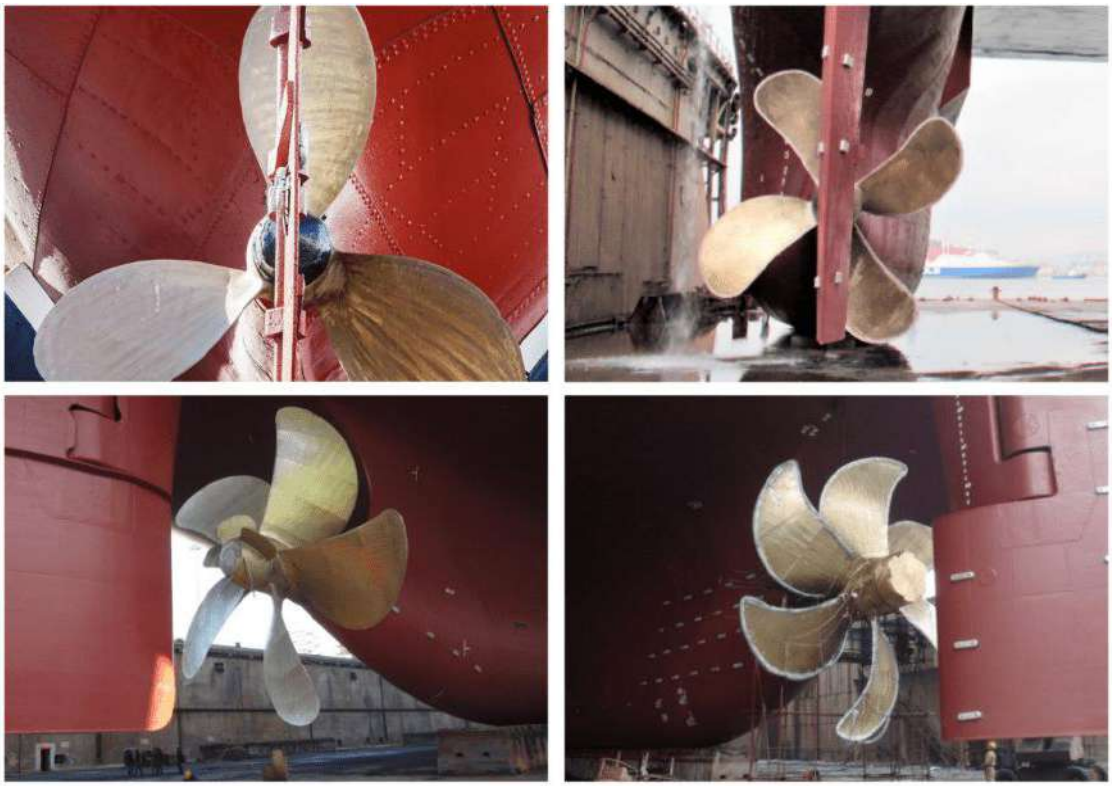

Fig 2. Propeller Blade Types

Source: https://shipnerdnews.com/propeller-types-construction-efficiency/

i) Three-Blade Propeller

The three-blade propeller is the most commonly used type in marine applications. It offers a balanced combination of performance, efficiency, and cost. This design provides

moderate thrust with smooth and stable operation, making it highly versatile. It is widely used in commercial ships, cargo vessels, and fishing boats due to its reliability. Compared to two-blade propellers, it ensures better fuel efficiency and smoother rotation; however, it produces slightly higher drag.

ii) Four-Blade Propeller

Four-blade propellers are larger and heavier, designed to deliver increased thrust and improved stability. They are especially suitable for vessels that require additional power and better control under varying sea conditions. These propellers are commonly used in large ships such as tankers and passenger vessels. Their advantages include reduced vibration, better handling, and improved performance in rough seas. However, they are more expensive and may cause increased drag, which can slightly reduce speed.

iii) Five-Blade Propeller

Five-blade propellers are used in heavy-duty applications where high power and smooth operation are essential. They provide excellent thrust and enhanced efficiency, particularly at lower speeds. These propellers are typically found in naval ships, luxury yachts, and large passenger vessels. Their main advantages include reduced vibration, improved comfort, and efficient performance under load. On the downside, they are costly to manufacture, heavier, and may generate more drag at higher speeds.

iv) Six-Blade (or More) Propeller

Propellers with six or more blades are relatively rare and are designed for specialized applications. They deliver maximum thrust, exceptional stability, and minimal vibration, making them ideal for military ships and submarines. These propellers perform efficiently under demanding conditions where precision and power are critical. However, their high cost, increased weight, and complex design limit their use to specific vessels rather than general applications. The right combination of these elements ensures optimal power transmission from the engine to the water, enhancing fuel efficiency and overall vessel performance.

7.3. Types of Marine Propellers

Marine propulsion systems use different types of propellers based on operational requirements:

Controllable Pitch Propellers (CPP):

The blade pitch in CPPs can be adjusted while in operation, offering greater control

over thrust and power output. This flexibility allows for better maneuverability, efficiency, and fuel savings, especially in vessels with variable speed or load demands. CPPs are commonly used in vessels where frequent changes in direction or speed are needed, such as ferries or tugs.

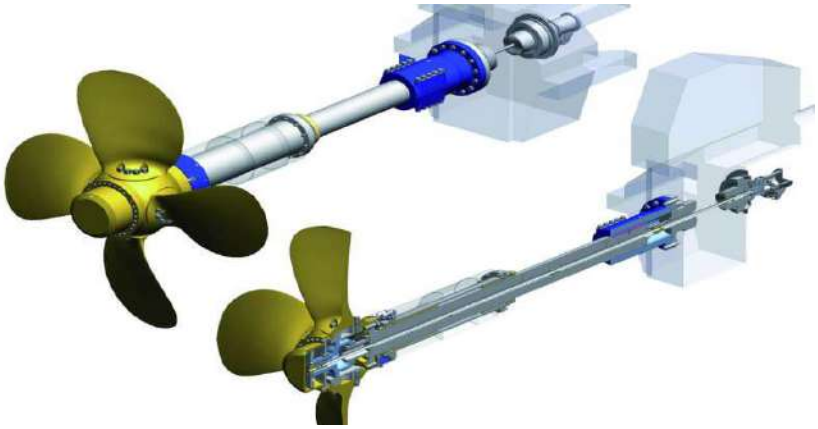

Fig 3. Controllable pitch propeller

Source: https://www.maucour.fr/en/cms/800HPV.jpg

Fixed Pitch Propellers (FPP):

These propellers have blades fixed at a set angle, meaning the blade pitch cannot be altered during operation. FPPs are simple, durable, and widely used in applications where consistent speed and direction are required. However, they are less flexible in adapting to changing operational conditions like varying speeds or loads.

Fig 4. Fixed pitch propeller

Source: https://www.researchgate.net/figure/Fixed-Pitch-Propeller_fig1_325813488

Ducted or Kort Nozzle Propeller

A ducted propeller, also called a Kort nozzle, is a propeller enclosed in a fixed cylindrical shroud. It improves thrust and efficiency, especially for heavily loaded vessels or those with small propeller diameter. It was developed by Luigi Stipa (1931) and later by Ludwig Kort (1934). The nozzle shape helps guide water flow and increase performance at low speeds (below 10 knots). It provides better stability and protection from debris, but reduces efficiency at higher speeds and may increase cavitation. It is commonly used in fishing boats, trawlers, and tugboats.

Fig 5. Kort Nozzle Propeller

Source: https://www.wartsila.com/encyclopedia/term/kort-nozzle

Twin or Multi-Propeller Configuration

Twin or multi-propeller configuration refers to the use of two or more propellers on a vessel instead of a single propeller. This arrangement improves thrust, maneuverability, and overall propulsion efficiency.

Fig 6. Twin or Multi-Propeller Configuration

https://syro.co/en/news/integrating-ship-propulsion-and-energy-models-digital-twin/

Twin propellers (twin-screw systems) are commonly used in fishing vessels, naval ships, and large commercial ships for better control and safety. Multi-propeller systems provide redundancy, ensuring continued operation even if one propeller fails. However, they increase construction cost, maintenance, and system complexity

Azimuth Thrusters (Podded Propellers)

Azimuth thrusters, also called Azi pods, are rotating propulsion units that provide both thrust and steering. They can turn 360°, allowing ships to move in any direction without a rudder. This gives vessels excellent maneuverability, especially in ports and narrow waterways. They are widely used in offshore vessels, tugs, and research ships for precise control. When combined with dynamic positioning systems, they help vessels maintain exact positions at sea. Despite higher cost and complexity, they are essential for modern marine operations.

Fig 7. Azimuth Thrusters

Source: https://www.onesteppower.com/post/azimuth-thrusters

8. What is Cavitation and How is it Formed on a Propeller?

8.1 What is Cavitation?

Cavitation is a phenomenon that occurs when the pressure on a liquid decrease to a point where vapor bubbles form, typically due to rapid changes in the fluid flow around an object, such as a propeller. When these vapor bubbles move into higher pressure areas, they collapse or implode violently, causing shock waves. This can lead to significant noise, vibration, and even physical damage to the surface of the propeller.

Fig 8. Blade Damaged by Cavitation Erosion

Source: https://www.britannica.com/technology/naval-architecture/Cavitation

8.2 How is Cavitation Formed on a Propeller?

Cavitation on a ship's propeller occurs when localized pressure on certain areas of the blade drops below the vapor pressure of water. Here's how it forms:

Pressure Differences on Blade Surfaces:

- A propeller generates thrust by pushing water backward, which propels the ship forward. This causes the pressure on the front side (leading edge) of the propeller blades to be higher, while the back side (trailing edge) experiences a lower pressure.
- When the pressure on the back side of the blade drops below the vapor pressure of the water, vapor bubbles begin to form.

Vapor Bubble Formation:

- In these low-pressure zones, the water turns into vapor, forming tiny bubbles or cavities (hence the term "cavitation"). These vapor bubbles occur because the local pressure is insufficient to keep the water in its liquid form.

Bubble Collapse:

- As the bubbles travel through the propeller's rotation and enter areas of higher pressure, they collapse or implode.
- The implosion of these bubbles creates intense shock waves, which can erode the surface of the propeller blades over time, causing pitting and surface damage.

High-Speed and Load Conditions:

- Cavitation is more likely to occur at high speeds or when a ship's propeller is overloaded (e.g., operating beyond its designed capacity). These conditions exacerbate the pressure differences on the propeller blades, increasing the risk of cavitation.

Consequences of Cavitation:

- Reduced propeller efficiency and loss of thrust.
- Increased vibration and noise.
- Long-term damage to the propeller, such as erosion, pitting, and blade fatigue, which can reduce its operational lifespan.

9. Transmission Efficiency and Maintenance

Transmission efficiency plays a crucial role in ensuring the smooth and effective operation of marine propulsion systems. This guide covers factors affecting transmission efficiency, the importance of regular maintenance for key components, and common problems along with preventive measures to maintain optimal performance.

9.1. Factors Affecting Efficiency in Power Transmission

Transmission efficiency in marine systems is the ratio of useful power output to the total input power. Several factors can affect this efficiency, including:

Gearbox Design and Condition:

The efficiency of a gearbox depends on its design, type of gears, and how well it is maintained. High-quality gears with low friction reduce power losses, while worn or misaligned gears increase inefficiency.

Shaft Alignment:

Proper alignment between the engine, gearbox, and propeller shaft is critical for efficient power transmission. Misalignment can lead to excessive vibrations, increased friction, and accelerated wear of components, reducing overall efficiency.

Lubrication Quality:

Insufficient or improper lubrication can lead to overheating and friction in gears, shafts, and bearings, significantly reducing transmission efficiency and causing damage to critical components.

Propeller Condition:

Fouling, damage, or improper sizing of the propeller can result in reduced thrust and

higher fuel consumption, decreasing the efficiency of the entire propulsion system.

9.2. Importance of Regular Maintenance for Gearbox, Shafting, and Propeller

Routine maintenance is essential for sustaining high transmission efficiency in marine propulsion systems. Key components such as the gearbox, shafting, and propeller must be regularly inspected and maintained to avoid costly breakdowns and performance losses:

Gearbox Maintenance:

Regular inspection of gear teeth for wear, ensuring proper lubrication, and checking oil levels are essential tasks. Any abnormal noises, vibrations, or heat generation should be addressed immediately to prevent gear failure.

Shafting Maintenance:

Proper alignment checks, vibration analysis, and shaft seal inspections are vital to ensure smooth power transmission. Regular checks prevent misalignment and damage to bearings, reducing the risk of costly repairs.

Propeller Maintenance:

Propeller blades should be routinely inspected for damage, fouling, or imbalance. Cleaning and maintaining the propeller's surface improves its hydrodynamic efficiency and reduces fuel consumption.

9.3. Common Problems and How to Prevent Them (Alignment, Lubrication)

Marine transmission systems are susceptible to several common problems that can severely impact performance and reliability. Below are key issues and how they can be prevented:

Misalignment:

Misalignment between the engine, gearbox, and shafting can lead to excessive vibration, noise, and component wear. Preventive maintenance includes regular shaft alignment checks and adjusting the position of components to ensure optimal alignment.

Inadequate Lubrication:

Poor lubrication can result in overheating, increased friction, and eventual failure of the gearbox, bearings, and shaft. Prevent this by using high-quality lubricants and following recommended lubrication schedules, along with monitoring oil levels and condition.

Bearing Wear and Damage:

Bearings are essential for smooth transmission, and excessive wear can lead to

breakdowns. Regular inspection, proper lubrication, and replacing worn bearings promptly help prevent this issue.

10. Importance in Fishing Operations

Efficient propulsion systems play a vital role in the performance and success of fishing vessels. They enable faster access to fishing grounds, allowing fishermen to save time and increase operational efficiency. At the same time, well-designed propulsion systems help reduce fuel consumption, thereby lowering overall operating costs. Improved maneuverability provided by efficient propulsion enhances catch efficiency, especially during net deployment and retrieval. In addition, a reliable propulsion system ensures safety and stability during operations at sea. Overall, proper maintenance and efficient functioning of propulsion systems minimize breakdowns, reduce downtime, and support smooth and productive fishing activities.

Conclusion

Marine propulsion systems are vital for the efficient functioning of fishing vessels, directly influencing speed, fuel consumption, and operational success. From engine power generation to propeller thrust, each component must function in harmony to ensure maximum efficiency. Advanced technologies such as controllable pitch propellers and azimuth thrusters have significantly improved vessel maneuverability and performance.

Proper maintenance of gearboxes, shafting systems, and propellers is essential to prevent failures and maintain high transmission efficiency. Additionally, understanding issues like cavitation helps in reducing damage and improving system longevity. Overall, a well-designed and maintained propulsion system enhances fishing efficiency, reduces operational costs, and supports safe and sustainable marine operations.

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REGENERATIVE AGRICULTURE

Article ID: AG-VO6-I04-110

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Abstract

Conventional agricultural practices, characterized by mono cropping, excessive use of synthetic fertilizers and pesticides, and intensive tillage, have led to severe soil degradation, loss of biodiversity, water pollution, and greenhouse gas emissions. These challenges threaten global food security and environmental sustainability. Regenerative agriculture offers a promising alternative by restoring soil health, increasing biodiversity, enhancing water retention, and capturing atmospheric carbon. Practices involved in regenerative agriculture are cover cropping, reduced tillage, agroforestry, stubble retention, reducing synthetic inputs, rotational grazing, and composting. The benefits of regenerative agriculture extend beyond environmental gains to include enhanced food quality, economic resilience for farmers, and improved water and air quality. Moreover, it plays a pivotal role in reversing desertification and restoring degraded lands, making it a critical strategy for sustainable development. Future thrusts in regenerative agriculture involve integrating technology, such as remote sensing and AI, to monitor soil health and optimize practices.

Key words: Soil Health, Carbon Sequestration, Sustainable ecosystem, Biodiversity

Introduction

Conventional agricultural practices, characterized by mono cropping, excessive use of synthetic fertilizers and pesticides, and intensive tillage, have led to severe soil degradation, loss

of biodiversity, water pollution, and greenhouse gas emissions. These practices have resulted in the deterioration of soil health, loss of biodiversity and climate change. In order to restore our soil health, biodiversity and environment, we should adopt the practices that work with nature and not against it. So, in the existing situation of climate change and environmental issues, it is appropriate to extend the concept of regenerative agriculture by stating that the health of soil, plants, animals, people, and environment is one and indivisible. Regenerative agriculture has the capability of restoring and nourishing our soil and biodiversity and also helps in mitigating climate change through its principles of minimum or no till, growing cover crops, crop rotation, maintaining living root and integrating livestock. Critically, regenerative agriculture is not only sustainable, but it also maintains (does no harm to) the existing soil, and further enhances its quality via methods that not only renourish, but actually regenerate soil. It integrates traditional knowledge with modern science to create farming systems that are productive, sustainable, and environmentally friendly. Regenerative agriculture practices can significantly impact climate change by enhancing soil health, increasing carbon sequestration, and reducing greenhouse gas emissions. This article explores regenerative agriculture in detail, emphasizing its systemic benefits**,** trade-offs, and real-world applications.

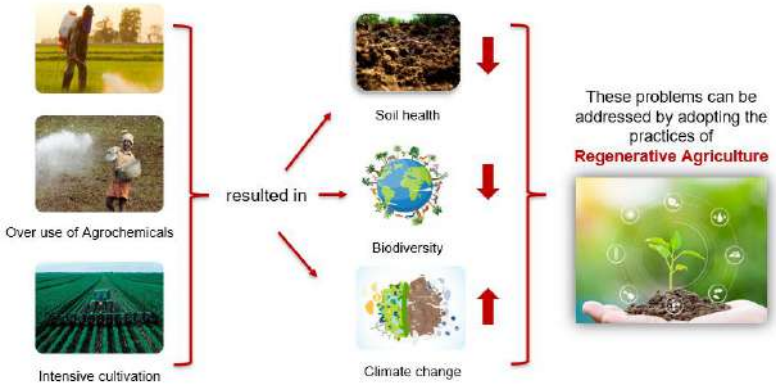

Fig. 1. Need for regenerative agriculture

Regenerative agriculture

The word Regenerative means the capacity to bring into existence again. Regenerative agriculture is an approach to farming and land management that has the capacity for restoring and enhancing ecosystems, like improving soil health, increases the water percolation and retention, enhances and conserves biodiversity. Typically employs techniques that are used more generally in organic agriculture, with the aim to preserve/build soil organic matter, including

minimum tillage, growing cover crops and green manures, composting, mulching and crop rotation.

Aims of Regenerative Agriculture

The primary aim of regenerative agriculture is to increase the levels of soil organic matter. This leads to multiple positive outcomes such as,

- Better resilience to extreme weather events
- Increased efficiency in the soil ‘s water holding capacity
- Fewer diseases due to the beneficial soil biota controlling pathogens
- Increases in the bioavailability of the nutrients that plants, animals and humans need

Goals of regenerative agriculture

Its goal is to apply the concept of more from less to agriculture and produce more from less. Less means,

- Less land area
- Less input of chemicals
- Less use of water
- Less emission of greenhouse gases
- Less risk of soil degradation
- Less use of energy-based inputs

Objectives of Regenerative Agriculture

- To rebuild soil organic matter and enhance soil fertility for long-term productivity.
- To promote ecological balance by integrating natural systems into farming practices.
- To reduce greenhouse gas emissions and increase carbon storage in soils and vegetation.
- To conserve water resources by improving soil water-holding capacity and reducing surface runoff.
- To encourage biodiversity conservation in agricultural landscapes through crop and habitat diversity.
- To minimize external inputs and promote self-sustaining agricultural ecosystems.
- To empower farmers and rural communities through knowledge sharing, improved livelihoods, and resilient food systems.
- To create scalable, adaptable models that can be applied across diverse agroecological zones globally.

Principles of Regenerative Agriculture

Regenerative agriculture operates on key principles that are tailored to local climates, cultures, and ecosystems. Some of the primary practices include:

i. Soil Health Management

Soil is treated as a living ecosystem. Practices such as cover cropping, compost application, minimal tillage, and the use of organic amendments enhance soil microbial activity and organic matter.

ii. Biodiversity Promotion

Monoculture farming is replaced with polycultures, agroforestry, and crop rotation systems. These practices attract a variety of organisms, contributing to a more resilient ecosystem.

iii. Integration of Livestock

Managed grazing mimics natural herbivore movements and enhances nutrient cycling. Livestock are not kept in confinement but rotated through pastures.

iv. No or Low Tillage

Conservation tillage reduces soil disturbance, preserving soil structure and microbial life. This limits erosion and increases water absorption.

Techniques in Regenerative Agriculture

i. No-till or minimal tillage farming: Reduces soil disturbance to preserve structure, moisture, and microbial life.

ii. Cover cropping: Grows non-cash crops during off-seasons to protect and enrich soil.

iii. Crop rotation and diversification: Breaks pest and disease cycles while enhancing soil nutrients.

iv. Composting and use of organic amendments: Adds nutrients and improves soil microbiology.

v. Agroforestry: Integrates trees with crops and livestock for shade, biodiversity, and carbon sequestration.

vi. Rotational and holistic grazing: Moves livestock strategically to mimic natural grazing, allowing pasture recovery.

vii. Integrated pest management (IPM): Uses natural predators, plant diversity, and minimal chemicals for pest control.

viii. Mulching and residue retention: Maintains moisture, suppresses weeds, and adds organic matter.

ix. Water harvesting and management: Builds swales, ponds, and contour lines to conserve water.

x. Use of biofertilizers and biopesticides: Replaces synthetic inputs with eco-friendly biological alternatives.

Benefits of Regenerative Agriculture

i. Improved Soil Health

Regenerative practices like composting, cover cropping, and no-till farming restore soil organic matter, improve structure, and enhance microbial activity. Healthy soils increase nutrient availability, support plant growth, and reduce erosion, making farms more resilient to droughts and floods.

ii. Enhanced Biodiversity

Crop diversification, agroforestry, and integrated livestock systems promote a diverse ecosystem above and below the soil. This leads to more pollinators, beneficial insects, soil organisms, and a more stable agro-ecological environment.

iii. Carbon Sequestration and Climate Mitigation

By building soil organic matter and integrating perennial vegetation, regenerative agriculture helps capture and store atmospheric carbon. This contributes to climate change mitigation by reducing greenhouse gas concentrations in the atmosphere.

iv. Water Conservation and Quality

Regenerative soils have better water infiltration and retention. Practices like mulching, reduced tillage, and cover cropping help decrease runoff and water evaporation, improving efficiency and reducing the risk of contamination from fertilizers and pesticides.

v. Reduced Input Costs

As regenerative systems rely on natural processes and organic inputs, farmers can significantly cut back on synthetic fertilizers, pesticides, and irrigation, leading to lower production costs over time.

vi. Increased Farm Resilience

Diverse cropping systems and healthy soils buffer farms against pests, diseases, and extreme weather.

Regenerative farms are often more adaptive and productive in the face of climate variability.

vii. Improved Food Quality and Nutrition

Healthier soils often produce more nutrient-dense food. This enhances the nutritional value of crops and livestock, contributing to better public health outcomes.

viii. Rural Economic Development

By encouraging localized, knowledge-intensive farming practices and reducing dependency on external inputs, regenerative agriculture can empower farmers, create jobs, and strengthen rural economies.

ix. Enhanced Ecosystem Services

These include pollination, pest control, water purification, and climate regulation, all of which are naturally supported by regenerative practices.

x. Social and Cultural Benefits

Regenerative agriculture often aligns with traditional and indigenous farming knowledge, supporting cultural preservation and farmer autonomy.

Challenges and limitations of Regenerative Agriculture

i. Knowledge and Skill Gaps

Many farmers are unfamiliar with regenerative methods and require comprehensive training. Universities and extension services may not yet be fully equipped to provide such education.

ii.Initial Financial Investment

Transitioning from conventional to regenerative systems may involve upfront costs for new tools, livestock fencing, or composting equipment.

iii. Policy and Institutional Barriers

Government subsidies often favor monoculture or conventional practices. Lack of policy incentives for regenerative farming hampers its adoption.

iv.Yield Volatility

During the transition period, yields may fluctuate. Farmers may also face challenges in marketing regenerative products unless clear certification schemes exist.

v. Scientific Standardization

Regenerative agriculture lacks a globally accepted definition or framework, making it difficult to

compare outcomes across studies or geographies.

Conclusion

Currently, majority of the soils are unhealthy and emission of greenhouse gases due to improper agricultural practices create a negative impact on both soil and environment. As the practices of regenerative agriculture work in harmony with nature, it can be strongly taken up by the farmers thereby regenerating the soil health to produce healthy food and reducing the impact of global warming.

"A nation that destroys its soils destroys itself."

- Franklin D. Roosevelt

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SEXED SEMEN TECHNOLOGY: A SMART TOOL TO BOOST DAIRY FARM PROFIT

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Abstract

Sexed semen technology represents a significant and farmer-friendly advancement in modern dairy farming, offering a practical solution for improving herd productivity and management. This innovative technique allows farmers to produce calves of a desired sex—most commonly female—with a high degree of accuracy ranging from 80 to 90 percent. Such precision is especially beneficial for dairy farmers, as female calves (heifers) are the foundation of milk production and herd replacement. By increasing the proportion of female births, farmers can systematically strengthen their dairy operations and ensure a steady supply of high-producing animals. In addition to improving herd composition, sexed semen technology helps reduce the economic burden associated with rearing unwanted male calves, which often have limited utility in dairy-focused systems. This not only saves resources such as feed, labor, and housing but also allows farmers to allocate their inputs more efficiently toward productive animals. Furthermore, the use of sexed semen accelerates genetic improvement by enabling the selective breeding of superior cows and bulls, thereby enhancing desirable traits such as higher milk yield, better fertility, and disease resistance over successive generations. From a sustainability perspective, this technology contributes to more efficient livestock production by optimizing resource utilization and minimizing wastage. It supports long-term farm planning and profitability while aligning with modern goals of ethical and environmentally conscious farming. Overall, sexed semen technology serves as a powerful tool in advancing dairy farm efficiency and economic

returns. This article aims to present the concept, working principle, advantages, limitations, and practical field-level applications of sexed semen in a clear and simple manner, making it easily understandable for farmers, students, and other stakeholders involved in the dairy sector.

Keywords: Sexed semen, dairy farming, heifer production, artificial insemination, herd improvement

Introduction

The dairy sector plays a crucial role in supporting rural livelihoods and strengthening the agricultural economy, particularly in countries like India where livestock farming is an integral part of smallholder systems. With the rising demand for milk and milk products, there is an increasing need to adopt advanced reproductive technologies that can enhance productivity, improve herd quality, and ensure sustainable dairy farming. Traditional breeding methods, although widely practiced, often result in an unpredictable ratio of male and female calves, which can limit the efficiency and profitability of dairy enterprises.

In this context, sexed semen technology has emerged as a promising innovation that allows for the pre-determination of the sex of the offspring, thereby offering greater control over herd composition. By enabling the preferential production of female calves, this technology aligns well with the primary objective of dairy farmers to maximize milk production and improve genetic potential. The adoption of such precision breeding tools not only enhances farm efficiency but also reduces economic losses associated with the rearing of less productive animals.

Given its growing importance and field-level applicability, understanding the principles and benefits of sexed semen technology is essential for farmers, veterinarians, and other stakeholders. This article, therefore, focuses on explaining the concept, working mechanism, advantages, limitations, and practical applications of sexed semen in a simple and accessible manner.

What is Sexed Semen?

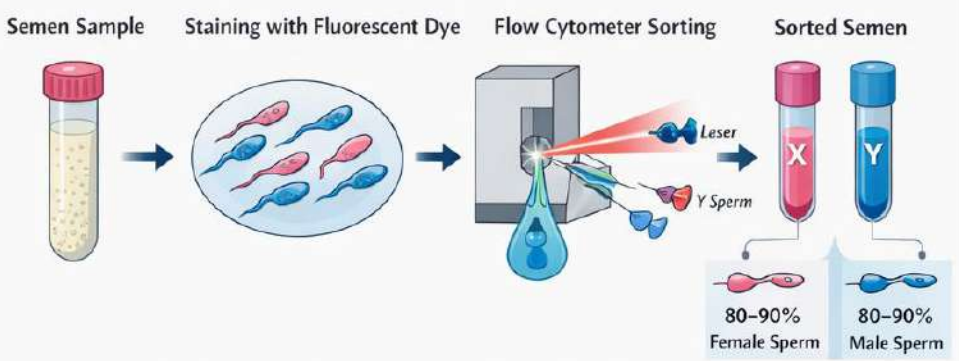
Sexed semen refers to semen that has been scientifically processed to contain a higher proportion of sperm carrying either the X chromosome (female-producing) or the Y chromosome (male-producing), depending on the desired outcome. Under natural conditions, semen contains an approximately equal proportion of X- and Y-bearing sperm, resulting in an equal chance of male or female offspring. However, with the help of advanced reproductive biotechnology, this

ratio can be altered to favor the production of calves of a specific sex, most commonly females in dairy farming systems.

The accuracy of sexed semen technology generally ranges between 80 to 90 percent, making it a reliable tool for farmers aiming to increase the number of heifer calves. This is particularly beneficial in dairy enterprises where female animals are economically more valuable due to their role in milk production and herd replacement. By ensuring a higher probability of female births, sexed semen helps in strategic herd expansion, improved genetic planning, and efficient resource utilization.

Moreover, sexed semen contributes to reducing unwanted male calf births, which often pose management and economic challenges in dairy-oriented farms. With increasing awareness and adoption, this technology is gradually becoming an important component of modern breeding programs, especially in organized and semi-organized dairy sectors.

Figure 1: Flow Cytometry-Based Sperm Sorting Process



Working Principle

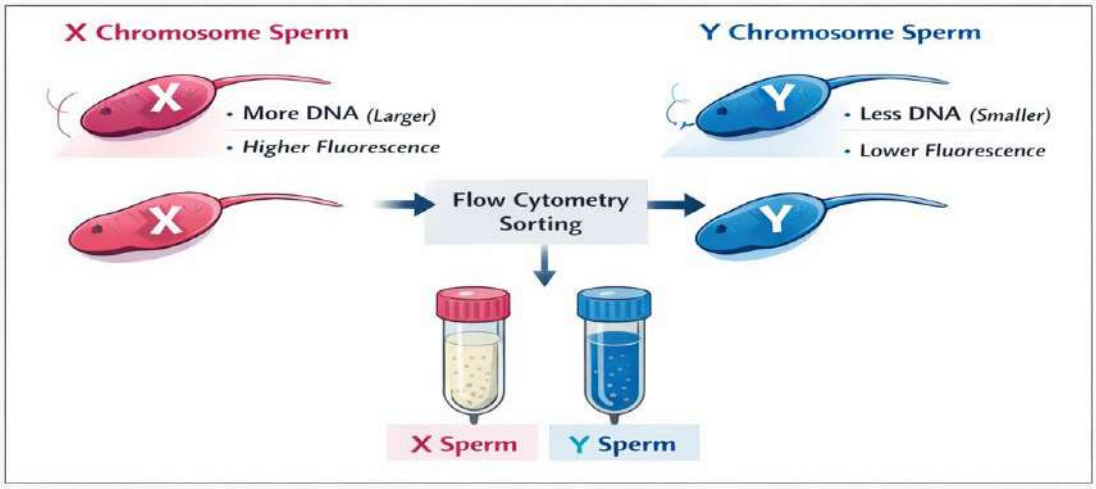
The fundamental principle behind sexed semen technology lies in the biological difference between X- and Y-chromosome-bearing sperm. The X chromosome is larger and contains slightly more DNA—approximately 3–4% more—than the Y chromosome. Although this difference is very small, it is sufficient to allow separation using advanced laboratory techniques.

In the sex-sorting process, semen is first stained with a special fluorescent dye that binds specifically to DNA. When the stained sperm pass through a machine known as a flow cytometer, they are exposed to a laser beam. Due to the difference in DNA content, X-bearing

sperm emit slightly higher fluorescence compared to Y-bearing sperm. The machine detects this variation and sorts the sperm into separate groups using an electrostatic deflection system.

The sorted sperm are then collected, processed, and packed into semen straws for artificial insemination. Despite the high precision of this method, the process is complex, requires specialized equipment, and may slightly reduce sperm viability compared to conventional semen. Nevertheless, continuous advancements in technology are improving both the efficiency and fertility outcomes associated with sexed semen.

Figure 2: Difference Between X and Y Chromosome-Bearing Sperm



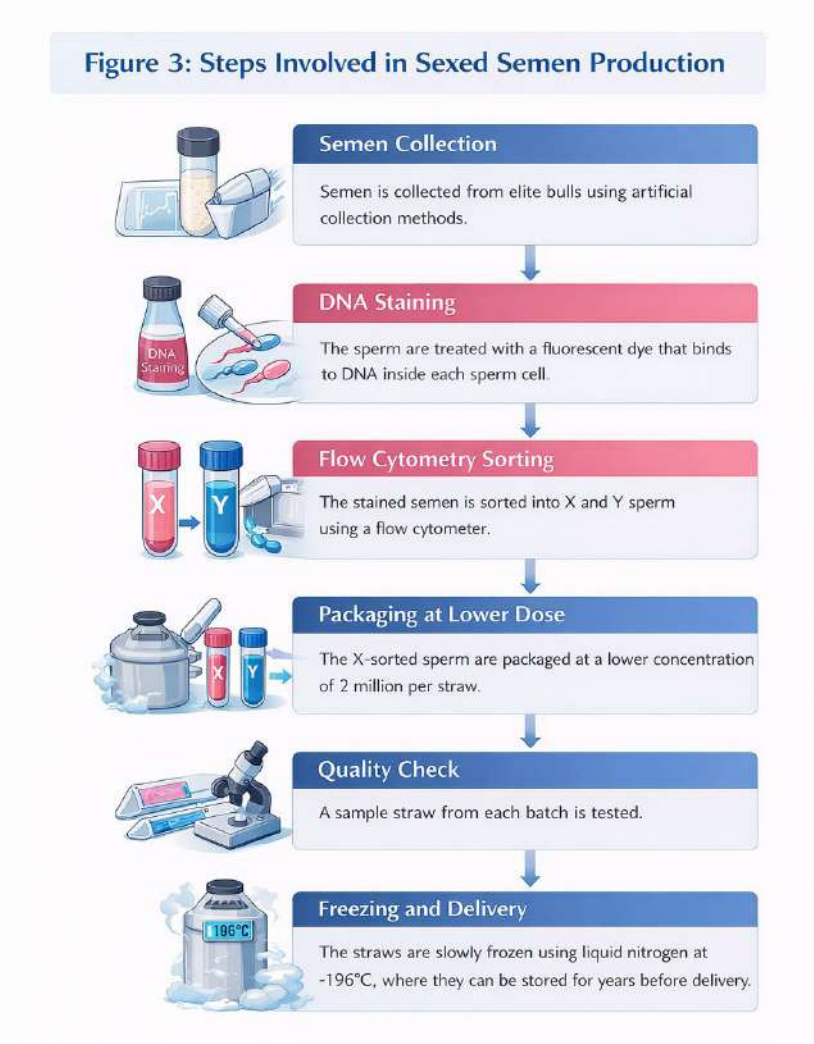
How Sexed Semen Is Made

The production of sexed semen is a highly specialized and precise laboratory process that involves several carefully controlled steps to ensure accuracy and sperm viability. The process begins with the collection of high-quality semen from genetically superior bulls using standard artificial collection methods. Only semen that meets strict quality parameters such as motility, concentration, and morphology is selected for sex sorting.

After collection, the semen is diluted and prepared for staining. A special fluorescent dye is added, which binds specifically to the DNA present in the sperm cells. Since X-chromosome-bearing sperm contain slightly more DNA than Y-chromosome-bearing sperm, they absorb more dye and emit a stronger fluorescent signal when exposed to a laser. This difference forms the basis for separating the sperm.

The stained semen is then passed through an advanced instrument called a flow cytometer. In this machine, sperm cells move in a single-file stream and are exposed to a laser

beam. Based on the intensity of fluorescence emitted, the machine identifies whether a sperm carries an X or Y chromosome. Each sperm cell is then given a tiny electrical charge, and using an electrostatic deflection system, the sperm are separated into different streams—one enriched with X-bearing sperm and the other with Y-bearing sperm.

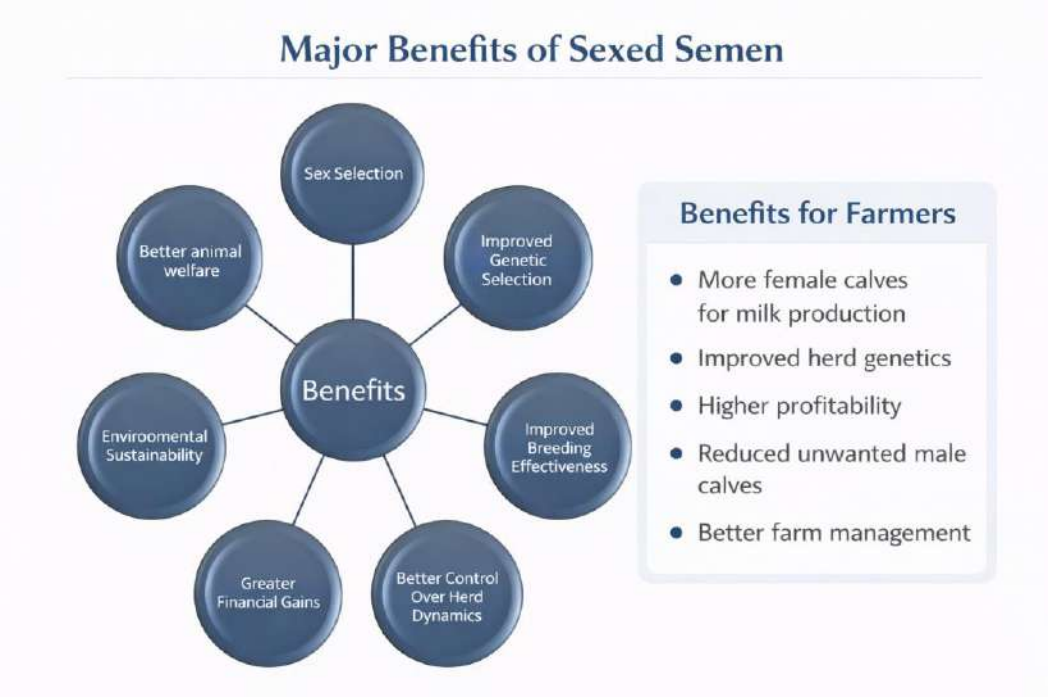


Once sorting is complete, the desired sperm fraction (usually X-bearing for dairy purposes) is collected. These sorted sperm are then diluted with a specialized extender, carefully packaged into semen straws, and cryopreserved using liquid nitrogen at extremely low temperatures (-196°C). This ensures long-term storage and maintains sperm viability until use.

Before distribution, the sexed semen straws undergo quality control checks to ensure adequate sperm concentration, motility, and sorting accuracy. Although the process is more time-consuming and costly compared to conventional semen production, it provides a highly valuable tool for controlled breeding and genetic improvement in modern dairy farming.

Benefits for Farmers

Sexed semen technology offers several major benefits that significantly improve the efficiency and profitability of dairy farming. One of the most important advantages is the increased production of female calves, which are essential for milk production and herd replacement. This helps farmers expand their dairy operations more strategically. Additionally, the use of sexed semen enhances herd genetics by enabling the selection of superior animals, leading to improved milk yield, fertility, and overall productivity. It also contributes to higher profitability by reducing the cost associated with rearing unwanted male calves and optimizing the use of farm resources such as feed, labor, and housing. Furthermore, better control over herd composition allows for improved farm management and long-term planning. From a broader perspective, this technology supports environmental sustainability and animal welfare by minimizing resource wastage and ensuring more purposeful breeding practices.



Practical tips for framers

For successful use of sexed semen technology, farmers should follow a few practical and scientific guidelines. First, sexed semen should be used only in healthy, well-nourished animals with good reproductive status, as fertility rates are slightly lower compared to conventional semen. Proper heat detection is critical—insemination should be carried out at the correct time of estrus (ideally in mid to late heat) to improve conception chances. It is also important to maintain

accurate breeding records and monitor animals regularly for signs of estrus and pregnancy. Good management practices such as balanced nutrition, clean housing, stress reduction, and timely veterinary care further enhance reproductive efficiency. Additionally, farmers should rely on trained technicians for artificial insemination and use high-quality semen from reliable sources to achieve the best results.

Conclusion

Sexed semen technology has emerged as a transformative innovation in modern dairy farming, offering farmers a practical and efficient tool to improve herd composition and overall productivity. By enabling the production of a higher proportion of female calves, it directly supports the primary goal of dairy enterprises—enhanced milk production and better herd replacement. This targeted approach not only accelerates genetic improvement but also reduces the economic burden associated with rearing less productive male calves. Although the technology involves higher costs and slightly lower conception rates compared to conventional semen, its benefits can be maximized through proper animal selection, accurate heat detection, skilled insemination, and good management practices. When used under suitable conditions, sexed semen significantly contributes to efficient resource utilization, improved farm planning, and increased profitability.

In the long run, the adoption of sexed semen technology aligns well with the goals of sustainable and scientific dairy farming. It promotes ethical breeding practices, minimizes wastage, and enhances the economic resilience of farmers. Therefore, with proper awareness, training, and field-level implementation, sexed semen can play a vital role in strengthening the dairy sector and supporting the livelihood of farmers.

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SUCCESS STORY ON ENHANCING RICE PRODUCTIVITY AND ECONOMIC RETURNS IN SALT-AFFECTED SOILS THROUGH THE ADOPTION OF SALINITY-TOLERANT VARIETY MCM-103

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Introduction

Agriculture in coastal regions is increasingly constrained by soil salinity, a condition characterized by the excessive accumulation of soluble salts, primarily chlorides (e.g., NaCl) and sulphates (e.g., Na_2SO_4 and $MgSO_4$). These salts accumulate in the root zone due to poor drainage, high evaporation, and seawater intrusion. They induce dual stress through ion toxicity and increased osmotic pressure, reducing soil water potential and hindering plant water uptake even under moist conditions. This ultimately results in poor germination, reduced tillering, and lower grain weight. In the SPSR Nellore district, where rice cultivation spans 66,868 hectares in the *kharif* and 157,319 hectares in the *rabi* season, approximately 10.39% of the land is salt-affected. A stark example of this degradation was observed on the farm of Sri P. Yedukondalu in Thikkavarappadu village, SPSR Nellore district, Andhra Pradesh where, former shrimp farming led to a highly alkaline soil pH of 9.70 and an Electrical Conductivity (EC) of 5.36 dS/m. Soil analysis by Krishi Vigyan Kendra, Nellore further revealed a severely depleted profile with low organic carbon (0.35%) and low available nitrogen (75.0 kg/ha), while phosphorus (37.0 kg/ha) and potassium (259.0 kg/ha) remained in the medium range, indicating comprehensive reclamation to restore productivity.

Saline-tolerant rice variety MCM-103

To address these constraints, the saline-tolerant rice variety MCM-103 was introduced as an appropriate intervention to enhance crop performance under saline conditions. It was released in 2022 by the Agricultural Research Station, Machilipatnam, under Acharya N.G. Ranga Agricultural University. This variety has a duration of 140-145 days, exhibits moderate

resistance to blast, sheath blight, and white-backed planthopper (WBPH), and performs well under saline conditions, with a potential yield of 5.0-5.5 t/ha. Recommended agronomic practices included the application of fertilizers at a rate of 120-60-40 kg NPK/ha, along with foliar application of zinc sulphate at 2 g/litre at 20 and 40 days after sowing.

Comparative Performance of MCM-103 and BPT-5204 under Saline Conditions

S. No.	Parameters	MCM-103	BPT-5204
1.	No. of hills/m^2	22.80	17.00
2.	Plant height (cm)	75.00	67.30
3.	No. of tillers/hill	25.60	23.00
4.	No. of filled grains/panicle	134.80	103.80
5.	1000-grain weight (g)	15.56	13.59
6.	Grain yield (kg/ha)	3,937	2,974
7.	Increase in yield (%)	24.46	-
8.	Cost of cultivation (Rs./ha)	63,555	63,255
9.	Gross returns (Rs./ha)	89,269	67,434
10.	Net returns (Rs./ha)	25,714	4,179
11.	B:C ratio	1.40	1.06

Salinity-induced damage in rice variety BPT-5204 (Samba Mahsuri)

The superior performance of the salinity-tolerant rice variety MCM-103 was evident from the early stages of crop establishment under severe edaphic stress conditions. Despite exposure to high soil alkalinity (pH 9.70) and elevated electrical conductivity (5.36 dS/m), MCM-103 maintained a significantly higher plant population density (22.80 hills/m^2) compared to the conventional cultivar BPT-5204 (17.00 hills/m^2). This enhanced establishment reflects greater physiological resilience to salinity-induced osmotic stress and ion toxicity, particularly sodium accumulation, which typically impairs germination and early seedling vigour in salt-affected coastal agro-ecosystems. Building on this strong establishment, MCM-103 exhibited superior vegetative growth, characterized by a higher tillering capacity (25.60 tillers/hill) and greater plant height (75.00 cm), whereas BPT-5204 recorded comparatively lower tillering (23.00 tillers/hill) and reduced plant height (67.30 cm). These improvements suggest more

efficient resource utilization and a better adaptive growth response under saline stress conditions. Consequently, the enhanced plant stand and improved morphological traits of MCM-103 created a robust physiological foundation for improved reproductive performance and yield formation.

This advantage was further reflected in yield attributes and final productivity. MCM-103 produced a higher number of filled grains per panicle (134.80) compared to BPT-5204 (103.80). These cumulative effects resulted in a grain yield of 3,937 kg/ha, representing a 24.46% increase over the conventional variety (2,974 kg/ha). The improved agronomic performance of MCM-103 also translated into enhanced economic returns. The variety achieved gross returns of Rs. 89,269/ha and net returns of Rs. 25,714/ha, with a Benefit-Cost (B:C) ratio of 1.40, compared to 1.06 for BPT-5204. This indicates that the adoption of salinity-tolerant varieties, when combined with balanced nutrient management and appropriate agronomic practices, can substantially improve both productivity and profitability in salt-affected environments. Furthermore, the

farmer's positive response to the performance of MCM-103 under saline conditions, along with the willingness to continue its cultivation, underscores its practical feasibility and acceptability.

Field visit during Front Line Demonstration (FLD) on saline-tolerant rice variety MCM-103 at Thikkavarappadu village, Venkatachalam mandal, SPSR Nellore district.

Conclusion

The success of this field demonstration highlights the strong potential for scaling up MCM-103 in other salt-affected areas of the district. It also emphasizes the critical role of Krishi Vigyan Kendras in disseminating location-specific, climate-resilient technologies that enhance the sustainability and resilience of coastal agricultural systems.

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USE OF ARTIFICIAL INTELLIGENCE IN POST-HARVEST MANAGEMENT OF HORTICULTURE CROPS

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Introduction

Food is the prime necessity of life and can be classified in different groups according to their nutritional value and function in the body.

1. **Energy giving food**: Any food which provides energy is classified as energy giving food. One gram of carbohydrate imparts 4 calorie while 1 g of fat provides 9 calorie of energy, e.g., cereals, roots, tubers, dried fruits, sugar, fat etc.

2. **Body building food:** Foods which are rich in protein are body building foods, e.g., milk, meat, fish, egg are rich in protein of high biological value. Secondly pulses, oil, seeds and nuts etc are rich in proteins. Though, these proteins contain many essential amino acids for synthesis of body tissues yet may not possess all essential amino acids required for the human body.

3. **Protective food**: Foods rich in protein, vitamin and minerals are called protective foods, e.g., milk, egg, green leafy vegetables and fruits.

During 2007, India exported 9.53 lakh tonnes of processed foods comprising of mango pulp, juices, concentrates, dried and processed vegetables, pickle and chutney, alcoholic and non-alcoholic beverages worth Rs 2,757.74 crores (APEDA 2007). As such export value of processed products was higher then that of export value of fresh fruits and vegetables (2411.7 crores) during the same year. Thus there is a good scope for processing of fruit and vegetables in to different products to reduce wastage and earn foreign exchange.

Objectives of fruit and vegetable processing

1. <u>To reduce wastage and losses</u>: Fruit and vegetable industry is the backbone of horticulture

industry as it takes care of all possible waste that occurs in spite of improvement in the distribution and marketing of fresh produce.

2. To handle glut: Produce during glut season utilized for making different processed products, thus fruit processing helps in reducing wastage and handling excess produce during glut season.

3. To stabilize farm prices and income: It stabilizes farm price by utilizing the excess produce in value addition to provide additional income to the farmers.

4. To utilize marketable surplus: Processing utilizes marketable surplus as well as cull and deformed produce, to ensure remunerative returns to the growers.

5. To generate employment: Processing of fruits and vegetables being a labour intensive helps to generate both direct and indirect employment for the masses.

6. To add variety to the diet: Value addition/processing make the food more attractive and palatable.

7. To ensure nutritional security.

8. To earn foreign exchange through export of processed fruit and vegetable products.

Major constraints in expansion of food industry

1. Variation in fresh produce quality involving frequent changes in production schedules.

2. Low productivity and high cost of raw material: Low production percent area in our country in comparison to horticulturally advanced countries is one of the major factors leading to high cost of raw material.

3. Lower quality of raw material (low in soluble solids) in our country leads to requirement of comparatively more raw material for production of equivalent quantity of finished products, thus resulting in higher cost of production.

4. Non availability of cost effective technologies for processing and packaging of fresh and processed products. 5. Lack of infrastructure for post harvest management, cool chain and cold storages.

6. Non-availability of trained man-power.

7. Low domestic demand of processed fruit and vegetable products due to high cost.

8. Irregular in supply and non-uniform quality of processed products due to variation in raw material quality and use of batch processes.

9. High cost of packaging material, higher taxes and excise duties.

10. Low capacity utilization in food industries.

11. Financial and fiscal constraints.

12. Infra-structural constraints in processing.

13. Inadequate farmer-processor linkage; leading to dependence on inter-mediataries.

14. Lack of strategies for market promotion.

15. Lack of strategies for utilization of processing industries waste (pomace, peel, core, stones/seed) for value addition.

16. Lack of R&D in food processing sector and its linkage with the food industry.

SWOT Analysis of food–processing industries in India

I. Strengths

- Abundant availability of raw material.
- Priority sector status for agro-processing given by the central Government.
- Vast network of manufacturing facilities all over the country .
- Vast domestic market.

II. Weaknesses

- Low availability of adequate infrastructural facilities.
- Lack of adequate quality control and testing methods as per international standards.
- Inefficient supply chain due to a large number of intermediaries.
- Higher requirement of working capital.
- Inadequately developed linkages between Research organizations and industry.
- Seasonality of raw material.

III. Opportunities

- Large crop and material base offering a vast potential for agro processing activities.
- Setting of Agri-export zone (AEZ) and food parks for providing added incentive to develop. green field projects.
- Rising income levels and changing consumption patterns.
- Favourable demographic profile and changing lifestyles.
- Integration of development in contemporary technologies such as electronics, material science, biotechnology etc. offer vast scope for rapid improvement and

progress.

• Opening of global markets.

IV. Threats

• Affordability and cultural preferences of fresh food.

• High inventory carrying cost.

• High taxation.

• High packaging cost.

Post harvest losses:

With respect to agricultural commodities, the loss is defined as a measurable reduction in foodstuffs which may affect either quantity, quality or both. Post harvest losses arise from the fact that freshly harvested agricultural produce is a living entity that breathes and undergoes changes during post harvest handing.

• Loss in form of damage, is the visible sign of deterioration and can only be partial e.g., chewed grain, birds eaten fruit/vegetable etc.

• Damage restricts the use of the product, while loss makes it use impossible.

• Food loss refers to total modification or decrease of food in quantity or quality and makes it unfit for human consumption.

Types of losses

1. Quantitative loss
2. Qualitative loss
3. Direct and indirect loss

1. Quantitative loss: It refers to a loss in terms of physical substance i.e. reduction in weight and volume which can be assessed and measured.

2. Qualitative loss: It refers to the food and reproductive value of the products. Broadly it includes loss in quality, nutrients, vitamins, appearance, seed viability and commercial loss.

3. Direct and indirect loss: Direct losses occur when the disappearance of food stuff is caused by leakage, pilferage or consumption by pests (insects, rodents, birds), loss in weight whereas indirect losses occur when a reduction in quality leads to the consumer's refusal to purchase.

Over view of AI and its application in horticulture:

The field of computer science known as artificial intelligence (AI), also referred to as machine intelligence, teaches machines how to mimic human physical movements and respond

in human-like ways. The term 'Artificial Intelligence' was coined by John McCarthy in 1950. How come artificial intelligence? It is viewed as a chance, particularly in challenging circumstances or issues that standard computing systems and humans are unable to adequately resolve. It has many uses in the horticulture sector. Machines may frequently be made to perform tasks more effectively than people, including planting, watering, and harvesting as well as testing new systems. In order to increase yield, the horticulture sector needs workers with expertise in artificial intelligence. Artificial intelligence (AI) technologies help produce healthier crops, provide information on current weather conditions, such as temperature, rain, wind speed, wind direction, solar radiation, pest control, and soil and growing conditions, organise data for farmers, lessen their workload, and enhance the food supply chain (Manaware, 2020).

Advantages of AI in Horticultural Sector

The following are some significant advantages of AI in horticulture:

- AI provides more efficient ways to produce, harvest and sell essential crops.
- AI implementation emphasis on checking defective crops and improving the potential for healthy crop production.
- The growth in AI technology has strengthened agro-based businesses to run more efficiently.
- Used in applications such as automated machine adjustments for weather forecasting and disease or pest identification.
- AI can improve crop management practices.
- AI solutions have the potential to solve the challenges farmers face such as climate variation, an infestation of pests and weeds that reduces yields.
- It wouldn't eliminate jobs of human farmers rather it will improve their processes.
- Produce maturity identification.

Automation system in Irrigation.

Artificial Intelligence (AI) can play a significant role in improving post-harvest management of fruits by **enhancing efficiency, reducing waste, and ensuring better quality.**

1. **Quality Assessment**:

- AI-powered image recognition systems can be employed to assess the quality of fruits based on their size, color, shape, and external defects.

- Machine learning algorithms can learn from vast datasets to identify subtle defects that may not be easily detectable by human eyes.

2**. Sorting and Grading**:

- Automated sorting systems can use AI algorithms to categorize fruits based on their quality, size, and ripeness.
- This ensures that fruits are distributed accurately, meeting market demands and reducing the chances of spoilage.

3. **Predictive Analytics:**

- AI can analyze historical data, weather conditions, and other relevant factors to predict optimal harvest times.
- This helps in planning harvest schedules, ensuring fruits are picked at the right time for maximum quality and shelf life.

4. **Supply Chain Optimization:**

- AI can optimize supply chain processes, helping in the efficient transportation and distribution of fruits from the farm to the market.
- Predictive modeling can assist in minimizing transportation time, reducing spoilage, and optimizing storage conditions.

5. **Cold Chain Management:**

- AI can monitor and control the conditions of cold storage facilities, ensuring that fruits are stored at the optimal temperature and humidity levels.
- Machine learning algorithms can adapt to changing external conditions and optimize the energy consumption of refrigeration systems.

6. **Inventory Management:**

- AI can be used for real-time monitoring of inventory levels and predicting demand patterns.
- This helps in preventing overstocking or understocking issues, reducing waste and ensuring a steady supply of fresh fruits.

7. **Quality Monitoring during Storage:**

- Continuous monitoring using sensors and AI can detect signs of decay, ripening, or spoilage during storage.
- Automated alerts can be generated to take corrective actions, such as adjusting storage conditions or expediting the distribution process.

8. **Decision Support Systems:**

- AI-powered decision support systems can provide recommendations to farmers and stakeholders based on data analytics, helping them make informed decisions about post-harvest processes.

9.**Traceability and Authentication:**

- Blockchain and AI can be combined to create a secure and transparent system for tracking the journey of fruits from the farm to the consumer.
- This enhances product traceability and ensures the authenticity of the produce.

By leveraging AI in post-harvest management, the agricultural industry can improve efficiency, reduce losses, enhance product quality, and contribute to a more sustainable and resilient food supply chain.

AI-based techniques for fruit quality assessment utilize various technologies to automate and enhance the accuracy of evaluating fruit characteristics. Here are some common AI approaches employed in this context:

1. **Computer Vision:**

- *Image Recognition:* Computer vision techniques, often powered by deep learning algorithms, can analyze images of fruits to assess their quality based on factors such as size, color, shape, and external defects.
- *Convolutional Neural Networks (CNNs):* CNNs are effective in feature extraction from images, making them suitable for tasks like fruit quality classification and defect detection.

2. **Machine Learning:**

- *Supervised Learning:* Algorithms can be trained on labeled datasets, where each image is associated with its corresponding quality attributes. This enables the model to learn patterns and make predictions on new, unseen images.
- *Ensemble Learning:* Combining multiple models or classifiers can enhance the overall accuracy of quality assessment by reducing individual model biases.

3. **Hyperspectral Imaging:**

- *Spectral Analysis*: Hyperspectral imaging captures detailed information about the electromagnetic spectrum reflected by fruits. AI algorithms can analyze this data to identify quality indicators not visible to the human eye, such as internal defects or ripeness levels.

4. **Near-Infrared Spectroscopy (NIRS):**

- *Chemometric Analysis:* NIRS measures the absorption of near-infrared light by fruit samples, providing information about their internal composition. AI-driven chemometric models can interpret these spectra to assess attributes like sugar content, moisture, and firmness.

5. **Sensor Technologies:**

- *Internet of Things (IoT):* Smart sensors can be deployed in storage facilities to monitor various parameters like temperature, humidity, and gas levels. AI algorithms analyze the sensor data in real-time to ensure optimal storage conditions and prevent quality deterioration.

6. **Data Fusion:**

- Multimodal Data Integration: Combining information from different sources, such as images, spectroscopy, and sensor data, can provide a more comprehensive assessment of fruit quality. AI models can fuse these diverse datasets to make more accurate predictions.

7. **Deep Learning:**

- *Recurrent Neural Networks (RNNs):* RNNs are suitable for processing sequential data, making them useful for tasks where the evolution of quality attributes over time needs to be considered, such as monitoring fruit ripening stages.

8. **Blockchain and Traceability:**

- *Immutable Records*: Blockchain technology can be integrated with AI to create a secure and transparent system for recording and verifying the quality assessment process. This enhances traceability and ensures the reliability of quality information.

9. **Automated Robotic Systems:**

- *Robotic Inspection*: AI-driven robotic systems equipped with cameras and sensors can automate the process of physically inspecting and sorting fruits based on quality criteria determined by the trained models.

Sensor Technologies:

Sensor technologies play a crucial role in post-harvest management by providing real-time data on environmental conditions, fruit quality, and storage parameters. Here are some key sensor technologies commonly used in post-harvest management:

1. *Temperature and Humidity Sensors:*

- Purpose: Monitor and control the storage environment to prevent temperature fluctuations and humidity levels that could lead to premature ripening, decay, or fungal growth.

- Application: Cold storage facilities, shipping containers, and transportation vehicles.

2. *Ethylene Sensors:*

- Purpose: Detect and measure ethylene gas, a plant hormone responsible for fruit ripening. Monitoring ethylene levels helps in managing the ripening process and optimizing storage conditions.
- Application: Ripening rooms, storage facilities.

3. *Gas Sensors:*

- Purpose: Measure the concentration of gases such as oxygen and carbon dioxide. Monitoring these gases is critical for managing the respiration rate of fruits and preventing anaerobic conditions.
- Application: Controlled atmosphere storage, modified atmosphere packaging.

4. *Weight Sensors:*

- Purpose: Monitor the weight of fruit batches to track inventory levels and assess changes in moisture content or freshness.
- Application: Conveyor belts, packaging lines.

5. Acoustic Sensors:

- Purpose: Detect internal quality attributes by analyzing the sound produced when tapping or vibrating a fruit. This can help identify issues like internal bruising or ripeness.
- Application: Quality assessment during sorting processes.

6. Color Sensors:

- Purpose: Measure the color of fruits to assess ripeness and external quality attributes.
- Application: Sorting and grading machines.

7. *Moisture Sensors:*

- Purpose: Measure the moisture content of fruits to prevent issues like dehydration or excessive moisture, which can lead to decay.
- Application: Storage facilities, packaging lines.

8. *RFID (Radio-Frequency Identification):*

- Purpose: Enable real-time tracking and traceability of individual fruit batches throughout the supply chain. RFID tags can store information such as origin, harvest date, and storage conditions.
- Application: Inventory management, traceability systems.

9. *Image Sensors (Cameras):*

- Purpose: Capture high-resolution images for computer vision applications, allowing for the visual inspection and quality assessment of fruits.
- Application: Sorting machines, quality control processes.

10. *Vibration Sensors:*

- Purpose: Monitor vibrations in storage or transportation equipment to identify potential issues, such as excessive mechanical stress or damage to fruits.
- Application: Conveyor systems, transportation vehicles.

11. *UV and NIR Sensors:*

- Purpose: Measure ultraviolet (UV) and near-infrared (NIR) light absorption to assess internal fruit quality attributes, such as sugar content and ripeness.

Application: Spectroscopy systems, non-destructive quality assessment.

The application of Artificial Intelligence (AI) in post-harvest technology brings several opportunities but also poses various challenges. Some of the key challenges include:

1. Data Quality and Availability:

- AI models rely heavily on high-quality and diverse data for training. In the post-harvest phase, obtaining comprehensive and accurate data can be challenging due to variations in crops, weather conditions, and storage environments.

2. Infrastructure and Connectivity:

- Many agricultural areas, especially in developing regions, may lack the necessary infrastructure and connectivity for seamless AI implementation. Limited access to reliable internet and power sources can hinder the deployment and operation of AI-based post-harvest technologies.

3. Resource Constraints:

- Small-scale farmers, who make up a significant portion of the agricultural sector, may face resource constraints in terms of finances, technology literacy, and access to modern equipment. Implementing AI solutions may require significant investments that are beyond the means of these farmers.

4. Adaptability to Diverse Crops and Conditions:

- Different crops and conditions require specific post-harvest treatments. Developing AI models that can adapt to the diversity of crops, storage facilities, and environmental factors is a

complex task.

5. Interdisciplinary Collaboration:

Successful AI applications in post-harvest technology often require collaboration between agronomists, data scientists, engineers, and other experts. Bridging the gap between these disciplines and fostering effective communication can be a challenge.

6. Ethical and Social Concerns:

The use of AI in agriculture, including post-harvest technology, raises ethical considerations such as data privacy, ownership of data, and potential displacement of labor. Ensuring fair and responsible AI practices is crucial.

7. Regulatory Frameworks:

- The implementation of AI technologies in agriculture may face challenges related to the lack of clear regulatory frameworks. Establishing guidelines and standards to ensure the safety, reliability, and ethical use of AI in post-harvest technology is essential.

8. Technology Integration:

- Integrating AI solutions with existing post-harvest technologies and practices can be complex. Compatibility issues and resistance to change from traditional methods may slow down the adoption of AI in the agricultural sector.

9. Scalability:

- Adapting AI solutions to different scales of farming operations, from smallholder farms to large agribusinesses, requires careful consideration. Scalability is crucial for widespread adoption and impact.

10. Environmental Impact:

- Assessing and mitigating the environmental impact of AI technologies in post-harvest processes is important. It's crucial to ensure that technological advancements contribute positively to sustainable agriculture practices.

Addressing these challenges requires collaboration among stakeholders, investment in research and development, and a holistic approach that considers the specific needs of different agricultural contexts.

Conclusion

Advanced technologies in AI are increasingly being used to automate a variety of on-farm sorting and transportation operations. In recent years, AI approaches have proven to be

useful and effective for automated fruit sorting and transportation at the on-farm post-harvest stage. This paper focused on determining the applications of AI for on-farm fruit sorting and transportation, identifying the challenges faced by these applications, and discussing the prospects and opportunities. Key findings related to data acquisition sensors, the use of AI models, and their merits are presented. Limitations and future research directions have been elaborated to provide an overview and in-depth analysis of potential applications of AI for on-farm sorting and transportation. We believe that these investigations will help direct future research toward building autonomous systems for on-farm sorting and transportation. In the context of increasing labor costs and the demand for better-quality produce in the fresh market, there will be a great need for AI-based systems for on-farm sorting and transportation. Given the rapid advancement of AI technologies, it is predictable that the use of AI for on-farm sorting and transportation will have a widespread application in precision agriculture in the near future.

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HEAT PUMP DRYERS: A SUSTAINABLE AND ENERGY-EFFICIENT REVOLUTION IN FOOD PRESERVATION

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Introduction

Drying is an essential process in agriculture and food preservation, as it helps extend the shelf life of perishable products by reducing their moisture content. Foods with high moisture levels are more susceptible to microbial growth and spoilage, making drying a necessary step in maintaining quality and safety. Despite its importance, drying is one of the most energy-intensive operations in the food industry, contributing significantly to overall energy consumption.

Conventional drying methods, such as sun drying and hot-air drying, typically use high temperatures to remove moisture. Although these methods are widely practiced, they often lead to a decline in product quality by affecting nutrients, color, texture, and flavor. As a result, there is a growing need for more efficient and gentle drying techniques.

Heat pump drying has emerged as a modern and promising alternative that addresses these limitations. This technology operates using a closed-loop system that carefully controls temperature and humidity, enabling effective moisture removal at lower temperatures. By recycling heat within the system, it significantly reduces energy consumption while maintaining high product quality.

Due to its energy efficiency, environmental benefits, and ability to preserve the nutritional and sensory properties of food, heat pump drying is gaining increasing attention in both industrial and small-scale applications. It represents an innovative approach to sustainable food processing and preservation.

Why Heat Pump Dryers Are Gaining Popularity

Heat pump drying has become increasingly popular due to its advanced technology and high energy efficiency. This method works by extracting heat from the surrounding air and using it to remove moisture from the product. Instead of wasting this heat, the system recovers and reuses it in a closed cycle, which significantly reduces overall energy consumption compared to conventional drying techniques.

One of the main reasons for its growing adoption is its suitability for drying sensitive materials such as food products and pharmaceuticals. Since the process operates at relatively low temperatures, it helps retain essential nutrients, natural color, texture, and flavor. In addition, precise control over temperature and humidity ensures uniform and consistent drying, resulting in better product quality.

Heat pump dryers are gradually replacing traditional drying systems because of several key advantages:

- They consume up to 50–60% less electricity
- They operate at lower temperatures, preserving nutritional and sensory qualities
- They provide uniform drying, improving overall product consistency
- They perform efficiently even in humid environmental conditions

These features make them ideal for drying a wide variety of products, including fruits (such as mango, banana, and apple), vegetables (like onion, tomato, and chili), as well as herbs, spices, meat, and fish.

Figure 1. Heat pump dryer

What Makes Heat Pump Dryers Different?

Controlled Temperature

Heat pump dryers typically operate within a temperature range of 30°C to 70°C. This controlled, low-temperature environment helps maintain the nutritional value, natural color, and flavor of the dried products.

Closed System Operation

The drying process takes place in a sealed chamber, which prevents contamination from external factors such as dust, insects, and polluted air. This ensures better hygiene and product safety.

Moisture Removal by Condensation

Unlike traditional dryers that expel moist air, heat pump systems remove moisture through condensation. The humid air is cooled, causing water vapor to condense and separate from the air, similar to the dehumidification process in an air conditioner. The dried air is then reheated and reused within the system.

How It Works

Heat pump drying operates on the principle of controlled air circulation and precise temperature regulation to remove moisture from products. In this system, moist air from the drying chamber is drawn into the unit and passed over a cooling coil. As the air cools, the water vapor condenses and is separated. The dehumidified air is then reheated and circulated back into the chamber to continue the drying process.

This continuous cycle forms a closed-loop system, which minimizes heat loss and allows accurate control of both temperature and humidity. As a result, drying occurs evenly and gently, making the method especially suitable for heat-sensitive materials.

In simpler terms, a heat pump dryer works by reusing the same air repeatedly:

- Warm air passes over the product and absorbs moisture
- The moist air is cooled, causing the moisture to condense and be removed
- The dried air is reheated and sent back into the chamber

Because heat is continuously recycled, the system requires less energy and operates effectively at lower temperatures compared to conventional dryers.

Main Components of a Heat Pump Dryer

A heat pump dryer consists of four key components:

- Evaporator – removes moisture from the air by cooling it

- Compressor – increases the temperature and pressure of the refrigerant
- Condenser – releases heat to warm the air before it re-enters the chamber
- Expansion valve – regulates the flow of refrigerant within the system

Together, these components ensure efficient moisture removal while conserving energy.

Although heat pump dryers involve a higher initial investment, they offer long-term savings through reduced energy consumption and improved product quality. This makes them a cost-effective and sustainable option over time.

Classification of heat pump dryers

Heat pump dryers used for food processing come in different types, each designed to meet specific needs depending on the kind of food and the scale of operation. One of the most common types is the ***closed-cycle heat pump dryer***, where the air inside the system is reused again and again. In this setup, moist air from the food is cooled to remove water, then reheated and sent back into the drying chamber. This controlled process helps maintain low temperatures and stable conditions, which is especially useful for preserving the color, flavor, and nutrients of foods like fruits, herbs, and spices

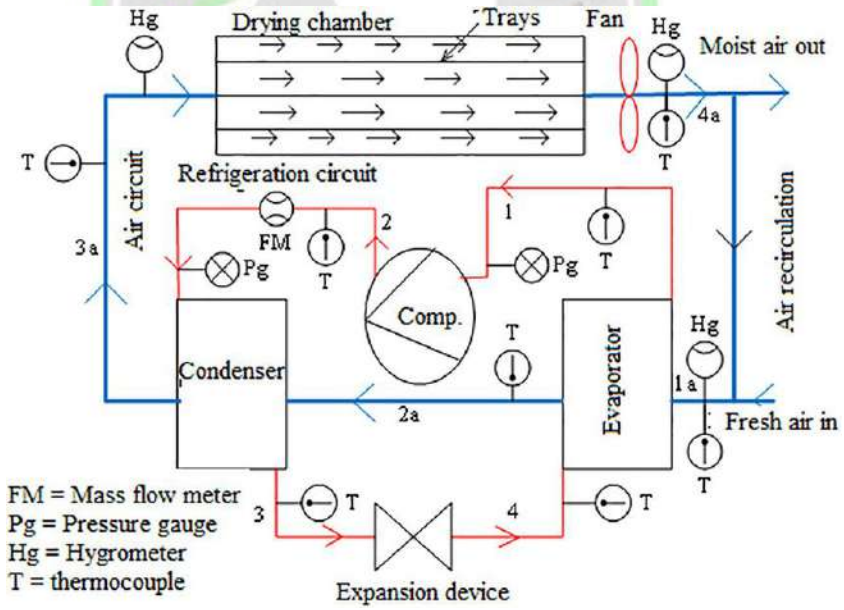

Figure 2. Schematic diagram of the heat pump drying system

(Source: Experimental energy-exergy performance and kinetics analyses of compact dual-mode heat pump drying of food chips - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Schematic-diagram-of-the-heat-pump-dryingsystem_fig1_339805214)

On the other hand, ***open-cycle heat pump dryers*** bring in fresh air from outside, heat it, and then release it after it has absorbed moisture. While these systems are simpler and cheaper, they are less efficient and their performance can be affected by weather conditions.

There are also ***hybrid heat pump dryers***, which combine the heat pump system with other heat sources such as solar energy or electric heaters (Figure 2). This makes them more flexible and capable of handling larger volumes or tougher drying conditions. Depending on how they operate, heat pump dryers can be either ***batch-type or continuous***. Batch dryers handle one set of food at a time and are commonly used by small businesses or farmers because they are easy to operate. Continuous dryers, in contrast, allow food to move through the system on conveyors, making them suitable for large-scale industrial production where speed and consistency are important.

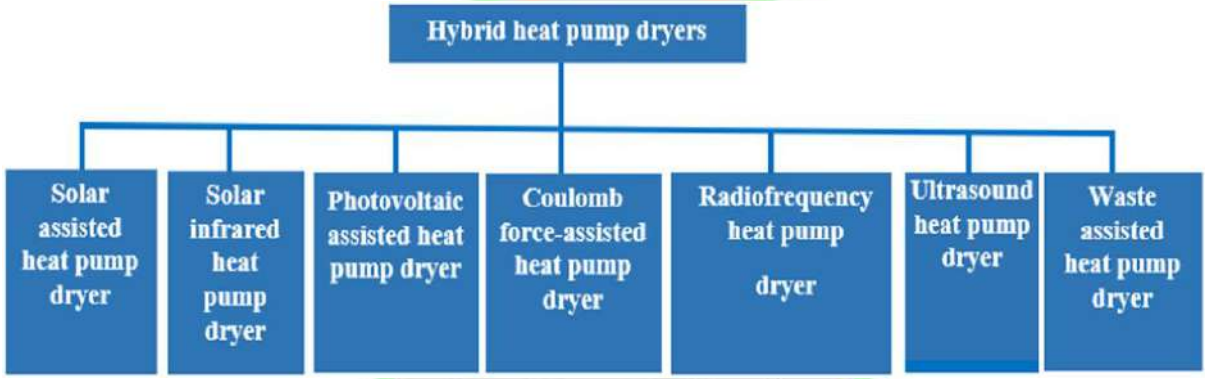

Figure 3. Various types of hybrid heat pump dryers

(Source: Loemba ABT, Kichonge B, Kivevele T. Comprehensive assessment of heat pump dryers for drying agricultural products. Energy Sci Eng. 2023;11:2985-3014. doi:10.1002/ese3.1326)

In terms of design, ***tray-type dryers*** are the most widely used. In these systems, food is spread out on trays, and warm air circulates evenly to remove moisture. They are simple, versatile, and suitable for a wide range of food products, although they require manual loading and unloading. Some advanced heat pump dryers are specially designed to remove moisture at very low temperatures, which is important for delicate products like medicinal plants and specialty herbs. Overall, the choice of a heat pump dryer depends on factors such as the type of food, the required quality, and the available budget, with each type offering its own balance of efficiency, cost, and performance.

Advantages of Heat Pump Dryers:

Heat pump drying offers several clear advantages over conventional drying methods, especially when it comes to energy efficiency and environmental sustainability. Unlike traditional dryers that rely on fossil fuels or electric heating, heat pump dryers work by recovering and reusing heat within the system. This significantly reduces energy consumption and operating costs. Since they can utilize ambient air or even recover waste heat generated during the process, they are considered an eco-friendlier option, producing fewer emissions and minimizing energy loss.

Another major benefit of heat pump drying is its ability to operate at relatively low temperatures while still maintaining effective drying. This makes it particularly suitable for heat-sensitive materials such as fruits, vegetables, and even pharmaceutical products. The gentle drying conditions help preserve important qualities like nutrients, natural color, flavor, and aroma, while preventing damage that typically occurs at high temperatures, such as nutrient degradation or structural changes in the product. In addition, these systems allow precise control over air temperature and humidity inside the drying chamber, ensuring consistent and uniform drying results.

Heat pump dryers are also highly versatile and adaptable. They can be designed for a wide range of applications, from small-scale or household use to large industrial operations. Their ability to maintain stable drying conditions regardless of external weather makes them reliable throughout the year, unlike traditional sun drying methods. Overall, with their combination of better product quality, energy efficiency, consistent performance, and environmentally friendly operation, heat pump dryers have become an attractive and effective solution for modern food drying needs.

Applications

Heat pump dryers are widely used for drying a variety of food products, including fruits such as mangoes and bananas, vegetables like carrots and tomatoes, as well as herbs, spices, meat, and fish. Drying is one of the oldest and most effective methods of food preservation, and heat pump drying improves this process by making it more efficient and controlled. In these systems, warm air is circulated over the food to remove moisture, while the heat required for drying is generated through a refrigerant cycle and supplied to the drying chamber.

As the air passes over the fruits and vegetables, it absorbs moisture and helps remove gases such as ethylene, which can accelerate spoilage. The moist air is then directed back into the system, where it is dehumidified, reheated, and recirculated. This continuous and controlled cycle ensures efficient moisture removal while maintaining the quality, safety, and freshness of the final product.

The drying process continues until the desired moisture content is achieved. Because the process is gradual and carefully controlled, it ensures uniform drying without damaging the structure, color, or nutritional value of the produce. Heat pump dryers are especially valued for their ability to reduce energy consumption while still delivering high-quality dried products. Due to their flexibility and efficiency, they are suitable for both small-scale farmers and large food processing industries, making them an important technology in modern food preservation.

Conclusion

Heat pump drying is an efficient and sustainable method for food preservation that offers clear advantages over conventional drying techniques. By reusing heat within the system, it reduces energy consumption and operating costs while maintaining consistent drying conditions. Its ability to operate at low temperatures makes it especially suitable for heat-sensitive foods, helping to preserve nutrients, color, and flavor.

In addition, heat pump dryers provide uniform and controlled drying, ensuring high-quality end products without structural damage. Their flexibility allows them to be used in both small-scale and industrial applications, making them a practical solution across the food processing sector. Overall, heat pump drying combines energy efficiency, product quality, and environmental benefits, making it an important technology for modern food processing.

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EVOLUTION OF INDIAN GARDENS: FROM INDUS-VALLY CIVILIZATION TO BRITISH COLONIAL ERA

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Abstract

Over the course of several historical eras, Indian gardens have seen a substantial transformation from prehistoric forest-based systems to planned and decorative landscapes. Sacred groves and the cultural significance of trees were highlighted in early Indus Valley Civilization and Vedic traditions. During the Buddhist, Mauryan and Gupta eras, gardens evolved further, combining practicality and beauty. With the advent of formal layouts, water features and a variety of plant species, garden design reached its pinnacle during the medieval period, especially under the Mughals and Rajput's. On the other hand, current landscaping techniques were influenced by European styles that were adopted during the British era, such as lawns, flower beds, and public parks. In general, Indian gardens showcase a fusion of aesthetic principles, ecological significance, and cultural legacy. They are now crucial to the preservation of biodiversity, urban planning, and environmental sustainability, demonstrating their applicability in tackling contemporary issues like climate change and sustainable development.

Keywords: *Indian gardens, History, Landscape design, Sacred groves, Biodiversity, Sustainability.*

Introduction

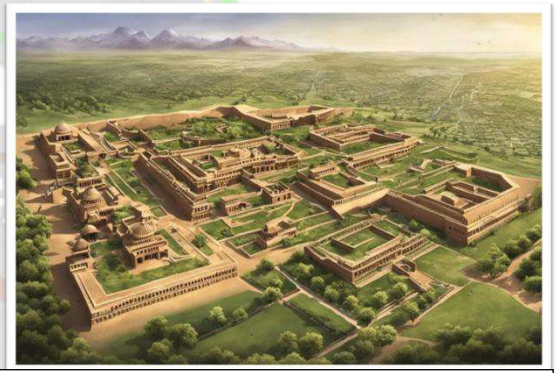
Gardens have existed since ancient times and have evolved significantly over the centuries. The earliest form of gardening can be traced to the "forest garden" of prehistoric times. During this period, the culture and lifestyle of people were closely associated with forests, or *vanas*. Trees were highly revered and several species were considered sacred. With the domestication of plants, cultivation for food production gradually became the primary focus of

human activity. However, the tradition of maintaining sacred groves continued, particularly around temples, where specific plants and trees held distinct religious and cultural significance. About 2500 years ago, Gautama Buddha advocated planting a tree every five years. As time went on, the garden began to grow herbs and other useful plants. Eventually, ornamental gardens emerged, which were first connected to the affluent segments of society. As time has gone on, gardens which were once mainly valued for their aesthetic qualities have become crucial to combating climate change-related global warming and preserving the planet. For urban society to live sustainably, urban landscaping has become essential. The key eras in the development of Indian gardens are listed here.

Indus Valley Civilization

The highly developed Indus Valley Civilization (3000–1500 BCE), which thrived along the Indus River in northwest India, is where Indian landscaping history starts. (Randhawa, G. S. *et. al.*,1986). Early indications of plant use can be found in archaeological discoveries from

Mohenjodaro Landscape Architecture



AI Generated View of Landscape Design with Gardens of Mohenjodaro

Mohenjo-daro and Harappa. in everyday situations and ceremonial settings. Important trees, including the Peepal (*Ficus religiosa*), which is still revered in Buddhism, Hinduism, and Jainism, are depicted on seals found at these locations Weeping Willow (*Salix babylonica*) indicating the awareness of different species and their symbolism. (Sharma et al., 2021). This implies an early understanding of species that have spiritual and metaphorical meaning. In the Indus Valley, homes frequently had central courtyards where valuable trees and plants that provided shade were grown, despite the lack of formal gardens as we know them now.

These areas functioned as miniature gardens for: Cooling the home, religious rituals, aesthetic comfort, Providing fruits, leaves and medicine

Vedic Period

The Vedic culture emerged in India between 1500 and 600 BC, following the demise of the Indus Valley culture around 1400 BC. The four Vedas the Rig Veda, Sama Veda, Yazur Veda, and Atharva Veda made the Aryans of the Vedic era famous. They loved flowers and trees. The Vedic Sanskrit texts make specific reference to lotuses. The Ashvattha tree, a peepal (*Ficus religiosa*) tree with beautiful leaves, is mentioned in the Atharva and Rig Vedas. Palaces with lovely gardens, trees, flowers, fruits, and lakes full of lotus flowers are also mentioned in the Aryan epics (*Ramayana and Mahabharata*). The Valmiki's Ramayana, which mentions roughly 182 plant species, goes into great depth about plant diversity (Murugesan, 2014). While the Kishkinda kanda talks about the forest and biodiversity of the Pampa Lake area, the Aranya kanda depicts the greenery in the Sage Agasthya's shelter, and the Bala kanda in the Ramayana highlights the region's woods and vegetation. The Ashoka (Saraca indica) trees themselves are the source of the term "Asokavana," where Sita, the wife of King Rama, was imprisoned by King Ravana. The following are a few plants and flowers that are referenced in this epic:

S. No.	Common name	Botanical Name
1.	Madhumalti	*Combretum indicum*
2.	Mogra (Arabian jasmine)	*Jasminum sambac*
3.	Taala palm	*Botassus flabellifer*
4.	Arjun	*Terminalia arjuna*
5.	Champa	*Michelia champaca*
6.	Sal	*Shorea robusta*
7.	Ashoka	*Saraca indica*
8.	Peepal	*Ficus religiosa*
9.	Bargad	*Ficus benghalensis*

Buddhist Period

There were lovely gardens in the cities of Nalanda and Taxila, and gardens were created around monasteries and stupas during the Buddhist era. In 563 BC, Lord Buddha was born beneath the Ashoka tree (*Saraca indica*), became enlightened beneath a Peepal tree (Ficus

religiosa), preached under the shade of Banyan (*Ficus benghalensis*) and Mango (*Mangifera indica*) trees and passed away in a Sal (*Shorea robusta*) forest. Other trees connected to Buddha, such as Kadam, Albizzia, Palash, Amaltas, Neem, Chandan, Aonla, Bel etc. have also been mentioned in a number of literary works. Jetavana, Nyagrodhvana, Mahavana, Venuvana and other forests (Vana) are directly associated with Lord Buddha (Bidari, 2022).

The Mauryan Empire

The Mauryan Empire was founded in 300 BC by Chandragupta Maurya a visionary who recognized the value of forests and designated a high-ranking official to maintain them. His advisor, Kauṭilya (also called Vishnugupta), wrote a treatise outlining the development and significance of flower gardens and fruit orchards in water-scarce areas. Arboriculture and avenue plantations were developed during the reign of the great emperor Asoka (273–232 BC), also known as Asoka-the-great (Gupta *et al*., 2000). He adopted Arboriculture as one of his state policies. He may be considered as the Father of Arboriculture in India. During his time, trees were planted on both sides of the road. This planting of roadside avenue trees was known as *Margeshuvriksha*. In Anuradhapur, Sri Lanka, where he was sent as a missionary to propagate the teachings of the Buddha, his son Prince Mahendra planted a sampling of the magnificent Bodhi tree (*Ficus religiosa*), which was brought from India.

Gupta Period

Kalidas, arguably the finest Sanskrit poet and dramatist, flourished under King Chandragupta II, often called Vikramaditya, during the Gupta era. In his well-known play "Shakuntala," Kalidas (c. 57 BC) describes a pleasure garden with trees like Kachnar (*Bauhinia varieagata*), Ashoka (*Saraca indica*), Arjuna (*Terminalia arjuna*), Kadamba (*Anthocephalus cadamba*), Maulsari (*Mimusops elengi*), Parijat (*Nyctanthes arbor-tristis*) and Palash (*Butea monosperma*). Similarly, scholar Amarasimha wrote the Sanskrit thesaurus "Amarakosha" during the Gupta era, which is regarded as an encyclopaedia of nature and encompasses research on plants and gardens, woodlands, crops, fertilizer etc. The plants that are revealed in the Amarakośacan be classified into huge trees, edible fruit trees, shrubs, herbs, creepers, water plants, grasses, pulses, cereals, wild cereals and others (Boddupalli, 2020).

Harshvardhana Dynasty

Following the fall of the Gupta empire, Emperor Harshavardhana (606–647 AD) emerged as a powerful and effective leader who unified Northern India. He established Kannauj as his

capital, a city with expansive structures, water tanks and lovely gardens. There were numerous temples and monasteries with hallowed flora and trees.

Pala Dynasty

The Chola Dynasty

Out of all the South Indian kingdoms, the Chola Dynasty was the most powerful. Religious offerings were made using a cascade of flowers as part of the customs of the festivals held during that time. Meetings took place beneath large trees, such as tamarinds. Committees were also established to maintain gardens. It was known that Rajadhiraja Chola II (1166–1178) had cultivated flower gardens all around his large palace.

Mughal emperor

The Mughal emperor Babur, who subjugated India in 1526, loved gardening and created gardens at Panipat and Agra. The Archaeological Department continues to maintain Aram Bagh in Agra. Bagh-i-Safa (The Garden of Purity) and Bagh-I-Wafa (The Garden of Fidelity) in Kabul, Afghanistan, were his favorite gardens. The design of Mughal gardens in the formal gardening style was the Mughal monarchs' greatest contribution to Indian horticulture. The Persian rose was brought to India by Babur. The introduction of exotic plants like cypress, carnation, narcissus, daffodils, lilies, tulips etc. was another significant addition. Akbar (1556–1605) loved gardens as well, and his new capital, Fatehpur Sikri, featured lovely gardens, trees and flowers. He founded the Nasim Bagh Garden in Srinagar, next to Dal Lake. One of the best examples of a Mughal garden from that era is Akbar's tomb garden at Sikandra. Both Jahangir and his spouse, Nur Jahan, had a deep love for flowers and gardens.

Amrit Udyan, New Delhi

Mughal Landscaping

He designed the gardens in Kashmir at Shalimar, Achhabal and Verinag. Jahangir also constructed the tomb at Itimad-ud-Daulah in Agra to honor his father-in-law. Mughal garden

architecture and floral design reached their pinnacle during the Shah Jahan era (1627–1658). In honor of his queen Mumtaz Mahal, he created the plan for the Taj Mahal garden in Agra. His greatest work was the Shalimar garden in Lahore, which is currently in Pakistan. The Chashme Shahi garden in Kashmir was established by one of his administrators. However, Firoz Shah Tughlaq (1351-1388 A.D.) had built canals and approximately twelve hundred gardens surrounding Delhi before to the arrival of the Mughals. After defeating Babur and briefly ruling India, Sher Shah Suri (1540–1544) made a major contribution by constructing the Grand Trunk Road (GT Road) and planting avenue trees on both sides. Wajid Ali Shah (1847–1856), the final Nawab of Oudh, made another important contribution by founding the Sikandar Bagh, which is now the National Botanical Research Institute (NBRI), Lucknow.

Rajput Kings

In addition to their bravery, the Rajput monarchs had a deep appreciation for gardening. The renowned garden at Amber Fort near Jaipur was started by King Man Singh (1590–1615) and completed by Jai Singh II (1699–1743). The park features a pool and three terraces it influences by Mughal Garden. Additionally, Jai Singh II (1727 A.D.) founded the city of Jaipur and built a palace with lovely gardens in its centre. Raja Abhai Singh (1724-1749 A.D.) created the Mandor garden close to Jodhpur. In Deeg, Rajasthan, Suraj Mal constructed the most exquisite gardens ever created by a Rajput monarch. The garden palace featured water courses and fountains. The Rai Praveen Mahal at Orchha, Madhya Pradesh, which served as the capital of the Rajput state of Bundelkhand from 1531 to 1783, has a view of the expansive Anand Mahal Bagh, a garden that is separated into two halves by tall walls (Fairchild, 2014). There was also a lovely garden with lotus pools, water tanks, and a baradari at the Nagaur fort (Ahhichatragarh Fort). The Chauhan Rajput Kings' palace, the Chitra Shali Palace garden in Bundi, Rajasthan, included a sizable garden terrace with a central swimming pool. Ghats (steps) and chattris (pavillions) were constructed around lakes or ponds in Rajput gardens because, according to Hindu tradition, submerging oneself in water is both a spiritual and a body-cleansing process. There are no lakes or ponds in the gardens built by the Mughals, who favored channels with flowing water since Islamic customs call for washing in flowing water rather than submersion.

The British Era

From the 17th century until 1947, the British attempted to create gardens in India that reflected their native surroundings. These gardens had well-kept grass, gravel walkways, and

herbaceous borders. Dahlias, sweet peas, hollyhocks, phlox, carnation, verbena, dahlias, larkspur, chrysanthemum and geraniums were among the annual flowers they loved and chose to the fragrant trees, shrubs, climbers and bulbs that were utilized in Indian gardens back then. They created lovely gardens with seasonal flowers and well-kept lawns in their bungalows. For English ladies, gardening was a pastime that kept them occupied and allowed them to import the exotic annual flowers from England. Roundabouts, avenue plantations, flower beds, and greenery all improved with the advent and growth of automobiles.

The construction of botanical gardens and public parks was one of the British's major contributions. The creation of Rashtrapati Bhavan Garden, a Mughal-style garden in New Delhi, by Edwin Lutyens on Lady Hardinge's guidance in 1929 is one of British India's most significant contributions to horticulture. Other significant figures who contributed to the growth of gardens in British India include Edward Clive, Wellesley and later Lord Curzon. Bengaluru also became very green during the British era, especially under Hyder Ali and Tipu Sultan. Together with Mirza Ismail, Diwan of Bengaluru and Mysore, Maharaja Krishna Raja Wodeyar of Bengaluru constructed numerous parks and small gardens across the city. Mirza Ismail had a keen sense of style and contributed significantly to Bengaluru's and Mysore's beauty. Due to its parks and gardens, this Karnataka capital is now also known as the "Garden City." The city's year-round temperate climate contributes to its abundance of vegetation.

Sim's Park, Conoor, by J.D. Sim

Indian Botanical Garden, Shibpur.

However, the Indian monarchs also made contributions to the development of horticulture during this British era. On the shores of Pichola Lake in Udaipur, Rajasthan, Maharana Sajjan Singh created the Gulab Bagh, also called Sajjan Niwas Garden, in the 1850s. It got its name from the variety of roses it had. In 1760, King Hyder Ali founded the Lal Bagh

Garden in Bengaluru, which his son Tipu Sultan completed. The Baradari garden in Patiala and the fruit orchard in Chail, where they brought the newest improved types of fruits and flowers, are credited to King Bhupinder Singh and his son Yadavindra Singh of Patiala.

Garden developed by British

S. No.	Name of Botanical Garden	District	Established in
1.	Horticulture Research Institute, Saharanpur	Uttar Pradesh	1750
2.	Indian Botanical Garden, Shibpur	Kolkata	1787
3.	Government Botanical Garden, in Ooty	Tamil Nadu	1848
4.	Agri-horticultural Society Garden, Kolkata.	West Bengal	1872
5.	Sim's Park, Conoor, by J.D. Sim	Tamil Nadu	1874
6.	Llyod Botanical Garden, Darjeeling	West Bengal	1878
7.	Botanical Garden, Coimbatore	Tamil Nadu	1908
8.	Bryant Park, Kodaikanal	Tamil Nadu	1909
9.	Forest Research Institute, Dehradun	Uttrakhand	1934

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ADVANCES OF *BOMBYX MORI* SILK AND ITS ECONOMIC IMPORTANCE

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Introduction

Bombyx mori cocoon silk fibroin has demonstrated encouraging promise as a biomaterial for biological uses. Fibroin, a protein a main component from silk that is extensively utilised in the biomedical industry due to its mechanical strength, toughness and elasticity as well as its biocompatibility and biodegradability (Bitar *et al*., 2024). The top producers of silk are China and India, then Japan and Thailand. For almost 5,000 years, the well-domesticated silkworm *Bombyx mori* has been used to produce silk (The International Silkworm Genome Consortium, 2008). India is the world's second-largest producer of silk, with an annual production of 23,855 MT in 2012-13, of which 19,735 MT (79.06%) came from mulberry raw silk and 1775 MT from bivoltine (Anon., 2016). Raising silkworms to make silk is known as sericulture. A complete understanding of chemistry, physics and biology as well as a wide range of characterization methods are necessary for research on silk (Pereira *et al*., 2015). Silk has also been widely utilised as a luxury raw material for textiles as it is the only known natural fibre that is continuous, robust, and simple to weave. Silk textiles have long been regarded as expensive, sophisticated materials due to the sparkling gloss of the fibre (Pereira *et al*., 2015). Silk fibroin has several biological uses, such as tissue engineering, bone regeneration, corneal regeneration and wound healing (Yaiphabi *et al*., 2025).

Silkworm biology

The most widely manufactured silk is made from the silkworm (larva or caterpillar) of the domesticated *B. mori* moth, a member of the Bombycidae family that is completely dependent on humans and no longer found in the wild. *B. mori* silk is made by silkworms consuming on the leaves of white mulberry trees (*Morus alba*), it is sometimes referred to as mulberry silk. *B. mori* silk passes through several phases in its development cycle. Silkworm eggs are laid in a controlled setting during the initial stage. The female dies nearly instantly after laying 300-400 eggs at a time, while the male only survives for a brief amount of time. The eggs are fed for around ten days in the second stage before hatching into larvae. The third phase, which feeding stage, which can last up to six weeks, is when the larvae are continuously fed mulberry leaves so they can store adequate nutrition and change their skins five times. The larvae are then prepared to spin silk fibres to form cocoons around themselves. During metamorphosis, cocoons shield the moth from possible predators as well as microbial deterioration and desiccation. The cocoon construction is where the transformation from pupa to moth takes place and raised commercially before the pupae emerge, *B. mori* silkworms are slaughtered. This process enables the entire cocoon, which can weigh several kilos, to unravel as a single, continuous silk thread that is between 600 and 1500 meters long (Kundu *et al*., 2013). Advance study was also conducted by Yaiphabi *et al*., 2025 on physicochemical characterization of Silk Fibrion film, about *Antheraea frithi* Moore, a non-mulberry silkworm, uses its natural cocoon to produce a silk fibroin film through a sequence of processes that include demineralisation, degumming, dissolving and casting of the resulting silk fibroin solution.

Table 1: Scientific classification of the silkworm (Akbay, 1981)

Sl.No.	Phylum	Artropoda
1.	Class	Insecta/Hexapoda
2.	Order	Lepidoptera
3.	Suborder	Macro Lepidoptera-Heterocera
4.	Super Family	Bomycoiden
5.	Family	Bomycidae
6.	Genus	Bombyx
7.	Species Insecta/Hexapoda	*B. mori*

Distribution of silkworm in India

India is the only nation in the world that produces all five types of silk-Mulberry namely Eri, Muga, Tropical Tasar and Temperate Tasar. According to latest data from the Indian government. In the financial year that concluded in 2016, India produced 28,523 metric tonnes of raw silk. The ten states in India that produce the most silk are as follows: Karnataka, Andhra Pradesh, Assam, West Bengal, Jharkhand, Tamil Nadu, Meghalaya, Nagaland, Manipur and Maharashtra (Gautam *et al*., 2022).

Bioactive compounds of *Bombyx mori* (Rajput *et al*., 2024)

1. Fibroin
2. Sericin
3. Nutritional content
4. Phenolic compounds- Proteins, Lipids, Vitamins
5. Other Metabolites -Ferulic, Cinnamic acid, Quercetin, Luteolin

Types of Silk worm

The five main commercially significant varieties of silk are produced by several kinds of silkworms, which in turn consume a variety of edible plants: Other types of silks, other than mulberries, can also be referred to as non-mulberry silks. The different types are mentioned below:

1. Mulberry
2. Tasar
3. Oak Tasar
4. Eri
5. Muga
6. Anaphe
7. Fagara silk
8. Spider Silk
9. Coan silk

Potential uses for silk-producing moths (*Bombyx mori*) in skincare and cosmetics (Rajput *et al*., 2024)

1. Moisturising and nourishing the skin
2. Anti-aging benefits

3. Skin regeneration and wound healing
4. Relaxing and anti-inflammatory properties
5. Antioxidant and antimicrobial qualities
6. Formulations for cosmetics utilising silk proteins

Silkworm Products in terms of Economic

Since it served as the foundation for both rural and urban economies in Asia, Europe and America, the production of silkworm silk thread-the primary product regarded as a natural protein filament and the finest yarns-had a significant influence on economic growth. A physical cultural legacy is also built on the production, processing and trading of silk, which promotes technological advancement, skill development, and work organization strategies and technology transfers, as well as creating different kinds of rural and urban landscapes. Because of these characteristics, sericulture activities are particularly well-suited to discussing economically significant issues from a global perspective (Hăbeanu *et al*., 2019). According to Data Bridge Market Research, the textile industry has grown significantly, which has raised the need for silk. Advanced tools and equipment are not needed to produce silk. These factors aid in the expansion of the industry. The useful substances known as silk fibrous proteins (sericin and fibroin) are created by biosynthesis in the silkworm sericogenic glands. Sericin, which accounts for 25-30% of the protein, forms the cocoon by protecting the fibroin fibre in a number of sticky layers. Sericin ensures the cocoons cohesiveness by binding the silk strands together (Zang, 2002). Additionally, another progressive study was also conducted by Yaiphabi *et al*., 2025 on silk fibroin films thermal stability for possible use as a biomaterial in biomedical applications. According to their current investigation, degummed silk fibre was more soluble in calcium nitrate tetrahydrate at lower concentrations and can be applied in medical applications.

Conclusion

The silkworm, or *Bombyx mori*, is the basis of the world's sericulture industry and is essential in both biological and economic settings. In addition to sustaining conventional textile markets, its capacity to manufacture high-quality silk fibroin has created new opportunities for industrial, cosmetic, and biological uses. Beyond its scientific value, raising silkworms gives millions of rural households a means of subsistence, greatly boosting job creation and economic stability, particularly in emerging nations. Moreover, silkworm silk promotes sustainable development objectives as it is an eco-friendly and renewable resource. As a result, the ongoing

development and use of silkworm resources has enormous potential to support both creative research fields and economic progress.

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CLIMATE CHANGE, AGRICULTURE AND PEST DYNAMICS: UNDERSTATING THE COMPLEX RELATIONSHIPS

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Introduction

Climate change has an impact on agriculture. Abiotic and biotic elements including temperature, humidity, rainfall, and sunlight all affect crop growth. Climate parameters are changing as a result of the atmosphere's growing concentration of greenhouse gases. The food supply is impacted both directly and indirectly by this, as are crops, land, animals, and insects. Crop growth will accelerate as atmospheric carbon dioxide levels rise, although crop periods will shorten as temperatures rise. This will decrease the impact of fertilizer application, increase evaporation, and alter the crop-pest balance. Additionally, agricultural production will be indirectly impacted by this change. Food security and agricultural productivity will suffer as a result. Crop pests are being impacted by climate change. Cotton has seen a decline in productivity over the past 45 years due to a high number of mealybugs and flower borers. In Maharashtra, tobacco leaf-eating caterpillars, semiloopers, and leafhoppers have caused significant harm to soybean crops. Environmental variables trigger genetic changes in pest populations. The following are some potential impacts of climate change on pests.

Geographic distribution: The pest's geographic range will be impacted by climate change. Additionally, the pest's current geographic spread will be impacted by how climate change affects their feeding plants. Extremely high and low temperatures have an impact on the mealybug's geographic range.

Outbreaks of pests: Cropping patterns, the availability of substitute food plants, and ineffective pest control will all be impacted by climate change. Large-scale pest outbreaks will result from this.

Migration of pests: When there is insufficient food and unfavourable weather for survival and reproduction, pests will move from one place to another. Changes in population dynamics: The frequency and quantity of insects are significantly impacted by climate change. Insects grow quickly and create more generations when temperatures are high. There will be a significant bug infestation as a result. New insect outbreak and secondary pest resurgence: New insects will appear if climate change creates a favourable environment. Additionally, the existing secondary pests will become the primary ones.

The environment has both biotic and abiotic components. Wind, sunlight, humidity, and temperature are examples of abiotic variables. The quantity of insects is directly impacted by these. By altering the biotic elements in the environment, these factors also have an indirect impact on the quantity of insects. The biotic factors include the food of insects and other living organisms, mainly their natural enemies.

Abiotic elements

Temperature, humidity, wind, and sunlight all have a significant impact on an insect's capacity to develop, persist, reproduce, and lay eggs. The death rate of insects and their natural enemies is increased by extremely high or low temperatures, humidity, and precipitation. Insects thrive and reproduce in a favourable environment; in a less favourable environment, their death rate rises and their population falls.

Temperature:

Insects typically inhabit areas with favourable temperatures. Insects are harmed by temperatures that are too high or too low. As a result, the insects perish and the ones that survive do not develop normally. However, whether the temperature is too high or too low, some insects hibernate instead of thriving. If the temperature drops, some insects, like locusts, cannot hibernate; they must either keep developing or perish. Certain insects, like cutworms and mealybugs, can survive at extremely cold temperatures. The cocoon stage of their life cycle is able to withstand temperature variations. If the conditions are not favourable, moths hibernate. The bug grows quickly and produces more generations if the temperature climbs to a specific point. If the conditions are not favourable, moths hibernate. The insect grows more quickly and produces more generations if the temperature rises to a particular point, and it grows more slowly if the temperature falls.

Humidity: Temperature affects humidity. The insect's body has less water when the humidity drops, which has negative consequences. The following are detrimental to the insect if humidity levels rise:

- A rise in bacteria, viruses, fungus, and other microorganisms that cause sickness in insects and ultimately lead to their death.
- Natural growth and feeding patterns are negatively impacted.
- In winter, insects cannot withstand cold temperatures if their bodies contain an excessive amount of water.
- High humidity speeds up the growth of some insects while harming others.

Sunlight: Unlike temperature or humidity, sunlight has no negative effects. Insect locomotion, feeding, adult emergence, mating, egg laying, and moulting are all impacted by sunlight. In addition to temperature, the insect is also impacted by humidity, sunshine, air pressure, air currents, and the concentration of carbon dioxide (CO2). Depending on air currents, aphids, mealybugs, scale insects, etc., can travel great distances.

Biotic elements: The population of insects is influenced by biological variables, including food and insect natural enemies.

Food: Crops are the primary food source for significant agricultural insects. Rather than the quantity of food, the type of food determines the number of insects. Higher quality food attracts more insects. Because of their poisonous contents and other characteristics, several plants are able to withstand insects. Inconsistent rainfall encourages the growth of weeds and the feeding of insects. The crop is then harmed by these insects. An insect will alter if its population grows in a particular area. Aphids, for instance, lack wings, but as their numbers grow, some of them acquire them and use them to migrate with air.

Natural Enemies: Insect’s natural enemies include parasitic insects, predatory insects and pathogens such as bacteria, viruses, fungus, and fungi. The number of insects' natural adversaries rises in tandem with the quantity of insects in the wild. Aphid populations on cotton, for instance, are positively correlated with the abundance of predatory insects like syrphid flies and lady bird beetles.

Favourable conditions for various pests on crops

Cotton	
Insect Pest	**Favourable condition**
Jassids	When temperatures, humidity, and rainfall rise and sunshine levels fall, locust incidence rises. The prevalence is increased when pyrethroid pesticides are used excessively.
White Fly	Whitefly outbreaks are caused by lack of rainfall, prolonged periods of rain, and high temperatures. Whitefly infestations increase when maximum temperatures and sunlight increase, and when minimum temperatures, rainfall, and humidity decrease.
Thrips	In hot and dry weather, the reproduction of flower bugs increases, the life cycle is completed in a shorter period, and more generations are produced.
Aphids	Continuous drizzle and high humidity are conducive to the growth of this pest.
American Bollworm	Low temperature, cloudy weather and high humidity are conducive to this pest. The infestation increases after heavy rains. Also, short planting distance and excessive use of synthetic pyrethroid insecticides are also conducive to the infestation of this pest. This pest feeds on many weeds and crops like sorghum, pethari and pigeonpea, gram, tomato etc.
Mealy bug	Hot and dry weather is conducive to the pest. This pest feeds on many weeds and crops such as carrot grass, pethari, wild okra, kolashi, china rose etc.
Soybean	
Insect Pest	**Favourable condition**
Leaf eating / folder	This pest remains active from July to October. But it causes more damage in the third week of September. Long

	exposure and then irregular rains increase the incidence. This pest also feeds on the trees.
Girdle beetle	At the end of the season, the larvae of this insect go into hibernation and then during the rainy season, the larvae pupate and the adults emerge and begin the infestation.
Stem fly Tobacco Leaf Eating Caterpillar	This pest is active from June-July to October, and good rainfall followed by dry and irregular rainfall increases the incidence of this pest. Low temperatures and high humidity are conducive to this pest.
Semilooper	The outbreak increases due to irregular rainfall.
Groundnut	
Insect Pest	**Favourable condition**
Aphids	Cold weather is conducive to this pest.
Thrips	Hot and dry weather is more conducive to the spread of this pest.
Red Hairy caterpillar	Prolonged exposure to rain and subsequent rain increases the incidence.
Tobacco Leaf Eating Caterpillar	Good rainfall followed by dry and irregular rainfall increases the incidence of this pest. Low temperatures and high humidity are conducive to this pest.
White grub	The adults of this insect emerge from the ground after heavy rains.
Pigeonpea	
Insect Pest	**Favourable condition**
Plume Moth	Sunlight and temperatures above 25 degrees Celsius during flowering increase the incidence of the feather moth.
Pod borer	Temperatures of 27-28 degrees Celsius are favourable for this insect.
Chickpea	
Insect Pest	**Favourable condition**

Gram Pod borer	Temperatures of 20 to 30 degrees Celsius are conducive to the growth of this pest. Also, alternative food plants like tur, tomato etc. increase the incidence of this pest.
Cutworm	High soil moisture and high organic matter content in the soil at the time of sowing are conducive to this pest.
Termite	termites are more prevalent in light, dry soil. They emerge from the soil in masses after the first rains and are attracted to light at night.
Safflower	
Insect Pest	**Favourable condition**
Aphids	Low temperatures and high humidity increase the incidence of this pest. Late sowing increases the incidence.

Grasshoppers: On the agricultural bunds, grasshopper eggs are latent. The young hatch and eat the nearby vegetation after the rains.

White grub: This insect's adults emerge from the ground following the first monsoon rains and spend the night feeding on the nearby plants. If the soil has less moisture, they are more numerous.

Conclusion

Sea levels are rising and temperatures are rising as a result of global climate change. As a result, rainfall has increased in certain locations while decreasing in others. The food chain has been impacted by this. The crop and the pests that affect it are no longer in equilibrium. Insect development, reproduction and geographic range are all impacted by climate change, and there is a chance that the prevalence of different pests on different crops may rise. For the past three to four years, there has been a widespread pest infestation on crops. We can control pests and stop potential damage if we understand how environmental factors affect them.

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HORMONAL CROSSTALK IN PLANTS: INTEGRATING GROWTH, DEVELOPMENT, STRESS RESPONSES, AND AGRICULTURAL RESILIENCE

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Abstract

Plants are continuously exposed to biotic and abiotic stresses such as drought, pathogen attack, and fluctuating light conditions. Since plants are immobile, they rely on internal chemical signalling systems regulated by phytohormones. These hormones rarely act independently; instead, they interact in a coordinated network known as Hormonal Crosstalk. This article discusses the interaction between major plant hormones with emphasis on (i) abscisic acid (ABA), auxin, and ethylene during drought stress, (ii) jasmonic acid (JA) and salicylic acid (SA) in defense responses, (iii) the integrative role of brassinosteroids (BRs), (iv) hormonal control of senescence and nutrient remobilization, and (v) integration of light and hormonal signalling. Understanding these interactions provides insights into plant adaptation and helps in developing stress-resilient crops.

Keywords: Hormonal crosstalk, ABA, auxin, ethylene, jasmonic acid, salicylic acid, brassinosteroids, senescence, light signalling

1. Introduction

Plants respond to environmental signals using a complex network of hormones such as ABA, auxin, ethylene, jasmonic acid, salicylic acid, cytokinins, gibberellins, and brassinosteroids. Rather than functioning individually, these hormones interact through signalling pathways to regulate plant growth, development, and stress responses.

Hormonal crosstalk enables plants to:

- Balance growth and stress tolerance

- Regulate resource allocation
- Respond efficiently to environmental changes

2. Interaction of ABA, Auxin, and Ethylene under Drought Stress

2.1 Role of ABA in Drought Response

Abscisic acid (ABA) is the primary stress hormone involved in drought tolerance.

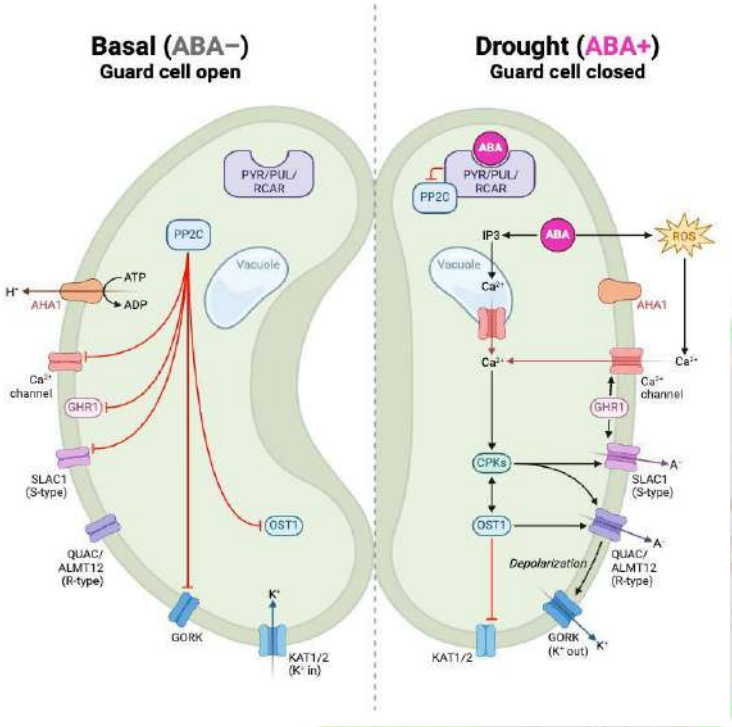

Figure 1: Abscisic Acid (ABA) Signalling in Guard Cells

Under water deficit conditions:

- ABA accumulates rapidly in leaves
- Induces stomatal closure to reduce transpiration
- Activates stress-responsive genes

At the molecular level, ABA signalling involves receptors (PYR/PYL/RCAR), inhibition of PP2C phosphatases, and activation of SnRK2 kinases, leading to transcriptional regulation of drought-responsive genes.

2.2 Auxin-Mediated Root Adaptation

Auxin regulates root architecture by controlling cell division and elongation. During drought stress:

- Auxin distribution shifts toward root tips
- Promotes deeper root growth and lateral root formation

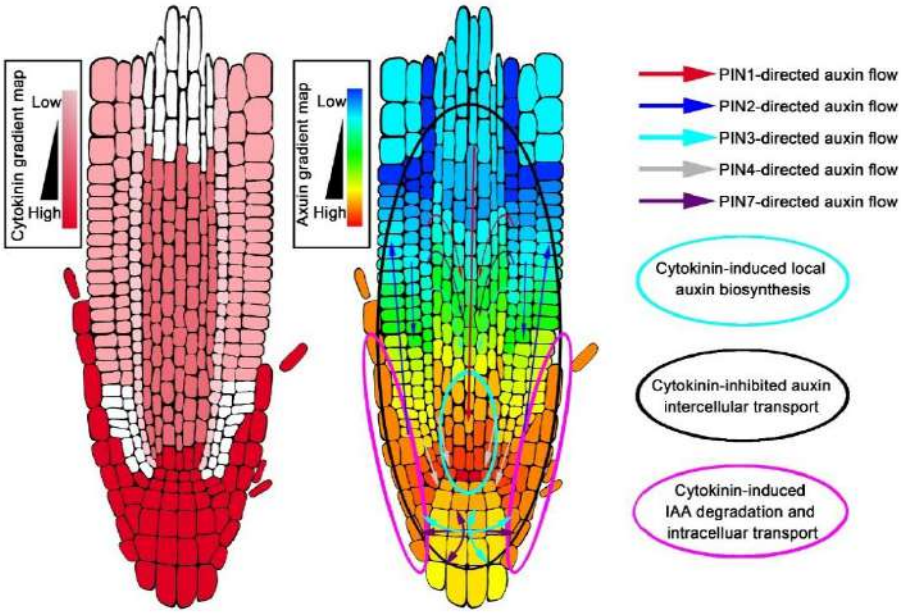

Figure 2. Cytokinin-controlled gradient distribution of auxin in Arabidopsis root tip.

ABA influences auxin transport by regulating PIN- formed proteins, thereby modifying root system architecture for improved water uptake.

2.3 Role of Ethylene in Growth Regulation

Ethylene production increases under drought stress:

- Inhibits cell elongation
- Promotes leaf senescence
- Enhances root hair development

Ethylene signalling involves transcription factors such as EIN3/EIL1, which regulate gene expression associated with stress responses.

2.4 Crosstalk Mechanism

- ABA regulates auxin transport and root growth
- Ethylene modifies auxin biosynthesis
- ABA and ethylene often show antagonistic effects
- These interactions determine whether the plant prioritizes growth or survival under stress conditions.

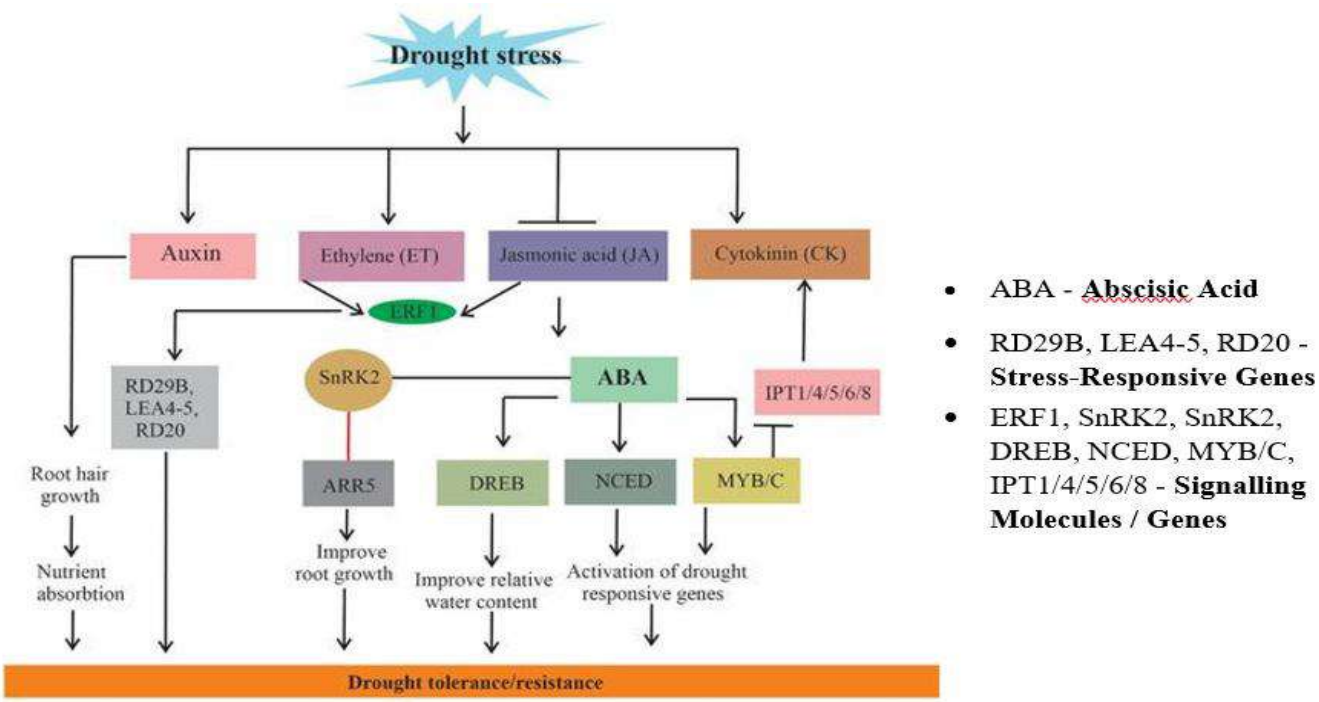

Figure 3: A proposed model illustrating the crosstalk among auxin, ethylene (ET), jasmonic acid (JA), cytokinin (CK), and abscisic acid (ABA) under drought stress conditions.

3. Crosstalk between Jasmonic Acid and Salicylic Acid in Defense Responses

3.1 Salicylic Acid Signalling

Salicylic acid (SA) plays a key role in defense against biotrophic pathogens:

- Activates systemic acquired resistance (SAR)
- Induces pathogenesis-related (PR) proteins

SA signalling is mediated through NPR1 (Nonexpressor of Pathogenesis-Related Genes 1), which regulates defense gene expression.

3.2 Jasmonic Acid Signalling

Jasmonic acid (JA) is involved in defense against necrotrophic pathogens and herbivorous insects:

- Regulates wound response
- Activates defense-related genes

JA signalling involves COI1 receptor-mediated degradation of JAZ repressors and activation of transcription factors.

3.3 Antagonistic and Synergistic Interaction

JA and SA pathways often act antagonistically, enabling plants to prioritize specific defense responses. However, under complex conditions, synergistic interactions may also occur.

3.4 Molecular Basis of Crosstalk

- **NPR1 regulates SA signalling** by activating pathogenesis-related (PR) genes and establishing systemic acquired resistance.
- **JAZ proteins repress JA signalling** by inhibiting transcription factors until they are degraded in response to jasmonic acid.
- **WRKY transcription factors mediate cross-regulation** by coordinating interactions between salicylic acid and jasmonic acid signalling pathways.
- **Redox changes influence pathway balance** by altering the activity of key regulatory proteins involved in hormone signalling.

4. Role of Brassinosteroids in Growth and Stress Tolerance

4.1 Brassinosteroids in Growth

Brassinosteroids regulate:

- Cell elongation
- Vascular differentiation
- Reproductive development

4.2 Role in Stress Tolerance

BRs enhance plant tolerance to:

- Drought
- Salinity
- Temperature extremes
- Oxidative stress

They improve antioxidant defense systems and maintain cellular stability.

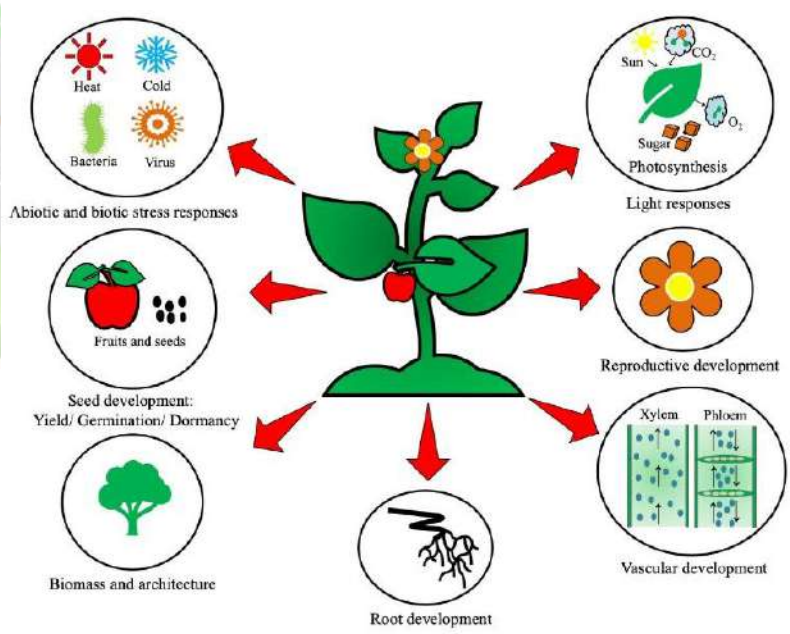

Figure 4: Role of **Brassinosteroids in plants abiotic stress tolerance**

4.3 Signalling Pathway

BRs are perceived by the BRI1 receptor, which activates a signalling cascade involving BIN2 kinase enzyme and transcription factors BZR1 and BES1, regulating gene expression.

4.4 Crosstalk with Other Hormones

BRs interact with:

- ABA (stress regulation)
- Auxin (growth control)
- Gibberellins (development)

Thus, BRs function as integrators of growth and stress signalling.

5. Hormonal Regulation of Senescence and Nutrient Remobilization

5.1 Hormonal Control of Senescence

Senescence is a genetically programmed process regulated by hormones:

- Ethylene and ABA promote senescence
- Cytokinins delay senescence
- Auxin regulates timing

5.2 Source–Sink Relationship

During senescence:

- Nutrients move from older leaves (source)
- To developing seeds or fruits (sink)

This process is essential for grain filling and crop yield.

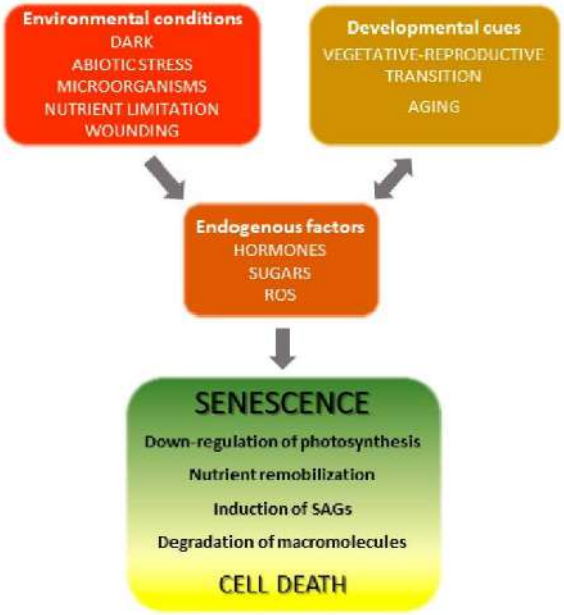

Figure 5: Overview of leaf senescence.

5.3 Molecular Regulation

- Senescence-associated genes (SAGs)
- NAC and WRKY transcription factors
- Hormone-responsive signalling pathways

5.4 Agricultural Significance

Manipulating senescence can positively impact on crops to:

- Improve yield
- Enhance nutrient-use efficiency
- Increase stress tolerance

6. Integration of Light and Hormone Signalling

6.1 Light Perception

Plants perceive light using photoreceptors such as phytochromes, cryptochromes, and phototropins.

6.2 Hormonal Interactions

- Light regulates auxin distribution (phototropism)
- Gibberellins interact with light during germination
- ABA integrates light and stress signals
- BRs regulate photomorphogenesis

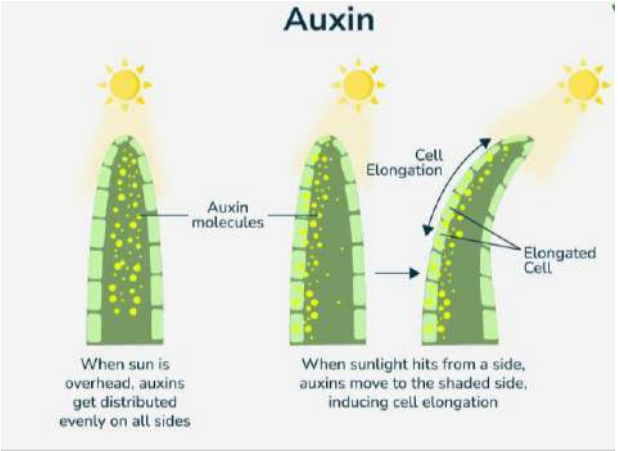

Figure 6: Auxin showing elongation.

6.3 Molecular Integration

Key regulators include:

- COP1 and HY5
- Phytochrome-interacting factors (PIFs)
- Circadian clock components

6.4 Functional Importance

This integration allows plants to:

- Optimize growth under varying light conditions
- Adapt to environmental stress
- Regulate developmental processes

7. Implications of Hormonal Crosstalk in Agriculture

7.1. Stress tolerance: Hormonal crosstalk improves plant resistance to environmental stresses such as drought, salinity, and temperature extremes by coordinating hormones like ABA, auxin, ethylene, and brassinosteroids, which enhance root growth, regulate water loss, and maintain cellular stability.

7.2. Yield and productivity: Interactions among auxin, gibberellins, cytokinins, and brassinosteroids optimize plant growth, branching, and source–sink relationships, leading to increased biomass, better grain filling, and improved crop yield and quality.

7.3. Disease and pest management: Crosstalk between salicylic acid (SA), jasmonic acid (JA), and ethylene strengthens plant defense systems, allowing targeted responses against pathogens and insects, thereby reducing reliance on chemical pesticides.

7.4. Senescence and post-harvest quality: Hormones such as ethylene and ABA promote aging and ripening, while cytokinins delay senescence, helping to improve yield, extend shelf life, and enhance nutrient remobilization.

7.5. Light and environmental adaptation: Hormonal interactions with light signals regulate plant architecture, germination, and photosynthesis, enabling better growth under varying environmental conditions and improved cultivation practices.

7.6. Plant breeding and biotechnology: Knowledge of hormonal crosstalk supports the development of stress-tolerant and high-yielding varieties through selection and genetic modification of hormonal pathways.

7.7. Sustainability and climate resilience: Overall, hormonal crosstalk contributes to reduced chemical inputs, efficient resource use, and improved adaptation to climate change, supporting sustainable and precision agriculture systems.

8. Conclusion

Hormonal crosstalk represents a complex regulatory system that enables plants to coordinate growth, development, and stress responses. The interaction among multiple hormones allows plants to make adaptive decisions under environmental challenges. Advances in molecular biology and biotechnology will enable better understanding and manipulation of hormone signalling pathways, contributing to the development of climate-resilient and high-yielding crop varieties.

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GENERATIVE AI IN SMART AGRICULTURAL APPLICATIONS

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1. Introduction

Generative Artificial Intelligence (Gen AI) is transforming agriculture into a smart, data-driven, and sustainable system. In smart agriculture, Gen AI can analyze large volumes of farm data—such as soil, weather, and crop conditions—and generate recommendations, predictions, and automated decisions to improve productivity and reduce risks.

2. Smart Agriculture and Generative AI

Smart Agriculture refers to the application of modern technologies such as Artificial Intelligence (AI), Internet of Things (IoT), sensors and drones, data analytics, and robotics to improve agricultural productivity and efficiency. These technologies enable farmers to monitor crop conditions, soil health, weather patterns, and farm operations in real time. By using digital tools and automated systems, smart agriculture helps farmers make data-driven decisions regarding irrigation, fertilization, pest control, and harvesting, rather than relying solely on traditional knowledge and manual observation. As a result, smart agriculture enhances resource utilization, reduces production costs, increases crop yield, and supports sustainable farming practices.

Generative Artificial Intelligence (Generative AI) is an advanced form of artificial intelligence capable of generating new information, predictions, and recommendations based on existing agricultural data. It can analyze large datasets and produce useful outputs such as crop management plans, yield forecasts, and disease prevention strategies. Generative AI can also create reports and advisories for farmers, simulate different farming scenarios, and suggest

optimal solutions for various agricultural challenges. By integrating data from multiple sources—such as drone images, soil sensors, satellite data, and weather forecasts—Generative AI systems provide real-time, actionable insights that help farmers improve productivity, manage risks, and adapt to changing environmental conditions.

3. Generative AI in Smart Agriculture

Generative Artificial Intelligence (Generative AI) in smart agriculture refers to the use of advanced artificial intelligence models that can create new information, predictions, and practical solutions to improve farming operations and agricultural management. These AI systems analyze large volumes of agricultural data collected from different sources and generate recommendations that help farmers make timely and accurate decisions. In smart agriculture, Generative AI plays an important role in optimizing the use of resources such as water, fertilizers, seeds, and labor, thereby increasing farm productivity and supporting sustainable agricultural practices. By using intelligent algorithms and machine learning techniques, Generative AI can identify patterns, predict future conditions, and suggest the most suitable actions for crop growth and farm management.

3.1 Precision Crop Management Using Generative AI

Precision Crop Management is one of the most important applications of Generative Artificial Intelligence (Gen AI) in smart agriculture. The main purpose of precision crop management is to optimize crop growth and improve farm productivity by using real-time data collected from various agricultural sources. Generative AI systems continuously monitor field conditions such as soil moisture, nutrient levels, temperature, rainfall, and humidity through sensors, satellites, drones, and weather stations. By analyzing this real-time information, the system can understand the current condition of crops and provide timely recommendations to farmers. This data-driven approach helps farmers manage crops more efficiently and reduces the risks associated with unpredictable environmental conditions.

Generative AI works in precision crop management by first collecting soil and climate data from different sources, including soil sensors, remote sensing devices, and meteorological services. The system then uses advanced algorithms to predict crop growth patterns, estimate plant health, and forecast potential problems such as nutrient deficiency, water stress, or pest attacks. Based on these predictions, Generative AI generates crop management plans that guide farmers on the best agricultural practices to follow at each stage of crop development. These

plans may include recommendations on irrigation timing, fertilizer application, pest control measures, and harvesting schedules. By providing accurate and timely guidance, Generative AI helps farmers maintain optimal growing conditions for crops throughout the farming season.

Precision crop management supported by Generative AI has several important applications in modern agriculture. It helps farmers in crop selection by recommending the most suitable crop varieties based on soil type, climate conditions, and market demand. It also supports yield prediction by estimating the expected crop production before harvest, allowing farmers and agricultural planners to prepare for storage, transportation, and marketing. In addition, Generative AI assists in crop rotation planning, which involves selecting different crops to grow in sequence on the same land to maintain soil fertility and reduce pest and disease buildup. These applications contribute to more sustainable and profitable farming systems.

The use of Generative AI in precision crop management provides many significant benefits to farmers and agricultural organizations. It leads to higher productivity by ensuring that crops receive the right amount of water, nutrients, and protection at the right time. It helps in reducing input costs by minimizing the waste of fertilizers, pesticides, and water through precise application methods. Furthermore, it promotes efficient land use by identifying the best crops and farming practices for specific field conditions, thereby maximizing the productivity of available agricultural land. Generative AI also enables farmers to simulate multiple farming scenarios using weather, soil, and pest data to determine the most effective management strategy before implementing it in the field. This capability supports better planning, reduces risks, and improves the overall sustainability of agricultural production systems.

A simple example of Generative AI in smart agriculture involves the collection of input data such as soil moisture levels, temperature conditions, crop type, and rainfall information. These data are gathered using sensors, weather stations, and agricultural databases. The Generative AI system processes and analyzes this information to produce useful **outputs**, such as an appropriate irrigation schedule indicating when and how much water should be applied, fertilizer recommendations specifying the correct type and quantity of nutrients required for the crop, and pest control plans suggesting preventive or corrective measures to protect crops from diseases and pests. Such automated recommendations help farmers respond quickly to changing environmental conditions and reduce the risk of crop failure.

Overall, Generative AI improves agricultural decision-making by analyzing large datasets, identifying trends, and optimizing the efficient use of natural resources. This leads to better crop productivity, reduced operational costs, improved environmental sustainability, and enhanced resilience to climate variability. As smart agriculture continues to develop, Generative AI is expected to become a key technology for modern farming systems, enabling precision agriculture and supporting global food security.

3.2 Pest and Disease Detection Using Generative AI

Pest and Disease Detection is a critical application of Generative Artificial Intelligence (Gen AI) in smart agriculture, aimed at identifying crop diseases and pest infestations at an early stage and generating appropriate treatment recommendations. The main purpose of this application is to protect crop health, reduce yield losses, and ensure sustainable agricultural production. In traditional farming, disease detection often depends on manual observation and farmer experience, which may lead to delayed identification and severe crop damage. However, with the integration of Generative AI, farmers can monitor crop health more accurately and respond quickly to emerging problems. By analyzing images and environmental data, Generative AI systems can detect symptoms of diseases and pests before they spread widely across the field. Generative AI-based pest and disease detection systems use advanced technologies such as computer vision, drones, and image processing to monitor crop conditions. Computer vision enables machines to interpret and analyze images of plant leaves, stems, and fruits to identify abnormalities such as discoloration, spots, or wilting. Drones equipped with high-resolution cameras can capture aerial images of large agricultural fields quickly and efficiently, allowing farmers to monitor crop health over wide areas. Image processing techniques are then applied to enhance image quality and extract important features that help in accurate disease identification. These technologies work together to provide real-time monitoring and precise diagnosis of crop health problems.

This application has several important uses in modern agriculture, including leaf disease detection, pest identification, and treatment planning. For example, Generative AI systems can identify common plant diseases such as leaf blight, rust, mildew, or bacterial infections by analyzing visual symptoms present on plant leaves. Once the disease or pest is identified, the system can generate a treatment plan that includes recommendations for suitable pesticides, biological control methods, or preventive measures. Such automated diagnosis reduces the

dependence on agricultural experts and enables farmers to take immediate action to protect their crops.

A practical example of this technology involves a farmer using a smartphone or digital device to capture and upload an image of a diseased plant leaf. The Generative AI system analyzes the image, compares it with a database of known crop diseases, and identifies the specific disease affecting the plant. It then suggests appropriate control measures, including the type of pesticide to use, the dosage, and the application method. This process helps farmers make quick and informed decisions without waiting for laboratory testing or expert consultation.

The use of Generative AI in pest and disease detection provides several significant benefits to agriculture. It enables early detection of diseases, which prevents the spread of infections and minimizes crop damage. It helps in reducing crop losses by ensuring timely treatment and effective pest management. Additionally, it supports lower pesticide use by recommending precise and targeted applications, thereby reducing environmental pollution and production costs. Overall, Generative AI models are widely used to improve disease prediction, crop health monitoring, and sustainable pest management in modern agriculture, making farming more efficient, productive, and environmentally friendly.

3.3 Smart Irrigation Management Using Generative AI

Smart Irrigation Management is an important application of Generative Artificial Intelligence (Gen AI) in smart agriculture, designed to manage water resources efficiently through automated irrigation systems. The primary purpose of smart irrigation is to supply crops with the right amount of water at the right time, ensuring optimal plant growth while minimizing water wastage. In many agricultural regions, water scarcity and irregular rainfall patterns pose significant challenges to farmers. Generative AI helps address these challenges by using advanced technologies to monitor soil and environmental conditions and make intelligent irrigation decisions. By automating irrigation processes, smart irrigation systems reduce manual effort, improve water efficiency, and support sustainable agricultural practices.

Smart irrigation systems work by using sensors installed in agricultural fields to continuously measure soil moisture levels, temperature, and humidity. These sensors send real-time data to an AI-based system that analyzes the information and predicts the water requirements of crops based on factors such as crop type, growth stage, weather conditions, and soil characteristics. Generative AI then generates an irrigation schedule that specifies when

irrigation should occur and how much water should be applied. The system can automatically control irrigation equipment, such as pumps and valves, to deliver water precisely according to the generated schedule. This intelligent and automated process ensures that crops receive sufficient water without over-irrigation or under-irrigation.

Smart irrigation management has several practical applications in modern agriculture. One key application is drip irrigation control, where water is delivered directly to the root zone of plants in small quantities, reducing evaporation and improving water efficiency. Another important application is water scheduling, which involves planning irrigation activities based on weather forecasts and soil moisture data to avoid unnecessary watering. Smart irrigation systems also play a crucial role in drought management by monitoring water availability and providing recommendations on water conservation strategies during periods of low rainfall. These applications help farmers maintain crop health even under challenging environmental conditions. The use of Generative AI in smart irrigation provides numerous benefits to farmers and agricultural systems. It promotes water conservation by ensuring that water is used efficiently and only when needed. It also leads to reduced energy consumption, as automated systems optimize the operation of irrigation pumps and minimize excessive water usage. Furthermore, smart irrigation contributes to improved crop yield by maintaining consistent soil moisture levels that support healthy plant growth. Smart irrigation systems are especially essential in regions facing water stress and climate variability, where efficient resource management is critical for long-term agricultural sustainability and food security.

3.4 Agricultural Robotics and Automation Using Generative AI

Agricultural Robotics and Automation is a significant application of Generative Artificial Intelligence (Gen AI) in smart agriculture, aimed at automating routine and labor-intensive farming operations. The primary purpose of agricultural robotics is to improve farm productivity, reduce dependence on manual labor, and ensure timely completion of agricultural tasks. In modern farming systems, labor shortages, rising labor costs, and the need for precision farming have increased the demand for automated solutions. Generative AI enables machines and robots to perform agricultural activities intelligently by analyzing field data, learning from past operations, and making real-time decisions. These automated systems can work continuously with high accuracy, thereby improving operational efficiency and reducing human effort.

Agricultural robotics includes various types of automated machines designed to perform specific farming tasks. Autonomous tractors are self-driving vehicles that can plow, sow seeds, apply fertilizers, and cultivate fields without direct human control. These tractors use sensors, GPS technology, and AI algorithms to navigate fields accurately and perform tasks according to pre-programmed instructions. Harvesting robots are another important example, designed to identify ripe crops and harvest them carefully without damaging the produce. These robots use cameras and computer vision technology to detect crop maturity and pick fruits or vegetables at the right time. Similarly, weed removal robots are used to detect and remove weeds from fields using mechanical tools or targeted herbicide application, reducing the need for manual weeding and minimizing chemical usage.

A real-world example of agricultural robotics involves AI-powered robotic systems that monitor pasture conditions and livestock behavior in grazing areas. These robots can analyze pasture health by collecting data on grass growth, soil condition, and moisture levels. Based on this information, the system can automatically guide livestock to better grazing areas where sufficient grass and nutrients are available. This intelligent movement of animals helps prevent overgrazing, protects soil quality, and supports sustainable land management practices. Such advanced robotic systems demonstrate how Generative AI can be used not only in crop farming but also in livestock management.

The adoption of agricultural robotics and automation offers several important benefits to farmers and agricultural industries. It helps in reducing labor costs by replacing manual labor with automated machines that can perform tasks efficiently. It enables faster operations, as robots can work continuously without fatigue and complete tasks within shorter time periods. Additionally, it leads to increased efficiency and precision in farming activities, resulting in better crop quality, higher productivity, and reduced resource wastage. Overall, agricultural robotics and automation powered by Generative AI play a crucial role in modern smart agriculture by improving farm management, enhancing sustainability, and supporting the future of automated farming systems.

3.5 Fertilizer and Nutrient Management Using Generative AI

Fertilizer and Nutrient Management is a vital application of Generative Artificial Intelligence (Gen AI) in smart agriculture, focused on optimizing fertilizer use based on soil conditions and crop requirements. The main purpose of this application is to ensure that crops

receive the right nutrients in the correct quantities at the appropriate time for healthy growth and maximum productivity. In traditional farming, fertilizers are often applied uniformly across fields without considering variations in soil fertility, which can lead to nutrient imbalance, increased costs, and environmental pollution. Generative AI addresses these challenges by analyzing soil data, crop requirements, and environmental conditions to generate precise fertilizer recommendations. This data-driven approach supports efficient nutrient management and promotes sustainable agricultural practices.

In modern agriculture, Generative AI systems perform soil nutrient analysis by collecting and analyzing data on essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), organic matter content, and soil pH levels. These data are obtained through soil testing laboratories, sensors, and remote sensing technologies. Based on this analysis, Generative AI generates fertilizer recommendations tailored to specific crops and field conditions. For example, the system can suggest the type of fertilizer, the required dosage, and the best time for application according to the crop growth stage. This process is known as precision fertilization, where fertilizers are applied accurately to meet the exact nutrient needs of crops. Precision fertilization ensures efficient nutrient uptake by plants and minimizes the risk of over-fertilization or nutrient deficiency.

The use of Generative AI in fertilizer and nutrient management provides several important benefits to farmers and agricultural systems. It helps maintain balanced nutrition in crops by supplying the correct proportion of essential nutrients required for plant growth and development. It also contributes to reduced fertilizer waste by preventing excessive application and ensuring that fertilizers are used efficiently, which lowers production costs. Furthermore, it supports environmental protection by reducing nutrient runoff into water bodies and minimizing soil degradation caused by improper fertilizer use. By analyzing large agricultural datasets and generating precise nutrient management strategies, Generative AI helps optimize natural resource usage, improve crop yield, and enhance overall production efficiency in modern agriculture.

3.6 Climate and Weather Prediction Using Generative AI

Climate and Weather Prediction is a crucial application of Generative Artificial Intelligence (Gen AI) in smart agriculture, designed to predict weather conditions and generate timely farming advice for farmers. Weather and climate play a major role in agricultural

productivity, as factors such as rainfall, temperature, humidity, and wind directly affect crop growth, soil moisture, pest development, and harvesting schedules. Traditional farming often relied on past experience and seasonal patterns to make decisions, but changing climate conditions and unpredictable weather have made farming more challenging. Generative AI addresses this issue by analyzing large volumes of historical and real-time weather data collected from satellites, weather stations, sensors, and climate models. Based on this analysis, the system generates accurate forecasts and practical recommendations that help farmers plan agricultural activities more effectively.

In agriculture, Generative AI supports several important applications, including rainfall prediction, drought warning, and crop planning. Rainfall prediction helps farmers determine the best time for sowing seeds, irrigating crops, and applying fertilizers. For example, if heavy rainfall is predicted, farmers can delay irrigation or fertilizer application to prevent nutrient loss and waterlogging. Similarly, drought warning systems use climate data and soil moisture information to detect early signs of water scarcity and recommend water conservation measures, such as adjusting irrigation schedules or selecting drought-resistant crop varieties. Generative AI also assists in crop planning by suggesting suitable crops and planting dates based on expected weather conditions, seasonal trends, and regional climate patterns. These applications help farmers adapt to climate variability and maintain stable crop production.

The use of Generative AI in climate and weather prediction provides several significant benefits to agricultural systems. It supports risk reduction by providing early warnings about extreme weather events such as droughts, floods, heatwaves, or storms, allowing farmers to take preventive actions. It enables better planning of farm operations, including planting, irrigation, fertilization, and harvesting, based on reliable weather forecasts. In addition, Generative AI plays a vital role in disaster management by helping government agencies and farmers prepare for climate-related emergencies and minimize damage to crops and infrastructure. Overall, Generative AI strengthens climate resilience in agriculture by modeling environmental changes and helping farmers adapt to unpredictable weather patterns, ensuring sustainable agricultural production and long-term food security.

4. Technologies Used in Smart Agricultural Applications

Generative Artificial Intelligence (Gen AI) in agriculture relies on a combination of advanced digital technologies that work together to create smart, efficient, and sustainable farming

systems. These integrated technologies enable the collection, processing, analysis, and sharing of agricultural data to support informed decision-making and automated farm management. Modern agriculture is increasingly dependent on these technologies to improve productivity, reduce resource wastage, and address challenges such as climate change, labor shortages, and food security. The major technologies used in smart agricultural applications include Artificial Intelligence (AI), Internet of Things (IoT), Machine Learning, sensors, drones, robotics, cloud computing, and Big Data, each playing a specific role in transforming traditional farming into precision agriculture.

Artificial Intelligence (AI) is the core technology behind smart agriculture, enabling computers and machines to simulate human intelligence and perform tasks such as decision-making, problem-solving, and prediction. In agriculture, AI is used to analyze crop data, identify diseases, predict weather conditions, and generate recommendations for irrigation, fertilization, and pest control. AI systems can process large volumes of agricultural data quickly and provide accurate insights that help farmers improve productivity and reduce risks. Closely related to AI is Machine Learning (ML**)**, a subset of AI that allows systems to learn from past data and improve their performance over time without being explicitly programmed. Machine learning models are widely used in agriculture for yield prediction, crop classification, soil analysis, and disease detection, making farming more efficient and data-driven.

The Internet of Things (IoT) plays a vital role in connecting agricultural devices and sensors through the internet, enabling real-time monitoring of farm conditions. IoT devices collect data on soil moisture, temperature, humidity, and crop health, and transmit this information to centralized systems for analysis. Sensors are essential components of IoT systems, as they continuously measure environmental and soil parameters that influence crop growth. These sensors provide accurate and timely data that helps farmers make better decisions about irrigation, fertilization, and pest management. By integrating IoT and sensors with Generative AI, farmers can automate farm operations and respond quickly to changing field conditions.

Drones are another important technology used in smart agriculture for aerial monitoring and data collection. Equipped with cameras and imaging sensors, drones can capture high-resolution images of crops and fields, allowing farmers to detect problems such as pest infestations, nutrient deficiencies, or water stress. Drones can also be used for spraying fertilizers and pesticides over large areas quickly and efficiently. Similarly, **robotics** technology enables the automation of

various farming activities such as planting, harvesting, weeding, and irrigation. Agricultural robots use AI and sensors to perform tasks with high precision, reducing manual labor and increasing operational efficiency.

Cloud computing provides the infrastructure for storing and processing large volumes of agricultural data generated by sensors, drones, and other devices. It allows farmers and agricultural organizations to access data and applications remotely through the internet, enabling real-time monitoring and decision-making from any location. Cloud platforms also support collaboration among farmers, researchers, and agricultural experts by providing shared access to data and analytical tools. In addition, Big Data technology plays a crucial role in managing and analyzing massive datasets generated from multiple sources, such as weather records, soil reports, crop performance data, and satellite imagery. By analyzing these large datasets, Generative AI systems can identify patterns, predict future trends, and generate optimized farming strategies.

Overall, the integration of these technologies forms the foundation of smart agricultural applications powered by Generative AI. Together, they enable precision farming, efficient resource management, improved crop productivity, and sustainable agricultural development.

5. Future Trends of Generative AI in Smart Agriculture

The future of Generative Artificial Intelligence (Gen AI) in smart agriculture is expected to bring significant advancements that will transform traditional farming into highly efficient, automated, and sustainable systems. As the global population continues to grow and the demand for food increases, agriculture must produce more with limited natural resources such as land and water. Generative AI will play a key role in addressing these challenges by enabling farmers to adopt modern technologies that improve productivity, reduce environmental impact, and ensure long-term food security. Future agricultural systems will increasingly rely on intelligent machines, digital platforms, and climate-smart practices to manage farming operations more effectively.

One of the major future trends in smart agriculture is the development of AI-powered smart farms, where farming activities are monitored and controlled using advanced technologies such as sensors, drones, and automated systems. In smart farms, Generative AI will continuously collect and analyze data related to soil health, crop growth, weather conditions, and resource usage. Based on this information, the system will automatically generate recommendations for

irrigation, fertilization, pest control, and harvesting. These smart farms will enable farmers to make precise decisions, reduce manual effort, and improve crop productivity while minimizing waste and environmental damage.

Another important trend is the use of autonomous farming machines, such as self-driving tractors, robotic harvesters, and automated irrigation systems. These machines will be capable of performing agricultural tasks without direct human intervention by using artificial intelligence, GPS technology, and sensors. Autonomous machines will increase operational efficiency by working continuously and accurately, even in large agricultural fields. They will also help address labor shortages in rural areas and reduce the physical workload of farmers. As Generative AI technology advances, these machines will become more intelligent, adaptable, and capable of handling complex farming operations.

Climate-resilient agriculture is also expected to become a key focus in the future of smart farming. Climate change has led to unpredictable weather patterns, droughts, floods, and extreme temperatures, which significantly affect crop production. Generative AI will help farmers adapt to these changing conditions by predicting climate risks, recommending suitable crop varieties, and suggesting efficient water and soil management practices. By analyzing climate data and environmental trends, AI systems can generate strategies that protect crops from adverse weather conditions and maintain stable agricultural production. This approach will help farmers reduce risks and ensure food availability even under challenging climate conditions.

The growth of digital agriculture platforms is another important future trend. These platforms will integrate farm data, weather information, market prices, and advisory services into a single digital system accessible through computers or mobile devices. Generative AI will support these platforms by generating personalized recommendations for farmers, such as crop selection, fertilizer management, and pest control measures. Digital platforms will also improve communication between farmers, agricultural experts, and government agencies, enabling faster information sharing and better decision-making.

Finally, the future of agriculture will emphasize sustainable farming systems, which aim to protect natural resources while maintaining high productivity. Generative AI will help promote sustainability by optimizing the use of water, fertilizers, and energy, reducing waste, and minimizing environmental pollution. It will also support environmentally friendly practices such as precision farming, organic agriculture, and conservation agriculture. By balancing

productivity with environmental protection, sustainable farming systems will ensure that agricultural resources remain available for future generations.

Overall, Generative AI is expected to play a major role in improving food security, increasing agricultural efficiency, and supporting the growing global population demand for food. Through the integration of advanced technologies and intelligent decision-making systems, the future of smart agriculture will become more resilient, productive, and sustainable.

6. Conclusion

In conclusion, Generative Artificial Intelligence (Gen AI) is rapidly transforming modern agriculture by enabling farmers to make intelligent, data-driven decisions that improve the efficiency and productivity of farming operations. By integrating advanced technologies such as sensors, drones, and data analytics, Generative AI supports various agricultural activities, including crop management, irrigation scheduling, pest and disease detection, fertilizer management, and climate prediction. These smart solutions help farmers optimize the use of resources such as water, fertilizers, and energy, thereby reducing production costs and minimizing environmental impact.

Furthermore, Generative AI plays a crucial role in promoting sustainable farming practices by ensuring balanced resource utilization and protecting natural ecosystems. It enables farmers to respond quickly to changing weather conditions, manage risks effectively, and maintain consistent crop production. As digital technologies continue to evolve and become more accessible, Generative AI is expected to become a key component of modern agriculture, driving innovation in smart farming systems. Ultimately, the adoption of Generative AI will support global food security, enhance agricultural resilience, and contribute to long-term environmental sustainability for future generations.

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NANOPARTICLES AS GUARDIANS OF THE GREEN: MITIGATING HEAVY METAL UPTAKE IN PLANTS FOR SUSTAINABLE RECLAMATION OF DEGRADED LANDS

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Abstract

Anthropogenic activities like rapid industrial development, agricultural practices, and irresponsible wastewater discharge have risen the concentration of heavy metals in land and aquatic resources globally, including in some parts of India, to a level that is highly toxic to human and animal health. These wastes include heavy metals like, Cd, Pb, As, Cr, and Hg that are readily absorbed by plant roots and slowly build up in plants, and infiltrate the food chain endangering human health. To resolve these problems metal oxide of nano-particles, such as ZnO, SiO_2, TiO_2, and $Fe3O_4$, have been successfully employed as cheap and environmentally friendly medium that reduce the absorption of these heavy metals by plants. Nano-particles can be used *via* various mechanism such as reactive oxygen species scavenging, immobilization of the cell wall, pH management of the rhizosphere, and competitive ion removal in root zone. The current paper highlights the existing knowledge of mechanisms and metal oxide of nano-particles used for specific heavy metals, their practicality in the soil reclamation and their application in the field, particularly in the geographically and ecologically sensitive region of Northeast India.

Keywords: degraded land, heavy metal toxicity, phyto-remediation, , nanotechnology, sustainable agriculture.

1. INTRODUCTION

The current problem of declining food security and ecological balance in food chain is taking place throughout the globe. This is due to human activities which leads to soil and water pollution. Another problem of heavy metal pollution, is now affecting the water and soil quality.

High concentrations of heavy materials like cadmium (Cd), lead (Pb), arsenic (As), chromium (Cr), nickel (Ni), and mercury (Hg) in fertile land are caused due to activities like as mining, smelting plants, tanneries, electroplating plants, heavy usage of phosphate fertilizers, and application of sewage sludge in the fields. The occurence of heavy metals has also been recorded in the cultivated soils of industrial regions of West Bengal, Jharkhand, Tamil Nadu, Punjab, along with the river plains and fertile regions of India. Heavy metals persist in the soil for a longer duration since they accumulate and are non-biodegradable. As soon as they enter the root system of plants using transporter proteins that evolved for essential nutrients, they climb up the xylem and get stored in the leaves, grains, fruits, and vegetables, which humans and other living beings consume. Therefore, in celebration of World Earth Day in 2026, it would be quite right to focus on such a technology. Nanoparticles (1–100 nm range), have been proven an excellent tools to maintain plant physiology in the case of metal stress. They help to block heavy metal uptake in plants, and help to grow food in degraded soils.

2. THE HEAVY METAL CRISIS: SCALE AND CONSEQUENCES

2.1 How Heavy Metals Enter the Soil-Plant System

Heavy metals leach into the soil from abandoned mine tailings, irrigating with contaminated water, use of sewage sludge as fertilizer, and untreated deposition of industrial waste. This effects the soil acidity (pH), organic matter content, redox potential, and microbiological activity. The availability of metals such as cadmium, lead, and zinc increases in acidic soil environment (pH < 6.0). The primary process of metal absorption in plants is initiated by plant roots. The transporters designed for zinc absorption facilitates the absorption of cadmium while calcium channel proteins facilitate the absorption of lead. Since, the heavy metals mimic the molecules of essential nutrients in plants, it becomes very hard to remove them without affecting their uptake in plants.

2.2 Impact on Plant Physiology and the Food Chain

Heavy metals generate ROS that affect the DNA and cell membrane and disturb the movement of water and nutrients. They displace essential ions at enzyme reaction sites, and interfere with the enzyme action, especially during photosynthesis and nitrogen metabolism. This effects the chlorophyll content of leaves, reduces growth rates, darken the roots, wilting, and ultimately loss of yield of crops.

The intake of these heavy metals accumulated foods such as rice, greens, wheat, and fruits for longer duration leads to complications such as kidney damage, neuro-degenerative diseases, cancer, and developmental issues in children. Despite the presence of WHO and FSSAI guidelines for heavy metal content in foods, most of the produces does not have effective agricultural monitoring practices.

3. NANOPARTICLES: THE SCIENCE OF PROTECTION

3.1 Zinc Oxide Nanoparticles (ZnO NPs)

ZnO nanoparticles widely used nanoparticles in agriculture. Their protective action against heavy metal uptake follows four distinct mechanisms:

- Competitive ionic exclusion: Zn^{2+} ions compete with Cd^{2+} and Pb^{2+} at root absorption sites. When zinc is present in adequate ionic form, the transporters preferentially bind Zn^{2+}, blocking cadmium and lead entry. This is feasible because of identical ionic radii of Cd^{2+} and Zn^{2+}.
- Cell wall immobilization: ZnO NPs bind with pectin and hemicellulose in the root cell wall, which thickens apoplastic barrier. Heavy metals then get trapped in this heavy matrix, reducing their transportation to shoots and grains.
- Rhizosphere pH elevation: ZnO NPs raise the pH which encourage the precipitation of As, Pb, and Cd into insoluble hydroxide or phosphate complexes, which lowers their bio-availability with root surfaces.
- ROS scavenging and antioxidant upregulation: Oxidative damage is brought on by heavy metal stress through the buildup of ROS. ZnO NPs reduce cellular damage and maintain photosynthetic efficiency in contaminated soils by increasing the activity of the plant's natural antioxidant machinery, superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD).

  ZnO NP application at 50–100 mg/kg soil or 25–50 mg/L foliar spray has consistently improved chlorophyll content, shoot biomass, and grain production while reducing cadmium uptake in rice, wheat, and spinach by 30–60% in field and greenhouse trials.

3.2 Silicon Dioxide Nanoparticles (SiO_2 NPs)

Silicon is a widely used essential element which enhances stress tolerance in plants. SiO_2 NPs significantly increase this action at the nano-scale. They deposite silica layers in the Casparian strip, which is a crucial endodermal barrier in roots and stops the heavy metal uptake

by plant. Research has shown that SiO_2 NP display improved number of tillers tiller and panicle length while lowering the absorption of 40–55% less arsenic and cadmium from contaminated soilsin rice fields. Also, silicon preserves the membrane integrityof cells by reducing metal-induced electrolyte leakage.

3.3 Titanium Dioxide Nanoparticles (TiO_2 NPs)

Heavy metals are reduced into less exchangeable forms by TiO_2 NPs' photo-catalytic activity, which chenges the rhizosphere's redox chemistry. By blocking the reaction centers of photosystem II (PSII), they also improve photosynthetic efficiency under metal stress. TiO_2 NPs at 0.25–1 g/L have been proven to improve chlorophyll a/b ratios while reducing lead deposition in shoot tissue by up to 45% in tomato and spinach research. They are especially helpful in open-field settings with strong sun irradiation because of their photo stability.

3.4 Iron Oxide Nanoparticles (Fe_3O_4 NPs)

Magnetite (Fe_3O_4) nanoparticles act as potent sorbents in the rhizosphere, their high surface area (up to 100 m^2/g) enabling them to bind with arsenic, chromium, and lead easily. Additionally, Fe_3O_4 NPs contribute to the formation of iron plaque on root surfaces — a known natural barrier against arsenic in rice. When applied externally, they reduce Arsenic uptake in roots. Studies on arsenic-contaminated soils show Fe_3O_4 NP treatment reducing grain arsenic content in rice by 35–50%.

4. COMPARATIVE OVERVIEW OF NANOPARTICLE ACTION

The table below summarizes the key nanoparticles, their target metals, primary mechanism, and recommended application mode:

Nanoparticle	Target Heavy Metals	Primary Mechanism	Optimal Dose	Application Mode
ZnO NPs	Cd, Pb, Zn (excess)	Competitive exclusion, cell wall immobilization, ROS scavenging	50–100 mg/kg soil	Soil drench / foliar
SiO_2 NPs	As, Cd, Cr	Casparian strip reinforcement, apoplastic blockade	100–200 mg/L	Hydroponic / foliar

Nanoparticle	Target Heavy Metals	Primary Mechanism	Optimal Dose	Application Mode
TiO_2 NPs	Pb, Cu, Cr	Rhizosphere redox modification, PSII protection	0.25–1 g/L	Foliar spray
Fe_3O_4 NPs	As, Cr, Pb	Surface sorption, iron plaque enhancement	50–150 mg/kg soil	Soil amendment

5. APPLICATION IN DEGRADED LAND RECLAMATION

One of the major causes of soil degradation is heavy metal poisoning. Insmall scale farming practices, traditional methods for soil restoration, such as soil digging, washing, electro-kinetic soil remediation, or lime addition, are very costly and unreliable for developing countries. One possible solution for this problem would be in-situ nanotechnology-based soil restoration, which decreases metal absorption by crops, thus providing an opportunity for profitable cultivation of the land which includes :

- Semi-urban farmlands lining within industrial zones, such as the West Bengal and Tamil Nadu tanneries, where the concentration of chromium and lead in the soil is found exceeding than the safe levels.
- Flood-irrigated of rice fields on alluvial floodplains irrigated by canals contains sewage water which is contaminated by arsenic and cadmium frequently.
- Minerals present at mining sites such as iron, manganese, lead, and arsenic regularly leach into lining agricultural lands in states of Jharkhand, Odisha, and Chhattisgarh which hampers the quality of crop production.
- In the North-eastern part of India, particularly in Tripura, a major concern include cadmium toxicity in lowland rice soils and arsenic accumulation which is a result of applying untreated irrigation water. This can be reduced by the application of zinc oxide and silicon dioxide nano-particles which benefits the farmers of the region.

6. THE EARTH DAY IMPERATIVE: WHY NANOTECHNOLOGY IS A SUSTAINABLE ANSWER

The revival of nature resources and maintenance of the good health of the planet are the fundamental goals to approach. Soil degradation and contamination of the food chain due to environmental issues are the two most critical problems today, and metal contamination is one major point where they intersect. Nanoparticle-based approaches align well with the philosophy behind Earth Day for several reasons:

- Little but effective: Since nanoparticle solutions work well at parts per million levels, their application is significantly less toxic compared to conventional methods of soil amendments.
- Possibilities of green synthesis: Various plants can be employed in order to produce ZnO and SiO_2 nanomaterials, turning organic waste into useful products and closing an economic cycle.
- Friendly to soil microorganisms: Unlike chemicals such as EDTA that eliminate microorganisms, metal oxide of nanoparticles do not affect the soil microorganism population if applied in small quantities.
- Enabling food production on wasted lands: Application of NP makes it possible for agricultural practices to be carried out safely without any risks, allowing farmers to stay on their land and not have to leave due to pollution.

7. CAUTIONS, LIMITATIONS AND THE ROAD AHEAD

Trade-offs exist in every technological intervention, and nanoparticles are no exception. Zinc oxide and titanium dioxide nanoparticles pose a risk to plants when they are highly concentrated, inhibiting root growth, and disrupt the growth of symbiotic microorganisms such as mycorrhizae. Under Indian field conditions, there is a lack of knowledge about nanoparticle behaviour in the ecosystem, including how long they persist and aggregate and the possibility that they could seep into the ground waters. Prior to making any recommendations, thorough studies need to be conducted regarding the impact on aqua-ecosystems as well as soil life, including earthworms and nematodes. India lacks regulations regarding the use of nanoparticles in farming, while even the ICAR and DBT have initiated nanotech agronomy research programs.

This innovative technology must be considered by all parties involved as a precision tool, which needs to be assessed in advance and applied in parallel with more widespread interventions such as pH adjustment and organic matter enrichment.

Long-term field tests on various Indian soils, development of sustainable nanoparticles, incorporation into phytoremediation plants like sunflower, vetiver grass, and Indian mustard, and formulation as granules or slow-release soil amendments without specialized equipment are some areas of future research that merit consideration.

8. CONCLUSION

One of the most concerning and least known problems of agriculture in modern India is related to contamination of soils and waters with heavy metals. Now, the times call for increasing need of efficient, cost-effective, and eco-friendly approaches. Increasing industrialization and lowering watertable induced by climate change carry out pollutants throughout our landscape. Therefore, nanoparticles of ZnO, SiO_2, TiO_2, and $Fe3O_4$ offer a truly promising and scientifically proven solution for providing a way against metal-induced stress to plants, reducing the accumulation of heavy metals in edible plants, and allowing for the cultivation of food crops on land unfit for growing any because of its poor soil quality. On World Earth Day in 2026, as we work to heal our planet, it is crucial to understand that protecting our soil means protecting our health and the health of our future generations, as the two are inevitably interconnected. When used wisely, nanotechnology can be a powerful tool for future research purposes .

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MARINE SNOW AND THE OCEAN CARBON PUMP: A CRITICAL PATHWAY FOR GLOBAL CARBON SEQUESTRATION

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Abstract

Marine snow is a key driver of the ocean's biological carbon pump, facilitating the transfer of organic carbon from surface waters to the deep ocean. Composed of aggregated organic and inorganic particles, marine snow plays a fundamental role in carbon sequestration, nutrient cycling, and deep-sea ecosystem functioning. Approximately 5–12 Pg C yr^{-1} of carbon is exported from the euphotic zone, of which a significant fraction is mediated by marine snow (Ducklow et al., 2001; IPCC, 2021). However, only about 1–3 Pg C yr^{-1} reaches the deep ocean due to microbial remineralization (Herndl & Reinthaler, 2013). This article discusses the formation, composition, sinking dynamics, microbial degradation, and environmental controls of marine snow, along with the impacts of climate change and emerging threats such as microplastics. Understanding these processes is essential for predicting future ocean carbon cycling and climate regulation.

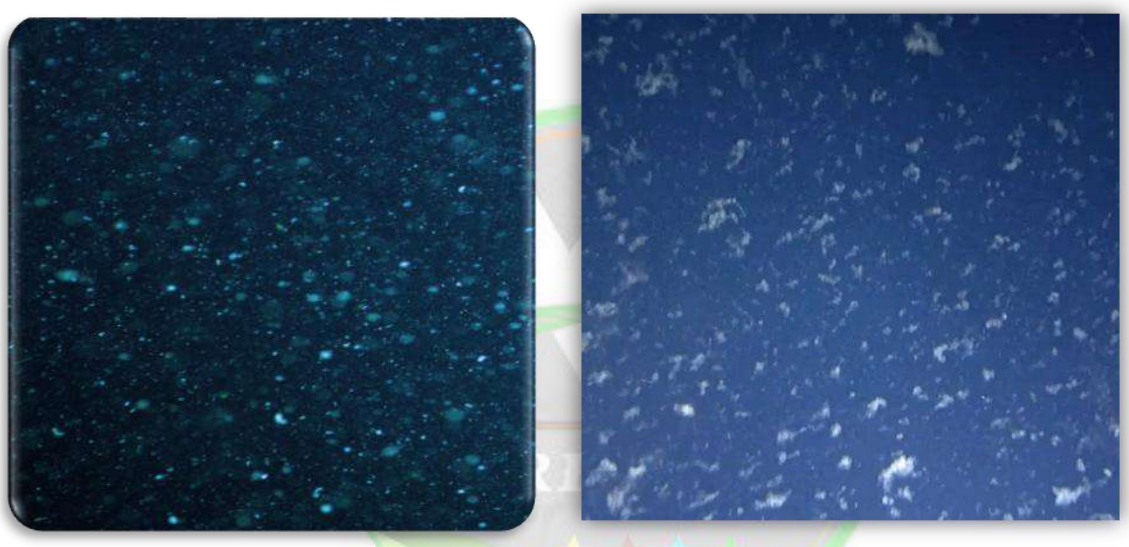
Keywords: Marine snow, Biological carbon pump, Carbon flux, Remineralization, Deep ocean sequestration, Microplastics, Climate change

Introduction

Marine snow refers to a continuous shower of organic and inorganic particles that sink from the upper ocean to deeper waters. It was first observed during bathysphere dives (Beebe,

1930s) and described first by Alldredge A. L. and Silver M. W. in 1988, marine snow includes aggregates larger than 0.5 mm composed primarily of water (>90%) and organic matter (Alldredge & Silver, 1988). It is called marinw snow because it resembles white, fluffy snowflakes.

The ocean plays a major role in global carbon cycling by absorbing approximately 25–30% of anthropogenic CO_2 emissions (Intergovernmental Panel on Climate Change, 2021). Marine snow is central to this process as it facilitates the vertical transport of carbon through the ocean carbon pump.



Marine snow

Biological Carbon Pump

The biological carbon pump is a process that transfers carbon from the atmosphere to the deep ocean through biological activity. It is **one of the most significant carbon sequestration mechanisms on Earth, and responsible for maintaining the ocean as a net sink of atmospheric CO_2.**

Key Steps and Quantitative Data:

1. **CO_2 fixation through Photosynthesis**

   Phytoplankton fix atmospheric **CO_2** and produce organic matter

2. **<u>Aggregation</u>**

   Particles combine → marine snow

3. **Sinking**

   Marine snow sinks downward at rates of 10 –500 m day^{-1}

4. **Remineralization**

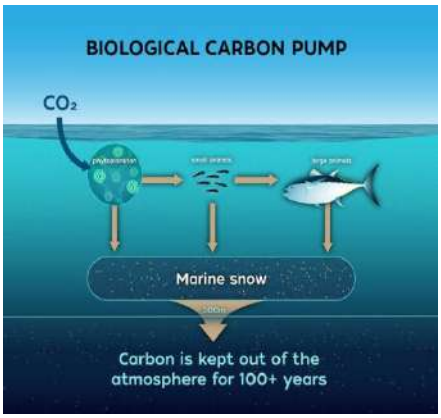
   Bacteria and ZP decomposes particles → CO_2 + nutrients

5. **Deep ocean sequestration**

   Carbon stored in deep ocean (>1000 m)

6. **Efficiency**

   Export efficiency: **5–25% of primary production**



Marine snow is responsible for a **major fraction (up to 70–80%) of vertical carbon flux** in some oceanic regions (Turner, 2015).

Composition of Marine Snow

Marine snow is not a simple substance, it is a complex, heterogeneous mixture consisting of

1. Organic Components
2. Inorganic Components
3. Binding Material

1. Organic Components

- Phytoplankton (diatoms, cyanobacteria)
- Zooplankton fecal pellets
- Dead organisms (detritus)
- Bacteria and archaea

Organic carbon constitutes **20–50% of dry mass** (Simon et al., 2002)

2. Inorganic Components

- Biogenic silica (diatoms)
- Calcium carbonate (coccolithophores)
- Mineral dust
- Microplastics

Recent studies show microplastics can contribute up to **5–10% of particle mass in polluted regions** (Roberts et al., 2024)

3. Transparent Exopolymer Particles (TEP)

TEP are Gel-like, polysaccharide-rich particles, produced as waste product primarily by phytoplankton and bacteria. It enables disaggregated particles to coalesce into marine snow and they enhance particle sticking efficiency by up to 100×(Passow, 2002).

Formation of Marine Snow

It is a multi-step process that transforms dissolved and small particulate organic matter into large, sinking aggregates.

1. Production of Organic Matter

Marine snow formation begins in the surface ocean, where phytoplankton perform photosynthesis and convert CO_2 into organic matter. Not all of this organic material is consumed within the food web; a portion is released into the surrounding water as dissolved organic matter (DOM) and small particulate organic particles. This leads to the accumulation of **tiny organic particles in the water column**, which serve as the basic building blocks for marine snow.

2. Formation of Sticky Matrix (TEP Production)

Phytoplankton and bacteria produce **Transparent Exopolymer Particles (TEP)**, which are gel-like and highly adhesive. These substances act as a **binding matrix**, allowing dispersed particles to stick together. The presence of TEP is crucial because it enhances the "stickiness" of particles and initiates the aggregation process.

3. Particle Collision and Aggregation

Particles come into contact through physical processes such as Brownian motion, turbulence, and differential settling. When these particles collide, the sticky TEP enables them to adhere and form small clusters called micro-aggregates. This stage marks the **initial aggregation of particles**, transforming dispersed materials into organized structures.

4. Growth into Marine Snow Aggregates

Micro-aggregates continue to grow by incorporating additional materials such as fecal pellets, dead plankton, and detritus. Biological processes, including zooplankton feeding and phytoplankton bloom collapse, further enhance aggregation. Over time, these particles increase in size (>0.5 mm), becoming **larger, fluffy, and porous aggregates**, which are recognized as marine snow.

5. Maturation and Initiation of Sinking

As marine snow aggregates grow in size and density, they begin to sink under the influence of gravity. During this stage, particles continue to collide and accumulate material, increasing their sinking potential. This marks the transition from formation to transport, where marine snow acts as a **carrier of carbon from the surface ocean to deeper layers**.

Role of Zooplankton

Appendicularians such as Oikopleura dioica produce mucus "houses":

- Houses discarded every **few hours**
- Can account for **up to 30% of vertical carbon flux** locally (Alldredge, 1998)

Sinking of Marine Snow

Marine snow sinks through the water column due to the interaction of two opposing forces: **gravity and drag.**

Condition for Sinking

- **Gravity < Drag** → particle may remain suspended → poor sequestration
- **Gravity = Drag** → particle sinks steadily → Moderate sequestration
- **Gravity > Drag** → particle accelerates downward → High carbon sequestration

Sinking Velocity

- Not all marine snow sinks the same
- Marine snow sinks between ~10 to 500 meters per day

Organic Matter	Sinking Speed	Role in Sequestration
Phytoplankton	< 1 m/day	Very low
Small particles	1–10 m/day	Low
Marine snow	10–200 m/day	High
ZP Fecal pellets	100–1000 m/day	Very high
Mucus houses	100–800 m/day	Very high

Factors Affecting Sinking

1. Particle Size

- Large aggregates → sink faster

- Small particles → remain suspended

2. Density

- Dense particles → faster sinking
- Light, fluffy particles → slower sinking

3. Composition

- Organic-rich → slow sinking
- Mineral-rich → fast sinking

4. Ballasting materials

- More ballast materials → increased Sinking speed

5. Fragmentation

- Breaking of large marine snow aggregates into smaller particles
- Increased surface area
- Slow sinking
- Enhanced microbial activity in the upper layer
- Reduced carbon sequestration

Microbial Remineralization

It is a process by which microbes convert organic carbon to inorganic carbon. The microbes responsible bacteria (heterotrophic bacteria), archaea, protozoa and zooplankton

Steps in Remineralization Process

Step 1: Attachment

- Microbes attach to particle surface
- Use chemotaxis (move toward nutrients)

Step 2: Enzyme Release

- Microbes release enzymes
- Break large organic molecules into smaller ones

Step 3: Decomposition

- Organic matter is degraded
- Used as energy source

Step 4: Respiration

- Microbes respire organic carbon

- Releasing CO_2 and nutrients (N, P)

Carbon Loss

- **~70–90% of organic carbon** is remineralized before reaching deep ocean (Herndl & Reinthaler, 2013)

Deep Ocean Carbon Sequestration

Carbon that reaches below ~1000 m gets stored for 100 – 1000 of years in 2 forms

1. Dissolved inorganic carbon (DIC)
2. Particulate organic matter (POM)

This is the final goal of the biological carbon pump

1. Dissolved in Deep Ocean Water

- Stays away from atmosphere for **100–1000 years**
- **Largest carbon storage pathway**

2. Burial in Marine Sediment

- Get buried in sediments
- Can stay for **1000–100000 years**
- **Hard materials (black carbon)**

Indian Context

Region	Sinks below photic zone	Reaches 100m	Reaches deep ocean (>1000m)
Indian Ocean	0.9–2.6 Pg C yr^{-1} highest in northern IO	Moderate	~0.14–0.42 Pg C yr^{-1}
Arabian Sea	~120–160 Tg C yr^{-1}	~40–70 Tg C yr^{-1}	~5–8 Tg C yr^{-1}
Bay of Bengal	~60 ± 20 Tg C yr^{-1}	~10 ± 5 Tg C yr^{-1}	~2–4 Tg C yr^{-1}

Conclusion

Marine snow is the engine of the biological carbon pump, transferring **~10.2 Pg C yr^{-1}** from the ocean surface toward the deep sea and sequestering atmospheric CO_2 on geological timescales. It is highly sensitive to environmental conditions and is currently being compromised by ocean warming, acidification, deoxygenation, and microplastic contamination. Reducing

greenhouse gas emissions and marine pollution (especially microplastics) to protect marine snow processes will sustain the ocean's ability to store carbon effectively.

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BIOGENIC SILICA: A POTENTIAL SUSTAINABLE SUPPLIER OF SILICON TO CROPS

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Abstract

Silicon (Si) is increasingly recognized as a "quasi-essential" nutrient for crops, providing significant benefits in mitigating biotic and abiotic stresses. However, the reliance on traditional mineral Si fertilizers is challenged by high costs and low solubility in certain soil environments. Biogenic silica (BSi), primarily in the form of phytoliths found in plant residues and biochars, presents a promising, sustainable alternative. This paper reviews the role of BSi as a potential supplier of Si to crops, exploring the mechanisms of its dissolution and bioavailability in soil. We compare the efficacy of biogenic sources with traditional mineral amendments and discuss the impact of BSi application on crop growth, yield, and stress tolerance. Furthermore, we evaluate sustainable agricultural practices for BSi recycling, such as crop residue management and biochar production. Despite the clear benefits, significant research gaps remain regarding the long-term kinetics of BSi dissolution and the standardization of analytical methods for measuring available Si. This review concludes that BSi recycling represents a vital strategy for closing the Si loop in sustainable agriculture, particularly in desilicated, highly weathered soils.

1. Introduction

Silicon (Si) is a beneficial nutrient element, plays a crucial role in plant growth and development. It increases nutrient availability in the rhizosphere and enhances nutrient uptake through various mechanisms. Silicon also influences the availability of other plant nutrients in soils by competing for binding sites on soil particles, leading to improved plant growth and resistance to abiotic and biotic stresses. However, the abundance of silica in nature has led to neglect in managing this essential resource. Human activities like crop intensification and export

of silica from agricultural soils through crop uptake and removal have significantly impacted silicon cycling globally. The loss of bioavailable silica due to crop harvest and removal varies widely among crops, posing challenges for agricultural production. Silicon exists in two forms: biogenic silica, derived from organisms, and phytogenic silica, found in living plants. In rice-based wetland ecosystems, biogenic silica sources include phytoliths from crop residues and microorganisms.

Silicon can be released from biogenic sources through mineralization and exported from the soil-plant system via drainage and leaching. Rice accumulates significant amounts of silicon, up to 10% of its dry weight, exceeding primary and secondary nutrients. Silicon sources include lithogenic/pedogenic reserves from weathering and biogenic reserves from phytoliths and microorganisms. Silicon cycling in rice fields involves release, translocation, addition, and removal/export processes. Leaching, accelerated by continuous submergence and anaerobic conditions in rice fields, dissolves silicon into water, leading to its removal. Irrigation water also contributes to significant losses of dissolved silicon. Additionally, precipitation and adsorption of silicon on minerals and organic compounds reduce its availability to plants. Consequently, silica availability decreases, causing rice plants to become vulnerable to pests and diseases. Effective management of silicon resources is essential to maintain soil fertility and ensure sustainable agricultural production.

Figure 1: Representation of Silicon: A sustainable approach to climate resilience and crop productivity

2. The Silicon Cycle in Agriculture: From Mineral to Biogenic

2.1 Mineral Si Sources

Most soil Si exists as crystalline primary and secondary minerals (e.g., quartz, feldspars, clays), which are largely unavailable to plants. Plant-available Si (PAS) exists primarily as mono-silicic acid (H_4SiO_4) in the soil solution.

Mineral fertilizers aim to replenish this pool, but their efficacy is highly dependent on particle size and soil pH.

2.2 The Rise of Biogenic Silica

Plants take up silicic acid and deposit it as amorphous silica (SiO2·nH2O) within cell walls and lumens, forming phytoliths. These structures are more soluble than many crystalline mineral forms. In natural and managed ecosystems, the recycling of BSi through litterfall or residue return can account for a significant portion of the annual Si uptake by vegetation.

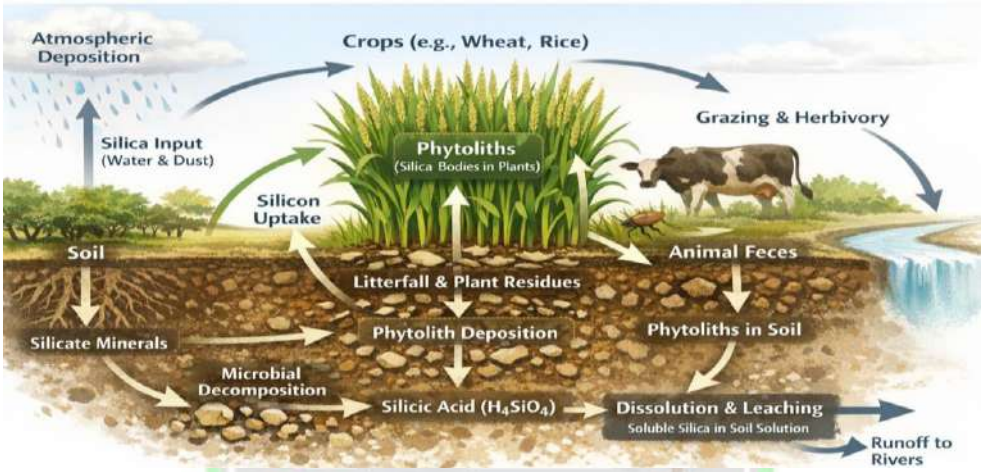

Figure 2: Schematic representation of the Biogenic Silicon Cycle in an agricultural ecosystem, showing the pathways from plant uptake to phytolith deposition and subsequent soil dissolution.

3. Mechanisms of BSi Dissolution and Bioavailability

3.1 Factors Governing Dissolution

- **Soil pH:** Higher pH generally accelerates the dissolution of amorphous silica. In acidic soils, BSi may remain relatively stable, limiting its immediate availability.
- **Soil Buffering Capacity:** Soils with low buffering capacity allow for more rapid changes in the Si equilibrium between solid and liquid phases.
- **Surface Area and Morphology:** The intricate shapes of phytoliths provide a high specific surface area compared to bulk mineral ores, facilitating faster reaction kinetics.
- **Pyrolysis Conditions:** When BSi is supplied via biochar, the temperature of pyrolysis significantly affects the structure and solubility of the silica. High-temperature biochar's may result in more recalcitrant Si forms

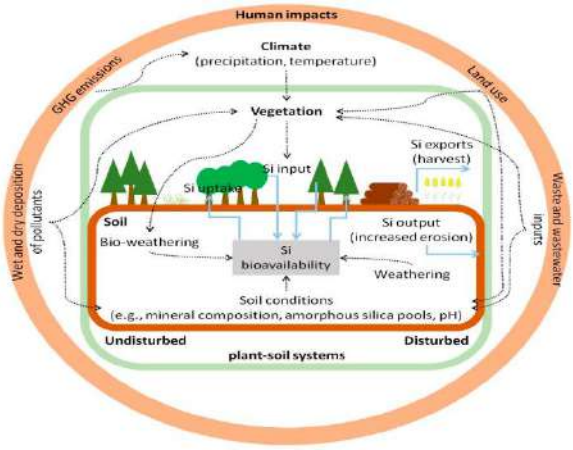

Figure 3: Representation of Silicon Cycle in Plant–Soil Systems Under Natural and Human Disturbance

3.2 Bioavailability vs Total Pool

It is crucial to distinguish between the total BSi pool and the bioavailable fraction. Standard extractions (e.g., CaCl2 or acetic acid) are used to estimate PAS, but these may not fully capture the long-term flux from BSi sources.

Table 1: Comparison of dissolution rates and Si release potential of various biogenic sources

S. No	Material	Type	Si Content (% dry weight)	Dissolution Rate (mg Si/L/day)	Si Release Potential
1	Rice Husk	Biogenic Residue	10–20	2.5–5.0	Moderate
2	Sugarcane Bagasse	Biogenic Residue	5–10	1.0–3.0	Low–Moderate
3	Biochar (from rice husk)	Pyrolyzed Biogenic	15–25	3.0–6.0	High
4	Wollastonite	Mineral Fertilizer	20–30	5.0–8.0	High
5	Sodium Silicate	Synthetic Fertilizer	>25	>10.0	Very High

4. Comparative Efficacy: Biogenic vs. Mineral Sources

4.1 Superiority of Phytolith-Rich Biochar

Research indicates that rice husk biochar can increase soil extractable Si and plant Si uptake more effectively than mineral wollastonite in certain soil types (Li & Delvaux, 2019). The amorphous nature of BSi in biochar provides a "slow-release" mechanism that sustains PAS levels over the growing season.

4.2 Economic and Environmental Advantages

Biogenic sources are often available as agricultural by-products (e.g., sugarcane bagasse ash, straw). Utilizing these "waste" streams reduces the environmental footprint associated with mining and transporting mineral fertilizers, supporting a circular bioeconomy.

5. Impact on Crop Growth and Stress Tolerance

5.1 Growth and Yield Enhancement

In crops like maize and rice, BSi amendments have been linked to increased biomass, higher chlorophyll content, and improved yield. For instance, sugarcane bagasse application has been shown to raise photosynthetic rates and yield components in alkaline soils (Al-Huqail *et al*., 2023).

5.2 Abiotic Stress Mitigation

- **Salinity:** Si helps maintain ionic homeostasis (e.g., K+/Na+ ratios) and reduces the uptake of toxic ions.
- **Drought:** By forming a silica-cuticle double layer, Si reduces transpiration and helps plants maintain turgor under water-limiting conditions.
- **Metal Toxicity:** BSi can help sequester heavy metals like aluminium and cadmium in the soil or within the plant tissue, reducing their bioavailability.

5.3 Biotic Stress Resistance

Phytoliths act as a physical deterrent to chewing insects and a barrier to fungal penetration. Furthermore, Si is involved in signalling pathways that prime the plant's systemic acquired resistance (SAR).

Figure 4: Conceptual diagram showing the multi-faceted benefits of Si (structural, physiological and biochemical) in mitigating environmental stress

6. Sustainable Practices and BSi Recycling

6.1 Residue Management

The systematic removal of crop residues (e.g., for fodder or fuel) depletes the soil's BSi reservoir, leading to "desilication." Returning straw or husks to the field is the simplest way to close the Si loop (Yang *et al*., 2020).

6.2 Valorisations of Industrial By-products

Industries such as sugar mills and rice processing units produce vast quantities of ash and husks. Converting these into stabilized biochar's or standardized soil amendments represents a major opportunity for sustainable Si fertilization.

7. Current Research Gaps and Future Perspectives

- **Long-term Kinetics:** Most studies are short-term (pot or single-season trials). We need long-term field data to understand how BSi pools evolve over decades.
- **Standardization:** There is a lack of harmonized analytical methods to quantify "phytogenic" Si vs. other soil Si fractions.
- **Synergy with Microbiota:** The role of Si-solubilizing bacteria in enhancing BSi dissolution is an emerging field that requires more exploration.

8. Conclusion

In conclusion, silicon is a vital nutrient element for plant growth and development, playing a crucial role in enhancing nutrient uptake, strengthening cell walls, and promoting drought tolerance. Despite its importance, silicon management has been neglected due to its abundance in nature. Human activities like crop intensification and export of silica from agricultural soils have impacted silicon cycling globally. Effective management of silicon resources is essential to maintain soil fertility and ensure sustainable agricultural production. Silicon fertilization can help plants overcome biotic and abiotic stresses, and various silicon fertilizers are available. Plants absorb silicon through their roots in the form of silicic acid, and the uptake process is influenced by factors like soil pH and nutrient availability. Overall, silicon is an essential element for crop health, growth, and productivity, and its importance should not be overlooked in agricultural practices.

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AVIAN PEST MANAGEMENT IN AGRICULTURE AND HORTICULTURAL CROPS USING IOT-BASED DEVICES AND EMERGING TECHNOLOGIES

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Abstract

Bird pests cause substantial economic losses in agricultural and horticultural crops worldwide, especially during sowing, seedling, and ripening stages. Traditional bird control methods such as scarecrows, netting, and acoustic devices provide only temporary relief due to habituation and operational limitations. Recent advancements in Internet of Things (IoT), Artificial Intelligence (AI), machine learning, laser-based deterrence, drone technologies, and acoustic sensor networks have revolutionized avian pest management. These modern systems enable real-time detection, automated deterrence, remote monitoring, and data-driven crop protection. Studies indicate that AI-integrated IoT systems can improve crop survival rates up to 90–95% compared to conventional approaches. This review highlights the economic impact of avian pests, evaluates traditional and emerging deterrent technologies, compares their effectiveness, and discusses future prospects for sustainable and precision-based bird management in agriculture.

Keywords: Avian pests, IoT, Artificial Intelligence, Laser deterrence, Drone management, Precision agriculture

Introduction

Birds are integral components of agro-ecosystems, contributing to pollination, seed dispersal, and insect pest control. However, certain bird species inflict severe damage to crops, especially cereals, oilseeds, fruits, and plantation crops. Globally, bird-related crop losses amount to billions of dollars annually. In India, more than 60 bird species are reported to cause economic damage to cereals, pulses, oilseeds, and fruit crops. Traditional deterrence methods such as scarecrows, reflective materials, and propane cannons have been widely used, but birds often adapt quickly to repetitive stimuli. The emergence of IoT, AI-based image recognition, drone surveillance, radar detection, and smart acoustic systems has opened new possibilities for precision avian pest management. These technologies provide scalable, non-lethal, environmentally friendly solutions aligned with sustainable agriculture.

1. Economic Impact of Avian Pests

In the United States alone, the estimated annual damage to grain, fruit, and berry crops from birds exceeds $150 million in direct costs, with European starlings, blackbirds, and crows being the most problematic species. In Australia, the fruit crop industry suffers an annual loss of approximately $300 million due to bird damage. Globally, blueberry crop loss averages about 30%, and up to a quarter of all US crops are lost each year due in part to bird activity.

Specific crop losses in the US include:

- Sunflower: >$15 million annually; North Dakota and South Dakota alone lose $4–7 million
- Ripening corn: $15–25 million; seeded corn: $20–50 million
- Cherries: $10 million
- Rice: >$20 million
- Grapes: $4 million

- Blueberries: $1–2 million

2. Traditional Bird Deterrent Methods

2.1 Visual Deterrents

Scarecrows are the oldest and most widely used bird deterrent, dating back thousands of years. They are typically constructed as human-like figures made from straw, old clothes, and other materials. However, their success largely depends on the specific pest type, and birds often become accustomed to their presence over time, rendering them less effective. Reflective materials such as ribbons, compact discs, and eye-spot balloons create visual disturbances. A 2025 study found reflective compact discs and high-visibility reflective tapes were among the most effective visual deterrents, significantly deterring pest birds from targeted spots within 60 minutes. Reflective ribbons were also found to be cost-effective in maize crop protection. Scarecrows and reflective tapes are cost-effective but prone to habituation.

2.2 Physical Barriers

Bird netting is one of the most effective physical barriers. In grape-growing regions, netting is widely used but is very costly approximately $1,000 per area and installing and removing nets is time-consuming. For larger vineyards and orchards, the cost of netting becomes prohibitive.

2.3 Acoustic Devices

Traditional acoustic methods include propane-fired cannons (bird bangers), pyrotechnic devices, and electronic distress call systems. Propane cannons are effective for scaring birds but suffer from noise pollution, neighbor complaints, and bird habituation over time. A study on alarm and distress calls from portable speakers found them significantly effective in deterring pest birds.

2.4 Chemical Repellents

Chemical bird repellents such as methyl anthranilate (a grape-flavored food additive aversive to birds) and anthraquinone have been investigated. Anthraquinone was found to be a more effective natural bird repellent compared to methyl anthranilate for maize seed protection. Anthraquinone-based repellents effectively protected rice seed from blackbirds under both captive and field conditions. Natural bird repellents in seed coatings reduced the risk of bird damage to maize below the 15% threshold. However, some chemical repellents are ineffective and most require repeated applications. Despite usefulness, traditional methods often fail to provide long-term sustainable protection.

3. IoT-Based Smart Bird Deterrent Systems

System Architecture and Components

Modern IoT-based bird deterrent systems typically integrate several hardware and software components:

Core Hardware:

- Microcontrollers: ESP32, Arduino Uno, ATmega328, Raspberry Pi
- Sensors: PIR (Passive Infrared) motion sensors, ultrasonic sensors, acoustic sensors, temperature and pressure sensors

- Cameras: HD cameras, webcams, stereo vision cameras for real-time image capture
- Deterrent actuators: Ultrasonic buzzers, sound emitters, voice playback modules, laser pointers, servo motors, LED floodlights
- Communication modules: Wi-Fi (ESP8266/ESP32), LoRa/LoRaWAN, GSM modules, ZigBee
- Power: Solar panels with rechargeable batteries for off-grid deployment

Software Stack:

- AI/ML models (CNN, YOLO, DenseNet, ResNet, Mask R-CNN) for bird detection
- Cloud platforms (Google Firebase, AWS IoT Core) for data storage and analytics
- Mobile applications for real-time alerts, remote monitoring, and manual control
- Edge computing for reduced latency and internet dependency

AI Algorithms for Bird Detection

- A systematic literature review of 20 articles (2015–2024) on automated bird deterrent systems found the following AI algorithms and their accuracy levels:

Algorithm	Detection Accuracy	Application
DenseNet	99.65% accuracy; 99.53% sensitivity	Sound/image pest analysis
ResNet-18	>90% accuracy; 550 FPS	Bird/background classification
YOLOv5	mAP@0.5: 0.89	Radar heatmap classification
YOLOv3 + ResNet100	High real-time accuracy; 30 FPS	Species-specific detection
CNN (general)	83.4–100% precision; 97.1% F1	Flock detection
Mask R-CNN	86.5% precision	Bird detection + laser targeting
Haar Cascade	76% accuracy	Image-based detection
CNN (ESP32 deployed)	92.8% accuracy; 93.2% precision; 91.7% recall	Field deployment on edge device

- YOLO-based models (v3, v5, v8) are particularly favored for agricultural field deployment due to their balance of speed and accuracy, enabling real-time detection on resource-constrained hardware.

Field implementations show crop survival improvements from 40% to over 90%. These systems allow remote monitoring via smartphone applications and cloud platforms.

4. Laser-Based Bird Repellent Systems

Automated laser bird repellent systems have shown remarkable effectiveness:

- Stockbridge Technology Centre, UK: Achieved 90% bird reduction on cabbages and sprouts using the AVIX Autonomic laser system over a 4–6 hectare projection area.
- Gazzola Farms, Australia: Reported approximately 90% bird reduction on vegetable crops after installing automated laser systems.
- Netherlands free-range poultry farm: A Class-III B automated laser achieved 98.2% overall efficacy in reducing wild bird visits, with 99.7% efficacy for waterfowl (Anseriformes) and 96.1% for passerines.
- US Sweet Corn (Laser Scarecrow): Reduced bird damage from 80% (no protection) to 20% with laser alone, and to just 8% when combined with Bird Gard audio device. In 2022 trials, unprotected fields averaged 20% damage vs. 7.5% with laser alone and 3% with laser + audio.
- Deep Learning-Based Laser Repellent (Taiwan, 2024): An automatic wild bird repellent combining deep-learning-based detection (Mask R-CNN) with a laser rotation mechanism achieved a daily bird repulsion rate of 40.3% at an outdoor duck farm.

- Laser systems exploit the natural aversion of birds to bright, moving light beams. They are non-lethal, environmentally friendly, and can cover large areas. However, birds may gradually adapt to fixed laser scan paths, necessitating randomized patterns.

5. Drone (UAV)-Based Bird Management

Unmanned Aerial Vehicles (UAVs) represent one of the most promising frontiers in avian pest management:

- Washington State University: Developed camera systems that detect birds and automatically deploy drones. Manually operated drones reduced bird counts four-fold and achieved a 50% reduction in damaged fruits in vineyards.
- University of Sydney (2020): UAVs incorporated with bird psychology principles were statistically as effective as netting in protecting vineyards. Damage percentages were comparable between UAV and netting treatments (e.g., 0.9% vs. 1.2% at one site), while visual deterrents resulted in significantly higher damage.
- Drones with Random Motion Events (RME) and Audio Bird Scaring Systems (ABSS) achieved 90–92% success rates by combining random flight patterns with predator sounds and distress calls.
- Biomimetic drones designed to mimic predator behavior and sounds have been tested for citriculture protection.

Key advantages of UAV systems include non-lethality, large area coverage, and reduced habituation risk when combined with audio-visual stimuli. Current limitations include battery life, regulatory compliance, and the need for autonomous operation at scale.

6. Acoustic and Ultrasonic Systems

6.1 Ultrasonic Bird Repellers

An experimental study on acoustic bird repellents in pear orchards found that an intermittent computer-vision-triggered ultrasonic device reduced pear damage to 6.03%, compared to 7.29% with continuous operation and 13.07% with no device. Ultrasonic repellers are harmless to humans and other animals, do not cause environmental pollution, and align with sustainable development principles.

6.2 Sonic Net Technology

Sonic Net technology, which masks bird communication by broadcasting ambient noise in specific frequency bands, reduced sunflower crop damage by blackbirds by 63.6%. Birds continued to avoid treated areas as the system prevented habituation by increasing perceived predation risk.

6.3 Multi-Modal Acoustic Systems

A study evaluating nine bird deterrent types found that alarm and distress calls from portable speakers (13.5–45.5 kHz) combined with flashing lights were significantly effective. The most effective deterrents were moving predator models, reflective compact discs, and high-visibility reflective tapes. However, sonic devices emitting only 24.5–45.5 kHz (without lower frequencies) were ineffective.

7. Radar-Based Bird Detection

MERLIN® Bird Detection Radar Systems, originally developed for the US Air Force and NASA, can detect bird and bat activity at ranges of 3–8 miles and have been deployed at wind farms, airports, solar farms, and agricultural sites. Over 1,000 systems have been delivered worldwide. While primarily used for aviation safety and wind energy mortality mitigation, radar technology has potential applications in large-scale agricultural bird monitoring.

8. Comparative Effectiveness of Bird Deterrent Methods

Method	Effectiveness	Coverage	Cost	Habituation Risk	Environmental Impact
Scarecrows	Low (birds habituate quickly)	Small area	Very low	Very high	None

Netting	Very high (physical barrier)	Limited	High ($1000+/area)	None	Low (entanglement risk)
Propane cannons	Moderate	Medium	Moderate	High	Noise pollution
Reflective materials	Moderate	Small–medium	Low	Moderate–high	None
Chemical repellents	Moderate (seed: <15% damage)	Targeted	Moderate	Low	Low (natural compounds)
Laser systems	Very high (90–98%)	Large (4–6 ha per unit)	High (initial)	Low–moderate	None (non-lethal)
Ultrasonic/acoustic	Moderate–high (54–84% reduction)	Medium	Moderate	Moderate	Low
Drone/UAV	Very high (comparable to netting)	Large	High (initial + maintenance)	Low (with RME)	None (non-lethal)
IoT-AI integrated	Very high (90–95% crop protection)	Scalable	Moderate–high	Low (adaptive ML)	None (solar-powered)

9. Integrated Bird Management Strategies

The most effective approach combines multiple deterrent modalities to prevent habituation:

- Multi-modal deterrence: Combining visual (laser, reflective), acoustic (distress calls, ultrasonic), and physical (drone presence) stimuli provides sustained deterrence.
- AI-powered adaptive systems: Machine learning algorithms learn bird behavior patterns and dynamically adjust deterrent schedules, reducing predictability.
- IoT-enabled remote monitoring: Cloud-connected sensors and mobile apps allow real-time monitoring, automated alerts, and remote control, reducing labor dependency.
- Habitat modification: Planting bird-resistant varieties, block plantations, altering crop maturity timing, and managing roosting habitat near fields reduce damage risk.

- Chemical seed treatments: Natural repellents (anthraquinone) applied as seed coatings protect crops during establishment without lethal effects.
- Reflective ribbons combined with bioacoustics: Found to be cost-effective in maize fields, reducing both depredatory bird abundance and crop damage.

10. Challenges and Future Directions

Current Challenges

- Habituation: Birds adapt to repetitive stimuli over time, reducing long-term effectiveness of single-method approaches.
- Small bird detection: Current AI models struggle with small pixel targets and fast-moving birds at various scales.
- Environmental interference: Sunlight, rain, wind, and vegetation can reduce sensor and camera performance.
- Cost and scalability: Advanced IoT/AI systems require significant initial investment, though costs are declining with open-source platforms and solar power.
- Regulatory constraints: Drone operations face federal aviation regulations that limit autonomous deployment.

- Limited long-term studies: Most studies evaluate short-term effectiveness; long-term ecological impacts on bird behavior and agricultural ecosystems remain understudied.

Future Directions

- Autonomous drone swarms: Coordinated multi-drone systems with AI-driven path planning for large-scale crop protection.
- Edge AI on low-power devices: Deploying optimized lightweight models (YOLOv6, TensorFlow Lite) on ESP32 and Raspberry Pi for real-time inference without cloud dependency.
- Species-specific deterrence: Systems that identify specific bird species and activate targeted deterrents (e.g., species-specific distress calls).
- LoRaWAN-based wide-area networks: Long-range, low-power communication enabling field-wide sensor networks for monitoring and deterrence coordination.
- Integration with precision agriculture: Combining bird pest data with other crop management data (soil health, weather, pest insects) for holistic farm management.

Robotic bird predator models: Moving predator decoys integrated with AI for dynamic, unpredictable deterrence.

Conclusion

Avian pest damage remains a significant constraint in agricultural and horticultural production. While traditional deterrent methods offer partial protection, their long-term effectiveness is limited. Emerging technologies such as IoT-based smart systems, AI-powered detection, automated laser deterrents, drones, and acoustic sensor networks represent transformative solutions for sustainable bird management. Integrated, adaptive, and multi-modal approaches are essential to minimize crop losses, reduce labor dependency, and enhance farm profitability. The future of avian pest management lies in precision agriculture driven by intelligent, non-lethal, and environmentally responsible technologies.

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SHRIMP TOILETS: A SMART SOLUTION FOR SUSTAINABLE SHRIMP FARMING

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Abstract

Shrimp farming has become one of the most rapidly expanding sectors in aquaculture, contributing significantly to global food security and rural livelihoods. However, the intensification of shrimp culture has led to serious challenges, particularly the accumulation of organic waste in pond systems, which deteriorates water quality and promotes disease outbreaks. The concept of "shrimp toilets," also known as central sludge collection systems, has emerged as an innovative and practical solution to manage pond waste efficiently. This article discusses the origin, design, functioning, and benefits of shrimp toilets in improving pond hygiene and shrimp health. By facilitating the concentration and removal of organic waste, this system reduces toxic gas formation, minimizes disease risks, and enhances production efficiency. The adoption of shrimp toilets represents a significant step toward sustainable and environmentally responsible shrimp farming practices.

Keywords

Shrimp farming, shrimp toilet, sludge management, aquaculture sustainability, pond hygiene, water quality, disease prevention

Introduction

Shrimp aquaculture plays a vital role in the global seafood industry and serves as an important source of income for farmers, especially in countries like India, Bangladesh, and other Southeast Asian nations. With the increasing demand for shrimp, farming practices have become more intensive, often involving high stocking densities and heavy feeding regimes. While these practices improve production, they also result in the accumulation of organic waste, including

uneaten feed, fecal matter, and microbial biomass, at the pond bottom. Over time, this waste settles, particularly in the central region of the pond, creating anaerobic conditions that lead to the formation of toxic gases such as ammonia and hydrogen sulphide. These gases impose stress on shrimp, weaken their immune system, and make them highly susceptible to opportunistic pathogens.

To address these challenges, farmers and researchers have introduced an innovative pond management technique known as the shrimp toilet. This system is designed to collect and remove sludge efficiently from the pond bottom, thereby improving water quality and reducing disease risks. The shrimp toilet has gained popularity due to its simplicity, cost-effectiveness, and significant impact on shrimp health and farm productivity.

Sludge Accumulation and Its Impact on Shrimp Health

In intensive shrimp culture systems, the continuous input of feed and organic matter leads to the rapid accumulation of sludge at the pond bottom. This sludge consists of decomposing organic material that consumes oxygen and creates anaerobic conditions. Under such conditions, harmful gases such as ammonia and hydrogen sulphide are produced, which are toxic to shrimp even at low concentrations. The presence of these gases not only affects shrimp growth but also leads to physiological stress, making them more vulnerable to infections.

Furthermore, sludge accumulation creates a favourable environment for the proliferation of pathogenic microorganisms. Diseases such as Early Mortality Syndrome, Acute Hepatopancreatic Necrosis Disease, *Enterocytozoon Hepatopenaei* infection, and White Fecal Disease are commonly associated with poor pond hygiene and organic waste buildup. These diseases can cause massive economic losses to farmers within a short period, highlighting the importance of effective sludge management in shrimp farming.

Concept and Design of Shrimp Toilets

The shrimp toilet is essentially a centralized waste collection system constructed at the center of the pond. It is designed to concentrate organic waste in a specific area, allowing for easy removal. Typically, about five to seven percent of the total pond area is allocated for the construction of the shrimp toilet. The pond bottom is designed with a gentle slope, usually ranging from 25 to 30 degrees, directing all waste materials toward the central pit.

The central pit, which is about two to three feet deep, acts as a collection point for sludge. The surface of the pond bottom is kept smooth to facilitate the movement of waste particles.

Continuous aeration plays a crucial role in this system by creating water currents that push organic waste toward the center. Once accumulated, the sludge can be removed using siphoning methods or pumps such as submersible or floating pumps. This regular removal of sludge prevents its buildup and helps maintain a healthy pond environment.

Recent Innovations in Shrimp Toilet Systems

In recent years, the shrimp toilet concept has been further improved with the introduction of advanced designs such as the use of HDPE or rubber parabola covers. These covers, typically around 2.5 meters in diameter, are placed above the central drain at a height of about two to three feet from the pond bottom. The presence of the parabola enhances the efficiency of sludge collection by creating a stronger suction effect, thereby increasing the area from which waste can be drawn into the central pit.

Additionally, the parabola structure helps prevent the loss of shrimp during sludge removal, which is a common concern in traditional systems. This innovation also reduces the frequency of siphoning, making the system more convenient and cost-effective for farmers. Such improvements demonstrate the evolving nature of shrimp toilet technology and its adaptability to modern aquaculture practices.

Sludge Production and Sustainable Management

Scientific studies indicate that approximately 500 grams of organic waste are generated for every kilogram of shrimp produced. In a typical production system targeting seven tonnes per hectare, this can result in the accumulation of around 3.5 tonnes of sludge. If not managed properly, this large volume of waste can have serious environmental consequences.

It is therefore essential to adopt sustainable sludge management practices. Farmers are advised to allocate a portion of their farm area, usually around five percent, as a sludge pit where collected waste can be stored and treated. Direct discharge of untreated sludge into natural water

bodies should be strictly avoided, as it can lead to environmental pollution and the spread of pathogens. Instead, the sludge should be allowed to settle and undergo proper treatment before disposal. Interestingly, treated sludge can also be utilized as an organic fertilizer in agriculture, thereby providing an additional benefit to farmers and promoting resource recycling.

Benefits of Shrimp Toilets in Aquaculture

The implementation of shrimp toilets offers numerous advantages in shrimp farming. By effectively removing organic waste, the system significantly reduces the formation of toxic gases, thereby improving water quality. This leads to better shrimp health, enhanced growth performance, and reduced mortality rates. The system also helps in minimizing the occurrence of major diseases, which are often associated with poor pond hygiene.

Another important benefit is the improvement in feed conversion ratio, as healthier shrimp utilize feed more efficiently. The reduced need for chemical treatments further lowers production costs and minimizes environmental impact. Overall, shrimp toilets contribute to a cleaner, healthier, and more sustainable aquaculture system.

Conclusion

Shrimp toilets represent a simple yet highly effective innovation in modern aquaculture. By addressing the critical issue of sludge accumulation, they play a vital role in improving pond management, enhancing shrimp health, and increasing farm productivity. As shrimp farming continues to intensify, the adoption of sustainable practices such as shrimp toilets becomes increasingly important. This system not only helps farmers achieve better economic returns but also ensures environmental protection and long-term sustainability. With proper design, regular maintenance, and responsible waste management, shrimp toilets can serve as a key component of successful and eco-friendly shrimp farming.

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LASER-BASED DISINFECTION SYSTEMS IN HATCHERIES: A NEXT-GENERATION APPROACH FOR BIOSECURITY AND DISEASE CONTROL

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Abstract

Hatcheries form the backbone of aquaculture and livestock production systems, providing high-quality seed for sustainable farming. However, these facilities are highly vulnerable to microbial contamination, including bacteria, viruses, fungi, and parasites, which can significantly compromise productivity and survival rates. Conventional disinfection methods such as chemical treatments, ultraviolet irradiation, and filtration systems have limitations related to efficiency, environmental impact, and resistance development. In recent years, laser-based disinfection systems have emerged as an innovative and highly precise technology for microbial control. These systems utilize specific wavelengths and energy intensities to inactivate pathogens through photothermal, photochemical, and photomechanical mechanisms. This article explores the principles, design, mechanisms, applications, advantages, challenges, and future potential of laser-based disinfection systems in hatcheries, highlighting their role in improving biosecurity and ensuring sustainable production.

Keywords: Laser disinfection, aquaculture health, microbial inactivation, photothermal effect, UV laser, water treatment

Introduction

Hatcheries are critical units in aquaculture, responsible for the production of larvae, fry, and juveniles under controlled conditions. The success of hatchery operations depends largely on maintaining optimal environmental quality and minimizing pathogen exposure. However, hatchery systems often face challenges due to high stocking densities, organic load, and

continuous water exchange, which create ideal conditions for microbial proliferation (Zhang et al.,2025). Disease outbreaks in hatcheries can lead to massive economic losses, particularly in shrimp and fish farming. Pathogens such as *Vibrio* spp., viral agents, and parasitic organisms can rapidly spread through water systems, affecting entire batches. Traditional disinfection strategies, including chlorination, ozonation, and UV treatment, have been widely used but are associated with limitations such as incomplete pathogen removal, formation of harmful by-products, and reduced efficacy under high organic loads. In this context, laser-based disinfection systems have gained attention as a novel, non-chemical, and highly targeted approach for pathogen control. By harnessing the power of laser light, these systems offer precise and efficient microbial inactivation without compromising water quality or organism health.

Principles of Laser Technology

Laser stands for "Light Amplification by Stimulated Emission of Radiation." Unlike ordinary light, laser light is monochromatic, coherent, and highly directional. These unique properties allow lasers to deliver concentrated energy to specific targets with high precision. Laser systems operate by exciting atoms or molecules in a gain medium, causing them to emit photons at a specific wavelength. The emitted light is amplified through optical feedback and released as a focused beam. Depending on the application, lasers can operate in continuous or pulsed modes, each offering distinct advantages. In disinfection applications, the wavelength and energy of the laser are carefully selected to target microbial structures such as cell walls, membranes, proteins, and nucleic acids. This targeted approach ensures effective pathogen inactivation while minimizing damage to surrounding biological system (Shang et al., 2026)

Mechanisms of Laser-Based Disinfection

Laser-based disinfection relies on multiple mechanisms that act individually or synergistically to inactivate microorganisms. One of the primary mechanisms is the photothermal effect, where laser energy is absorbed by microbial cells and converted into heat. This localized heating can cause protein denaturation, membrane disruption, and eventual cell death. Another important mechanism is the photochemical effect, particularly in the case of ultraviolet (UV) lasers. UV radiation can induce DNA and RNA damage, prevent replication and lead to microbial inactivation. This mechanism is highly effective against a wide range of pathogens, including viruses (Jing et al.,2025). The photomechanical effect involves the generation of shock waves or mechanical stress within microbial cells due to rapid energy deposition. This can lead

to structural damage and cell lysis. Additionally, lasers can generate reactive oxygen species (ROS), which further enhance antimicrobial activity by causing oxidative damage to cellular components.

Types of Lasers Used in Disinfection

- Various types of lasers are used in disinfection systems, each with specific properties and applications. UV lasers are particularly effective due to their ability to directly damage nucleic acids. Visible and near-infrared lasers are often used for photothermal applications.
- Pulsed lasers, such as femtosecond and nanosecond lasers, are capable of delivering high energy in short bursts, making them suitable for precise microbial targeting. Continuous-wave lasers, on the other hand, provide steady energy output and are commonly used in water treatment systems.
- The choice of laser depends on factors such as target pathogens, water quality, system design, and operational requirements.

Design of Laser-Based Disinfection Systems in Hatcheries

Laser-based disinfection systems in hatcheries are typically integrated into water circulation units. The system consists of a laser source, optical components, a treatment chamber, and control systems. Water flows through the treatment chamber, where it is exposed to laser irradiation. The design ensures uniform exposure and optimal energy distribution to maximize disinfection efficiency. Advanced systems may include sensors to monitor water quality parameters such as turbidity, temperature, and microbial load. Automation and control systems allow real-time adjustments based on environmental conditions, ensuring consistent performance. Compact and modular designs make these systems suitable for both small-scale and large-scale hatchery operations.

Applications in Aquaculture Hatcheries

- Laser-based disinfection systems have diverse applications in aquaculture hatcheries. One of the primary uses is water disinfection, where the technology effectively eliminates pathogenic microorganisms without altering water chemistry.
- These systems can also be used for surface sterilization of equipment, tanks, and pipelines, reducing the risk of cross-contamination. In larval rearing units, laser

disinfection helps maintain a pathogen-free environment, improving survival rates and growth performance.

- Additionally, laser systems can be applied to disinfect live feed cultures such as algae and Artemia, which are common sources of contamination in hatcheries.

Advantages Over Conventional Disinfection Methods

- Laser-based disinfection offers several advantages compared to traditional methods. Unlike chemical disinfectants, it does not produce harmful residues or by-products, making it environmentally friendly. The targeted nature of laser treatment ensures high efficiency and minimal impact on non-target organisms (Perini et al.,2021)
- The technology also reduces the risk of microbial resistance, which is a growing concern with chemical treatments. Furthermore, laser systems can operate continuously and require minimal consumables, thereby reducing long-term operational costs.
- Another key advantage is the ability to integrate laser systems with existing hatchery infrastructure, enhancing overall biosecurity without requiring significant modifications.

Impact on Hatchery Productivity and Biosecurity

- The implementation of laser-based disinfection systems can significantly improve hatchery productivity by reducing disease incidence and mortality rates. By maintaining a clean and stable environment, these systems support optimal growth and development of larvae and juveniles.
- Enhanced biosecurity measures also reduce the need for antibiotics and other chemical treatments, promoting sustainable aquaculture practices. This is particularly important in the context of increasing regulatory restrictions on antimicrobial use.

Environmental and Sustainability Aspects

Laser-based disinfection aligns with the principles of sustainable aquaculture by minimizing environmental impact. The absence of chemical residues ensures that discharged water does not harm surrounding ecosystems. Energy efficiency is another important consideration. Advances in laser technology have led to the development of low-power, high-efficiency systems that reduce energy consumption while maintaining high performance.

Challenges and Limitations

- Despite its advantages, laser-based disinfection technology faces several challenges. High initial investment costs may limit adoption, particularly in small-scale hatcheries.

- Technical expertise is required for system installation and maintenance.
- Water turbidity and organic matter can affect laser penetration and reduce efficiency. Therefore, pre-treatment processes such as filtration may be necessary.
- Additionally, long-term studies are needed to evaluate the effectiveness and safety of laser systems under different operational conditions.

Integration with Advanced Technologies

The future of laser-based disinfection lies in integration with other advanced technologies. Combining laser systems with sensors, artificial intelligence, and IoT can enable smart hatchery management. Real-time monitoring and automated control can optimize system performance and reduce human intervention. Integration with recirculating aquaculture systems (RAS) can further enhance efficiency and sustainability.

Future Perspectives

As research and development continue, laser-based disinfection systems are expected to become more affordable and widely accessible. Innovations in nanotechnology and photonics may lead to the development of more efficient and versatile systems. The technology has the potential to revolutionize hatchery management by providing a reliable and sustainable solution for disease control. Collaboration between researchers, industry stakeholders, and policymakers will be essential for successful implementation.

Case Studies and Emerging Research

Recent studies have demonstrated the effectiveness of laser-based disinfection in inactivating a wide range of aquatic pathogens. Experimental trials in hatchery settings have shown improved survival rates and reduced disease outbreaks.

Ongoing research is focused on optimizing system design, understanding microbial response mechanisms, and evaluating long-term performance. These studies provide valuable insights into the practical applications of this technology.

Broader Implications for Aquaculture Industry

- The adoption of laser-based disinfection systems can have far-reaching implications for the aquaculture industry. By improving hatchery success rates, the technology contributes to increased production and profitability.
- It also supports global efforts to reduce antibiotic use and promote sustainable practices.

- As consumer demand for safe and environmentally friendly seafood continues to grow, such innovations will play a crucial role in shaping the future of aquaculture.

Conclusion

Laser-based disinfection systems represent a transformative advancement in hatchery biosecurity and disease management. By offering precise, efficient, and environmentally friendly microbial control, these systems address many limitations of conventional methods. Although challenges remain, ongoing research and technological advancements are expected to overcome these barriers. The integration of laser technology into hatchery operations holds great promise for enhancing productivity, sustainability, and resilience in the aquaculture sector.

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SUSTAINABLE AND INNOVATIVE MODERN APPROACHES FOR POST-HARVEST PEST MANAGEMENT IN GRAINS

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Abstract

The destruction of cereals and grains by insects, rodents, birds and fungal growth is a significant issue in their post-harvest security, particularly in developing countries where storage infrastructure is limited. The application of conventional chemical fumigants and insecticides, although successful, has resolved several issues related to resistance development in insects, residues in food materials, environmental contamination, food safety, and government regulations. Consequently, there has been a growing interest in the development of eco-friendly alternatives for post-harvest pest control. This review critically combines the most recent developments in eco-friendly alternatives for post-harvest pest management techniques, including sensor-based monitoring systems, physical control techniques (temperature, atmosphere, and hermetic storage), biological control agents, botanical-based formulations, and emerging biotechnologies. Developments in nano-encapsulated botanicals, smart packaging systems and controlled-release formulations are also discussed. The review also highlights the integrated pest management practices that entail the combination of several sustainable practices to improve their flexibility and efficiency in the prevailing climatic changes. The regulatory, safety, and socio-economic considerations that influence the adoption of technology are also highlighted to ensure that the gap between the innovations in the laboratory and the application of the technology in the field is eliminated. Finally, the research gaps and future research

directions are highlighted to ensure that sustainable post-harvest pest management is a significant area that ensures food security.

Keywords: Post-harvest pest control, Alternative method, Pest control, Advanced technique, Sustainable pest control.

1. Introduction

The post-harvest protection of grains is one of the significant aspects in the global food security chain, considering the large quantities of grains that are quantitatively and qualitatively lost during the storage phase due to insects, rodents, birds and fungal growth. It is estimated that 10-30% of grains are lost every year in developing countries, which directly affects the income levels of the people. Thus, the post-harvest pest management is one of the significant aspects in the food security chain. The use of chemical insecticides, including malathion, dichlorvos, phosphine, and methyl bromide, is the prevailing method for the management of insects in grain storage. Even though these methods are effective, their overuse is responsible for some severe problems, including the development of resistance in insects, residues in food materials and environmental pollution. In this context, the present review aims to critically assess the recent developments in the management of insects for the post-harvest protection of grains. The review aims to provide an overview of the present status of sustainable methods, including their mechanisms, effectiveness, limitations, and the scope to fill the research gaps to develop the post-harvest pest management practices.

2. Post-harvest pests in grains

The grains in the granary can be attacked by a whole array of pests even after the harvest. This has been a cause for huge losses. The major insects that are responsible for the loss of grains during storage in the granary are *Sitophilus oryzae*, *Sitophilus zeamais*, and *Rhyzopertha dominica*. These insects feed on the grains and gradually reducing the weight of the grains. They may also affect the germination process of the grains. The secondary grain storage insects include *Tribolium castaneum* and *Oryzaephilus surinamensis* will feed on the damaged grains. Apart from this, there are various pests that affect the grains, which were tabulated in Table 1. Fungal infection of grains in the granary can cause huge losses. The development of storage fungi is primarily influenced by grain moisture content, temperature, humidity, and the lack of aeration facilities within the storage system. Among these most dangerous mycotoxins, which are associated with aflatoxins, ochratoxin A is predominantly produced by *Aspergillus* and

Penicillium species under favourable storage conditions. The rodents are capable of causing huge losses in the grains in the granary. During consumption of the grains, spilling, urinating and dropping feces in the grains.

Table 1. Major Post-Harvest Pests in Stored Grains

Serial Number	Common Name	Scientific Name	Pest Type	Grains Infested	Form of Damage Caused by the Pest
1	Rice weevil	*Sitophilus oryzae*	Beetles	Rice, wheat, maize	Internal feeding pest; larvae grow inside kernels making holes
2	Granary weevil	*Sitophilus granarius*	Beetles	Wheat, barley, maize	Drills into whole grains and feeds inside them, making their quality low
3	Lesser grain borer	*Rhyzopertha dominica*	Beetles	Wheat, rice, maize, sorghum	Larvae as well as adult stages feed on grains; creates powders
4	Red flour beetle	*Tribolium castaneum*	Beetles	Flour, wheat, processed grains	External feeding; contaminates grains with foul smell and secretions
5	Khapra beetle	*Trogoderma granarium*	Beetles	Wheat, rice, barley, maize	Extremely harmful pest; larvae attack grain germs leading to losses
6	Angoumois grain moth	*Sitotroga cerealella*	Moths	Maize, rice, wheat	Larvae develop inside kernels making holes within
7	Indian meal moth	*Plodia interpunctella*	Moths	Stored cereals, flour,	Contaminates grains by creating webs and

				nuts	feeds on grain surface
8	Saw-toothed grain beetle	*Oryzaephilus surinamensis*	Beetles	Broken grains, cereals, flour	External feeding pests; infest processed grains and storage products
9	Pulse beetle	*Callosobruchus chinensis*	Beetles	Pulses such as lentils, chickpeas and beans	Larvae grow inside seeds, causing holes and weight losses
10	Rust-red grain beetle	*Cryptolestes ferrugineus*	Beetles	Wheat, rice, cereals	Fees on grains and raises grain temperature

3. Factors influencing insect infestation

The insects in the stored grains are all about the interplay of biology, environment and the grain itself. The short life cycle, fast breeding and behavioural flexibility are the hallmarks of the dominant insects in the storage environment. These insects can rapidly infest and multiply in a closed environment of the storage system. Moreover, the larvae of many insect species live inside the grain, making them harder to manage and making it more difficult to detect. In addition to insects, fungi and microorganisms can co-occur and work in concert to hasten the deterioration of the grains. The way these commodities are stored is very important, and the interplay of temperature, humidity, and oxygen availability, makes possible the growth, survival, and reproduction of insects in the stored grain. The presence of poor ventilation, moisture migration, and increased temperatures due to climate change can cause an explosion of insect infestation in the stored grain. The grain itself has unique physiological and physical properties, and the moisture content, hardness, chemical composition, and integrity of the seed coat can all influence the insect infestation. Moreover, the presence of broken, damaged, or immature grains makes them more susceptible to insect infestations and microorganisms. In addition, the presence of phenolic compounds present in the grain can influence its level of resistance to insect infestations.

4. Sustainable Physical Control Strategies

The physical control methods provide effective and residue-free alternatives to chemical pesticides for the control of post-harvest insects in grains as figured out in Fig. 1. These methods mainly focus on the storage environment and physiology of the insects to reduce the chances of infestation while preserving the quality and safety of the grains.

4.1. Temperature and Humidity Management

The temperature and humidity levels also impact the survival and reproduction of the insects in the grains. For the majority of the insects, the ideal temperature for survival is around 25-35°C, along with grain moisture levels above 13%. Lower temperatures will reduce the rate of the insect's metabolism, reproduction, and growth which can be achieved by different methods such as aeration or refrigeration. The same is true for the growth of fungi and the formation of mycotoxins, where the relative humidity levels must be managed to restrict the movement of moisture, thereby affecting their growth.

4.2. Thermal disinfestation

Thermal disinfestation techniques are based on the fact that insects are very sensitive to heat. The simplest technique is to use the sun's heat, such as by leaving the grain in the sun. The heat will kill the insects in different stages of development. But care should be taken to avoid excess heating to maintain the quality of the grain. In addition, the use of hot air, microwave, infrared or RF heat can kill the insects without the use of chemicals. But the temperatures need to be well managed to maintain the quality, viability, and nutritional content of the grain. These techniques are eco-friendly and energy-saving.

4.3. Controlled and Modified Atmosphere Storage

The principle behind Controlled and Modified Atmosphere (CA/MA) storage is that the composition of gases in contact with the grain is changed to remove oxygen while adding carbon dioxide or replacing it with nitrogen. With less oxygen available to breathe, insects cannot breathe or develop properly, eventually dying off without any noxious byproducts. CA/MA storage is especially useful in small-scale storage facilities because it does not require much energy. Hermetic storage also plays its part in managing the insects in the grains. Hermetically sealed bags, silos, and vacuum storage have shown excellent results in controlling many species of insects.

4.4. Grain Sanitisation / Hygeinic Techniques

Grain sanitisation is the physical cleaning usually done with sieving, suction, brushing, polishing, etc. It is the removal of infested grains, insect parts, dust, and other unwanted materials. This reduces the pest population, providing better, safer storage conditions. Cleaning the surfaces of silos, bins, equipment also reduces the risk of reinfestation. Grain sanitisation, combined with other physical methods, improves the effectiveness of sustainable post-harvest pest management strategies.

Fig. 1. Sustainable Physical Control Strategies

5. Biological Approaches

Biological methods provide environmentally sustainable options for the management of post-harvest pests by utilising natural antagonists and biologically derived agents. The biological approaches are an environmentally friendly approach for the management of post-harvest pests using natural enemies, microbial agents, and biologically derived compounds figured out in Fig. 2. These methods have minimal chemical residues, are environmentally safe and resistant to development. The biological approaches are in line with the principles of Integrated Pest Management (IPM) and sustainable agriculture since they promote balance in and resistance and provide food safety during transportation and storage.

5.1 Use of Natural Enemies

Predators and parasitoids are examples of natural enemies that have proved highly efficient in curbing storage pest populations. They prey on insects from any of the stages of the

life cycle, including egg, larva, or adult stage of development. The parasitoid wasps Anisopteromalus calandrae and Theocolax elegans may be used to prey on grain beetle and weevil insects. These parasitoid insects lay eggs either in the bodies of the host insect or attach the eggs to the host, feeding the developing larvae on the hosts. As a result, the hosts are killed. Likewise, predatory insects prey on insect eggs and larvae.

The biological control method using natural enemies has been found efficient in controlled storage conditions like warehouses and storage of grains.

5.2 Microbial Biocontrol Agents

The microbial biocontrol agents are the most preferred type when it comes to protecting plants from insect infestation after harvesting. There are many bacteria, fungi, and viruses that act as the natural enemies of insects using different techniques like producing toxins that prevent the digestive processes of the insects. *Bacillus thuringiensis* (Bt) is the most widely used type of microbial biocontrol agent. It can produce toxins that hinder the digestive process of the insect population but at the same time is safe for human beings and other living organisms. Beauveria bassiana and Metarhizium anisopliae are entomopathogenic fungi that have proven very useful in dealing with insects that invade the stored products. They cause infections on the insects by penetrating their protective outer layer and causing their death.

5.3 Botanical Biopesticides

Botanical biopesticides refer to organic compounds obtained from plant materials that possess pesticidal characteristics in that they may either kill, repel or deter the growth of the pest insects. Essential oils from plant materials such as cloves, eucalyptus, peppermint, and lemongrass among others have been shown to have considerable activities against stored-product pests. The effectiveness of botanicals in the control of insect pests is attributable to several modes of action such as fumigation, antifeedation, repellency, and neurotoxicity.

This makes botanical pesticides ideal because they are easily biodegradable, environmentally friendly, and less toxic to humans than the synthetic versions. Other species of plant materials have proved to be effective in pest control. Neem (Azadirachta indica), for instance, contains azadirachtin, a growth regulator that deters insect feeding behavior and thus control a broad range of stored and field insects. Pyrethrum obtained from Chrysanthemum cinerariifolium provides immediate knockdown effect against flying insects owing to the neurotoxic properties of the compound. Garlic (Allium sativum) is highly repellent and possesses

antimicrobial characteristics and can, therefore, be used to protect grains against both insects and spoilage microorganisms. Eucalyptus (Eucalyptus globulus) and basil (Ocimum sanctum) also possess fumigant and repellent properties.

Although there are many benefits associated with them, the instability and degradation of the chemical compounds of the plant material tend to cause lower residue activity in practical situations. In order to solve this problem, modern drug delivery methods have been introduced, which include microencapsulation, nanoemulsion, and controlled release formulation. These processes help increase the effectiveness of botanical pesticides by enhancing their stability and targeted delivery.

5.4 Semi-chemicals and Behavioural Control

The semichemicals are chemical messengers that insects use in communication and control the direction. They include pheromones, attractants and repellents. They are useful in monitoring and managing insect populations. In stored grain storage, the use of pheromone traps is common in detecting early signs of infestation. Aggregation pheromones are chemical messengers that attract the insects to the trap. They can be useful in managing insects by interfering with mating and hence reducing the reproduction rate.

6. Integrated Strategies

Some interesting developments are coming up in the field of post-harvest insect management, especially when it comes to the combination of physical methods with natural compounds. The basic idea is to weaken the insects through physical stress, so the natural compounds perform better, even at lower concentrations. Recently, nanotechnology has also played its part in the implementation of integrated pest management methods for grains. For instance, plant extract, essential oil, or microbial byproduct nano-formulations have been developed to improve solubility, stability, and bioavailability, especially to address the problem of volatility or high degradation rate. At the same time, the implementation of smart packaging materials, especially those with insect-repelling, antifungal, or gas-modulating compounds, is also providing active protection to the grains by creating harsh conditions for the insects during storage. Another aspect is the implementation of the controlled-release method, which is also playing its part in the implementation of integrated pest management methods. For instance, the encapsulation of bioactive compounds in biopolymers such as chitosan, starch, or whey protein provides better protection to the grains from environmental degradation. The encapsulation also

allows the compounds to be released according to the changes in the relative humidity or temperature, thereby extending the duration of the activity. All this is not only helpful in the management of the insects but also enhances the shelf life of the grains while maintaining their quality.

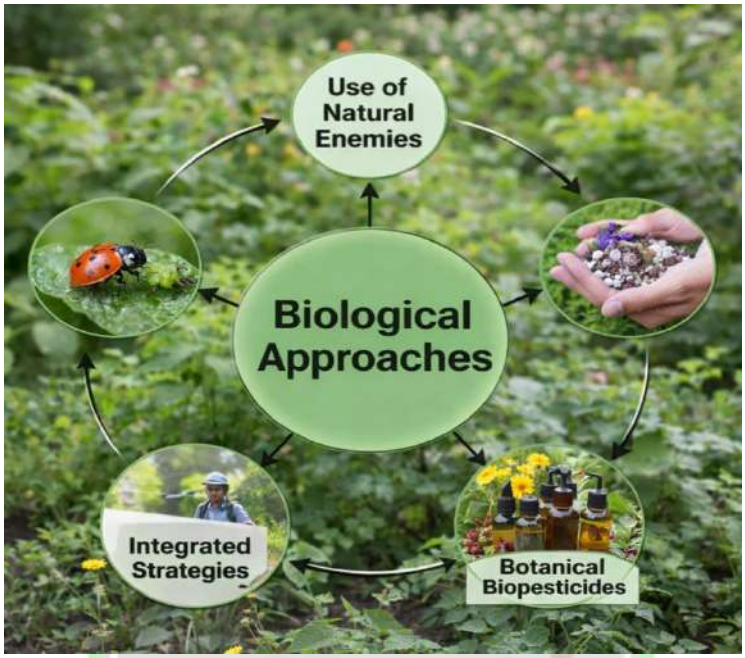

Fig. 2. Biological Approaches for Pest Control

Lastly, the implementation of the Internet of Things, especially the sensors, is also playing its part in the implementation of integrated pest management methods. For instance, the implementation of sensors to monitor the changes in the relative humidity, temperature, or the location of the insects provides real-time information on the status of the grains during the storage process.

7. Regulatory, Safety, and Socio-Economic Considerations

The driving forces for sustainable post-harvest insect management practices are mainly government regulations, safety, and economic factors. For instance, big organizations such as Codex Alimentarius, FAO, WHO, and so forth set standards for the maximum residue limit of insect control practices for grains. As the regulations become stricter for synthetic fumigants or pesticides, there has been a need for safer insect control practices. However, the biggest challenge has been standardizing the sustainable practices.

The assessment of the toxicity of the new technology of insect management has been a crucial issue in determining the acceptability of the new technology. The assessment of the new

technology must take into consideration of the toxicity to non-target organisms, allergenic potential, and long-term exposure.

The policy drivers, which include government incentives, extension support, capacity building, and innovation support, have been a driving force for sustainable post-harvest pest management practices. A unified policy can help in the rapid adoption of sustainable post-harvest insect management practices.

8. Research Gaps

However, there are still gaps in our knowledge of sustainable post-harvest pest management in which need attention. For instance, the issue of climate change has altered the geographical distribution of post-harvest insects, the population density of the insects, and the level of infestation of the grains. There is a need for multi-scale system models that will combine grain physiology, insect biology, and storage conditions to forecast the infestation levels. There are possibilities for the use of data-driven approaches and AI for the purpose of real-time monitoring, prediction, and precise management of the post-harvest insects. However, for this purpose, there is a need for the integration of the disciplines of entomology, microbiology, material science, and engineering.

9. Conclusions

The implementation of sustainable post-harvest insect management strategies is crucial for maintaining the quality of grains, food security, and environmentally safe practices. The combination of physical, biological, botanical, and advanced biotechnological methods is considered to be a good residue-free alternative to the chemical methods. New technologies, such as nano-technologies, smart packaging, controlled release of botanicals, and AI-based monitoring, are also being innovative methods. However, their adoption is also dependent on regulatory aspects, cost-effectiveness, and the awareness level of the farmers and stockholders.

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BLOSSOMS BEYOND CROPS: THE SECRET LIFE OF WEEDS

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Abstract

Weeds, often overlooked and underappreciated, possess a hidden beauty that emerges when they flower. This exploration highlights the aesthetic and ecological significance of flowering weeds, showcasing their vibrant colors, intricate structures, and resilience. Beyond their role as agricultural pests, these plants contribute to biodiversity, support pollinators, and enrich ecosystems. Through a visual journey and discussion, we reveal the unique charm of weeds in bloom, challenging conventional perceptions and encouraging a reevaluation of their place in our environment. This study highlights the diversity and aesthetic significance of flowering weeds present within the orchard ecosystem. While weeds are traditionally regarded as unwanted competitors affecting crop productivity, their flowering phase reveals an important ecological dimension, contributing to biodiversity, supporting pollinators, and enhancing the visual landscape. The observation focuses on the occurrence, abundance, and floral characteristics of common weed species in the fruit block during the spring season. The blooming of these weeds not only indicates their adaptive survival strategies but also reflects their role in maintaining ecological balance within managed horticultural systems. By documenting this seasonal phenomenon, the study aims to shift the perspective on weeds from mere agricultural nuisances to integral components of agro-ecosystems.

Introduction

Weeds - those pesky plants that grow where they're not wanted. But, have you ever stopped to appreciate their beauty? Beyond their often-ignored presence in our gardens and fields, many weeds produce stunning flowers that deserve recognition. From the delicate petals

of dandelions to the vibrant hues of wildflowers, weeds are capable of adding a splash of color to the most unexpected places. In this exploration, we'll venture beyond the conventional beauty of cultivated crops and discover the fascinating world of weeds in bloom. Let's uncover the **hidden charm** of these underappreciated plants and celebrate their unique contributions to our ecosystem.

While attention is often centered on cultivated crops and their seasonal growth, an equally fascinating yet overlooked phenomenon unfolds quietly at ground level—the flowering of weeds. These so-called "**unwanted plants**," often removed or ignored in agricultural practices, reveal an unexpected charm during this time as they enter their reproductive phase and cover the orchards with delicate and colorful blooms.

Far from being mere competitors for nutrients, light, and space, weeds during their flowering stage contribute to the ecological richness of the orchard ecosystem. Their blossoms attract pollinators, support biodiversity, and reflect the adaptive resilience of wild flora in managed landscapes. In April- March, the field becomes a **living canvas** where cultivated plants and wild species coexist, offering a unique blend of productivity and natural beauty.

This article explores the diversity, appearance, and ecological significance of flowering weeds in the Bharsar fruit block, highlighting how these unnoticed plants add a subtle yet striking dimension to the agricultural landscape.

Study Area Description

Bharsar, located in the Pauri Garhwal district of Uttarakhand, is a place of serene beauty. Situated at an altitude ranging approximately from 1800 to 2200 meters, the climate here is temperate, with a cool spring in April. The fruit block, filled with apple, peach, and plum trees, is a sight to behold. April is a favorable time for flowering, as the weather conditions are ideal for the blossoms to bloom, painting the landscape with vibrant colors.

- Location: Bharsar, Pauri Garhwal, Uttarakhand
- Altitude (1900–2000 m from MSL)
- Climate: Temperate, cool spring in March- April

Weed flora in flowering stage

During the month of April, the majority of weed species present in the fruit block of Bharsar enter their reproductive or flowering stage, marking a peak in their life cycle. This phase is characterized by a striking diversity of floral colors, including shades of yellow, white, purple,

and blue, which collectively enhance the visual appeal of the orchard floor. The weeds are observed to be well distributed across the fruit block, with higher density in open spaces, inter-row areas, and less-managed patches where competition is relatively low.

These flowering weeds exhibit strong adaptive strategies such as rapid growth, efficient seed production, and resilience to varying environmental conditions, enabling them to thrive alongside cultivated crops. Their presence during this stage not only reflects their ecological fitness but also contributes to the dynamic nature of the agro-ecosystem. Despite being considered undesirable, these weeds create a visually appealing and ecologically active environment during spring.

Weed identification

Sr. no.	Common name	Botanical name	Family	Flower color	Picture
1.	Bathua	*Chenopodium album*	Amaranthaceae	Greenish	
2.	Oxalis	*Oxalis corniculata*	Oxalidaceae	Yellow	
3.	Doob grass	*Cynodon dactylon*	Poaceae	Green	

4.	Wild mustard	*Brassica spp.*	Brassicaceae	Yellow	
5.	Clover	*Trifolium repens*	Fabaceae	White / pink	
6.	Dandelion	*Taraxacum officinale*	Astereceae	Yellow	
7.	Kandali / nettele grass	*Caradus ascanthoides*	Utiraceae	Greenish	
8.	Tridax daisy/ coat button	*Tridax procubens*	Asteraceae	White and yellow	

9.	Japanese mazus	*Mazus pumilus*	Fabaceae	White and purple	
10.	Shephard's purse	*Capsella bursa-pastoris*	Brassicaceae	White	
11.	Chickweed	*Stellaria media*	Caryophyllaceae	White	
12.	Bird's eye speedwell	*Veronica persica*	Plantiginaceae	Bluish	

13.	Crofton weed	*Ageratina adenophora*	Asteraceae	Creamish	
14.	Wild bellflower grass	*Campanula dulcis*	Solanaceae	White	
15.	Mint weed	*Lamium amplexicaule*	Labiate	Purple	

Ecological Importance of Flowering Weeds

Flowering weeds in the fruit block of Bharsar play a significant ecological role beyond their identity as unwanted plants. During their blooming stage, these weeds attract a variety of pollinators such as bees, butterflies, and other beneficial insects, thereby supporting pollination processes within the orchard ecosystem. Their presence enhances overall biodiversity by providing habitat and food resources for numerous organisms, contributing to a balanced and stable agro-ecosystem.

In addition, the ground cover formed by weeds helps in preventing soil erosion, especially in hilly regions like Bharsar, by reducing surface runoff and holding the soil firmly. Many weed species also possess medicinal properties and have been traditionally used in local healthcare practices. Furthermore, certain weeds act as indicator species, reflecting soil health,

moisture conditions, and environmental changes. Thus, flowering weeds, though often neglected, serve multiple ecological functions that are essential for sustaining the orchard environment.

Discussion

The flowering of weeds in the Bharsar during April can be attributed to favorable environmental conditions such as moderate temperature, adequate soil moisture, and increased day length, which collectively stimulate the transition from vegetative to reproductive growth. This seasonal shift enables weeds to complete their life cycle efficiently by producing flowers and seeds before the onset of harsher conditions.

The observed weed species exhibit strong adaptation to the temperate climate of the region. Their rapid growth, early flowering, and efficient seed dispersal mechanisms allow them to survive and persist in cultivated areas. These adaptive traits make them highly competitive, yet also ecologically significant within the orchard system.

Despite competing with fruit crops for nutrients, water, and light, weeds demonstrate a form of coexistence within the agro-ecosystem. During their flowering stage, they contribute to supporting pollinators and enhancing biodiversity, indirectly benefiting the overall health of the orchard.

Therefore, rather than complete eradication, there is a need for selective and sustainable weed management practices. Controlled removal, especially before seed setting, and maintaining a balance between crop productivity and ecological benefits can help in optimizing both agricultural output and environmental stability.

Conclusion

The flowering of weeds in the Bharsar, Uttarakhand highlights an often-overlooked aspect of the agro-ecosystem, where unwanted plants reveal both ecological value and natural beauty. While weeds are traditionally managed due to their competitive effects on crops, their presence during the flowering stage contributes significantly to biodiversity, supports pollinators, and helps maintain soil stability, especially in hilly terrains.

This study emphasizes that weeds should not be viewed solely as harmful, but rather as integral components of the ecosystem that reflect environmental conditions and ecological balance. A thoughtful and selective approach to weed management—rather than complete elimination—can help in preserving their beneficial roles while minimizing their negative impact on crop productivity. Thus, the blooming weeds of Bharsar's fruit block represent a harmonious blend of resilience, adaptation, and hidden beauty, reinforcing the need to appreciate and manage them sustainably within modern horticultural systems

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BLACK GOLD FOR BLUE FARMS: BIOCHAR IN AQUACULTURE SUSTAINABILITY

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Abstract

Biochar, a carbon-rich material produced through pyrolysis, has emerged as a promising, eco-friendly solution for improving soil and water quality in aquaculture systems. Derived from agricultural residues such as rice husk, coconut shells, and wood waste, biochar possesses a highly porous structure and large surface area, enabling it to adsorb nutrients and contaminants effectively. In aquaculture ponds, biochar enhances soil fertility by improving structure, stabilizing pH, and increasing nutrient retention. Simultaneously, it improves water quality by reducing toxic compounds like ammonia and nitrites, controlling algal blooms, and supporting beneficial microbial communities. Its application not only boosts productivity but also contributes to environmental sustainability through waste recycling and carbon sequestration. This article highlights the multifunctional role of biochar as a soil and water conditioner and its growing relevance in sustainable aquaculture practices.

Key Words: Biochar, Sustainable Aquaculture, Pyrolysis, Organic waste recycling, Soil and water conditioning

Introduction

Biochar has gained considerable attention as a promising **soil and water conditioner** in aquaculture systems. Biochar is a **charcoal-like material** produced by the **pyrolysis** of **biomass** in an oxygen-limited environment, resulting in a stable form of carbon intended for soil amendment and long-term carbon sequestration. This process results in a highly porous material with a large surface area and significant adsorption capacity, making it particularly effective in improving environmental conditions in aquaculture ponds. It is defined by the **International**

Biochar Initiative as the **"solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment".** When combined with composts or farmyard manure, biochar can significantly speed up SOM recovery, sequester carbon, and boost climate resilience.

The unique physical and chemical properties of biochar make it highly suitable for aquaculture applications. Its porous structure provides a favourable habitat for beneficial microorganisms, which play a crucial role in nutrient cycling and organic matter decomposition. Additionally, biochar has the ability to adsorb harmful substances such as ammonia, nitrites, and heavy metals, thereby improving water quality and reducing toxicity for aquatic organisms. It also acts as a buffering agent, helping to stabilize pH levels in both soil and water, which is essential for maintaining a healthy culture environment.

Potential of Biochar Production in India

India generates over 680 million tonnes of agricultural waste annually, much of which is burned, causing severe air pollution and environmental degradation. Converting 30–50% of this biomass into biochar through Pyrolysis could produce 15–26 million tonnes of biochar each year and significantly reduce carbon emissions.

Utilizing crop residues such as rice husk, wheat straw, and sugarcane bagasse for biochar production can improve soil health, enhance carbon sequestration, and reduce pollution. Integration into India's upcoming carbon market could also create carbon credits and rural employment opportunities. With its high stable carbon content, biochar offers a practical and scalable solution for sustainable agriculture and environmental management in India.

Biochar activation techniques

Activation increases biochar's porosity, surface area, and cation exchange capacity (CEC), enhancing its adsorption capacity.

- **Physical Activation**: Involves thermal treatment with oxidizing gases like steam or CO2 at 700–800°C for 30 min to 3 hours. This process is environmentally friendly and efficient for removing impurities and creating a higher surface area (e.g., increasing wheat straw biochar surface area from 5.8 to 310 m/g).
- **Chemical Activation**: Involves treating biochar with acidic (H3PO4, HCl) or basic (KOH, NaOH) agents to increase surface functional groups (carboxyl, hydroxyl).
- **Bio-functionalization (Loading):** Loading biochar with beneficial microorganisms (nitrifying bacteria) or minerals (Fe-oxide) enhances contaminant degradation.
- **Nano-engineering (Ball Milling):** Grinding biochar to nanoscale reduces particle size, boosting active sites, and improves stability in aquaculture environments

Role of Biochar in Soil and Water Quality Management in Aquaculture

Biochar, produced through Pyrolysis, plays a crucial dual role in managing both soil and water quality in aquaculture systems. In pond soils, it improves physical structure by reducing compaction and enhancing aeration, increases nutrient retention through its high cation exchange capacity, stabilizes pH, and supports beneficial microbial communities that aid in organic matter decomposition and nutrient cycling. It also helps immobilize heavy metals and reduces salinity stress in problematic soils.

In water, biochar functions as a natural biofilter by adsorbing toxic metabolites such as ammonia, nitrites, and hydrogen sulphide, thereby reducing toxicity and improving aquatic health. It regulates excess nutrients, preventing eutrophication and algal blooms, while also enhancing water clarity by trapping suspended particles. Additionally, its porous surface provides habitat for beneficial microbes that contribute to biological filtration and improved dissolved oxygen dynamics. Overall, biochar creates a more stable, productive, and environmentally sustainable aquaculture system.

Benefits of Biochar in Aquaculture

Biochar offers multiple benefits in aquaculture by enhancing environmental sustainability and system efficiency. Its stable carbon structure supports long-term carbon sequestration, helping mitigate climate change. Biochar improves water quality by adsorbing excess nutrients such as ammonia, nitrite, and phosphate, thereby preventing toxicity and eutrophication. It also enhances nutrient retention, reducing leaching and the need for frequent water treatment. Additionally, its porous structure provides habitat for beneficial microbes that aid in bioremediation by breaking

down pollutants like heavy metals and antibiotics. Overall, biochar promotes healthier aquatic environments and more sustainable aquaculture practices.

Conclusion

Biochar represents a transformative approach to sustainable aquaculture by addressing two critical components soil and water quality simultaneously. Its ability to improve soil fertility, adsorb pollutants, and support beneficial microbial processes makes it a highly effective natural conditioner. Moreover, its production from agricultural waste aligns with circular economy principles, reducing waste while enhancing resource efficiency.

The adoption of biochar in aquaculture systems offers both environmental and economic benefits, including improved productivity, reduced dependency on chemical treatments, and long-term ecological sustainability. As the demand for environmentally responsible aquaculture practices continues to grow, biochar stands out as a practical, affordable, and innovative solution. Embracing such nature-based technologies can pave the way for resilient and sustainable aquaculture systems in the future.

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THE SCIENCE BEHIND TRANSFORMATION OF GARLIC INTO BLACK GARLIC

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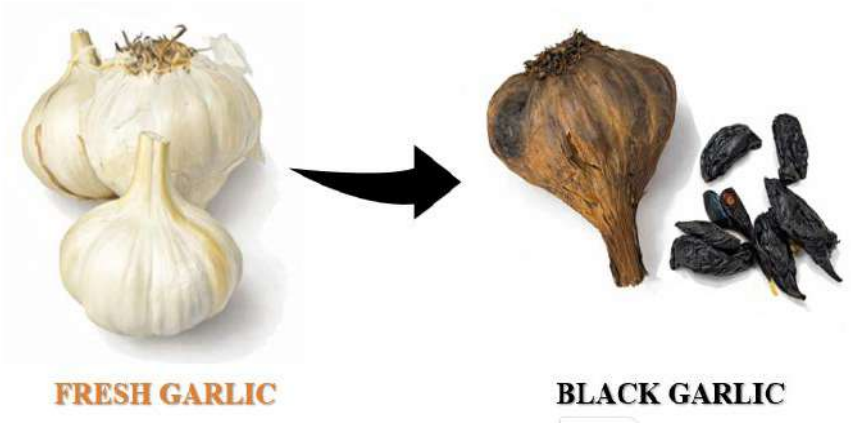
Introduction

Garlic (*Allium sativum* L.) has been valued for centuries not only as a culinary ingredient but also as a potent functional food. From traditional remedies to modern nutrition, it is widely recognized for its antimicrobial, cardioprotective, anti-inflammatory, and immunomodulatory effects. These health benefits are largely attributed to sulfur-containing compounds, particularly allicin, which is formed when garlic cloves are crushed or chopped.

However, despite its therapeutic potential, the regular consumption of raw garlic is limited by its strong pungency, persistent odor, and gastrointestinal discomfort or intolerance in sensitive individuals. Moreover, allicin is chemically unstable and degrades rapidly during storage, reducing its bioactivity. These constraints have led to growing interest in processing strategies which enhances garlic's stability, bioavailability, and consumer acceptability.



Among these, black garlic has emerged as a promising derivative which is produced through controlled thermal aging of whole garlic bulbs under high temperature and humidity. This process results in series of physicochemical and biochemical modifications, including a softened texture, dark color, mild sweet–umami flavor, and formation of more stable bioactive compounds. Therefore, black garlic represents a unique convergence of traditional knowledge and modern food science, with both improved palatability and enhanced health-promoting properties.

From fresh to black: The science of transformation

The transformation of fresh garlic into black garlic is primarily driven by controlled heat processing. Whole garlic bulbs are aged under regulated conditions, typically at temperatures between 60 and 90°C and relative humidity levels of 70–90% over a period of 2–6 weeks. Temperature, humidity, and duration work synergistically to influence reaction kinetics, moisture retention, and the stability of bioactive compounds. This determines the sensory and functional quality of the final product. Lower temperatures combined with longer aging durations favor gradual chemical transformations, preserving heat-sensitive bioactives while allowing the steady accumulation of stable organosulfur compounds. In contrast, higher temperatures accelerate these reactions, intensifying browning and flavor development through enhanced mallard reactions. But sometimes this may lead to partial degradation of thermolabile bioactives. Humidity plays an equal crucial role by preventing excessive drying and ensuring uniform heat penetration through the garlic bulbs. This helps maintain the soft jelly-like texture that characterizes black garlic. The duration of processing further determines the extent of sweetness, color development and bioactive enrichment.

Compositional changes during Conversion

Thermal aging triggers extensive compositional changes in garlic that refine both its sensory characteristics and functional properties. These transformations affect carbohydrates, lipids, amino acids and bioactive compounds.

In fresh garlic, carbohydrates are mainly present as fructans. These undergo progressive breakdown and generates mono- and disaccharides, particularly glucose and fructose. As a result, the reducing sugar content of black garlic increases significantly, providing the characteristic sweetness of black garlic and fueling mallard reactions responsible for its dark color and rich flavor.

Although present in lower concentration, garlic lipids also play important role in flavor development. Thermal processing induces hydrolytic and oxidative changes, producing aroma-active compounds such as aldehydes, ketones, alcohols, and lactones. These interact with mallard intermediates, collectively shaping the complex sensory profile associated with black garlic.

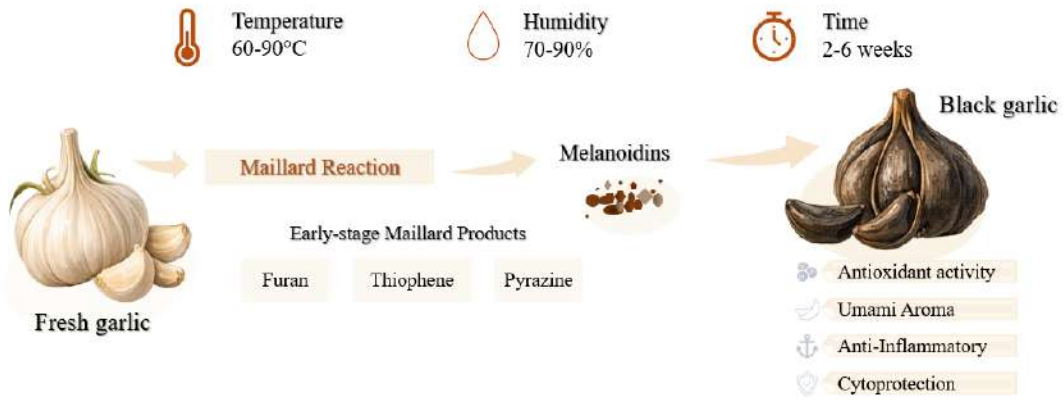
Similarly proteins and free amino acids, including sulfur-containing and aromatic amino acids, participate in Maillard reactions. While some branched-chain amino acids increase under specific conditions, others, particularly sulfur-containing ones, decline, influencing both antioxidant potential and flavor complexity. These contribute to the soft, jelly-like texture that distinguishes black garlic from fresh counterpart.

In addition, thermal processing also affects the polyphenolic content of garlic. Black garlic consistently exhibits higher total phenolic and flavonoid content compared to fresh garlic. This enhancement is attributed to release of bound phenolics and formation of low-molecular-weight antioxidant compounds during heat treatment. However, prolonged exposure may lead to degradation of thermolabile phenolics, highlighting the need for optimized processing conditions.

Chemistry behind the color and flavor

The principal chemical process responsible for the transformation of fresh garlic into black garlic during thermal aging is mallard reaction. This occurs when reducing sugars generated during thermal degradation of fructans react with free amino groups from proteins under controlled heat conditions. As the reaction progresses, it leads to the formation of early-stage intermediates, which subsequently polymerize into melanoidins. Melanoidins are high-molecular-weight brown polymers, responsible for the characteristic dark color of black garlic. These possess significant functional properties, including antioxidant activity and metal-chelating ability.

Moreover, the Maillard reaction generates a wide range of volatile compounds, including furan, thiophene, and pyrazine derivatives, which are the key contributors to the unique sweet–umami aroma of black garlic. Many of these compounds exhibit biological activities such as antioxidant, anti-inflammatory, and cytoprotective effects, further strengthening the functional value of black garlic.

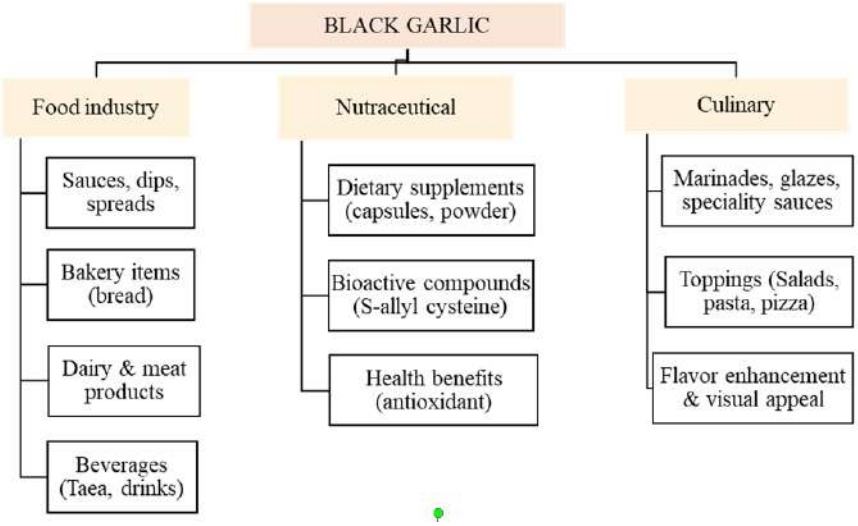


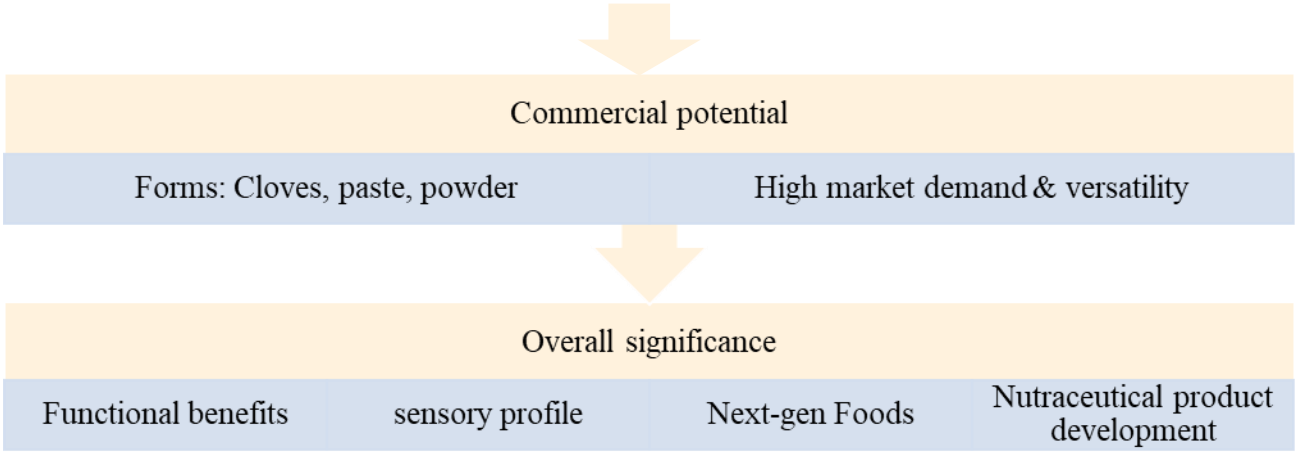
Fresh Garlic versus Black Garlic

Fresh garlic is rich in allicin, a highly reactive organosulfur compound responsible for its strong pungency and potent antimicrobial activity. However, it is thermally unstable and undergoes rapid degradation during processing and storage. Its intense flavor and potential to cause gastrointestinal discomfort further limit its regular consumption.

In contrast, thermal processing of garlic promotes the formation of more stable organosulfur compounds, notably S-allyl cysteine (SAC) and S-allyl mercaptocysteine (SAMC). These exhibit enhanced bioavailability compared to allicin, retain strong antioxidant, cytoprotective, and anti-inflammatory activities. Thus, black garlic offers improved benefits with reduced pungency and enhanced digestibility. Functionally, black garlic demonstrates higher antioxidative potential and is better tolerated by the gastrointestinal system, making it more suitable for regular dietary intake.

Applications of Black garlic





Future Perspectives

Despite the increasing interest in black garlic, several research gaps limit its full functional and commercial potential. One of the major challenges is the lack of a standardized processing protocol, as variations in temperature, humidity, and duration often lead to inconsistencies in product quality, sensory attributes, and bioactive composition. Additionally, the kinetics of bioactive compound formation and degradation during thermal aging remain insufficiently understood, making it difficult to control the accumulation of beneficial compounds such as SAC, phenolics, and melanoidins. Also, there is limited evidence regarding the bioaccessibility, bioavailability, metabolism, and in vivo effects. Addressing these gaps through comprehensive and well-designed studies will be essential to fully harness the potential of black garlic in functional food and nutraceutical applications.

Conclusion

As the demand for natural, functional foods continues to rise, black garlic stands out as a compelling example of how traditional ingredients can be reimagined through science. With further research and process optimization, it holds the potential to bridge the gap between nutrition, medicine, and modern consumer preferences.

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SMART SOLAR DRYERS FOR SUSTAINABLE POST-HARVEST MANAGEMENT

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Abstract

India loses 20–40% of perishable crops post-harvest due to inefficient open-sun drying, which exposes produce to weather, contaminants, and quality degradation. This paper reviews the evolution of solar drying technologies—from passive and active solar dryers to advanced hybrid microcontroller-assisted portable systems—and proposes a novel design integrating solar thermal energy, photovoltaic power, battery storage, and PID-controlled automation for temperature, humidity, and airflow. The hybrid dryer achieves up to 70% faster uniform drying, superior retention of nutrients, color, aroma, and essential oils, and 90–95% uptime with weather resilience via backups. Economic advantages include reduced losses, premium market pricing, two-year payback, and rural entrepreneurship, while environmental gains encompass lower fossil fuel use and emissions. Suitable for farmers, cooperatives, and processors drying fruits, vegetables, spices, herbs, and biomass, this technology strengthens sustainable post-harvest chains. Future IoT enhancements promise remote monitoring for enhanced efficiency.

Key words: *solar dryer; microcontroller-assisted; post-harvest losses; sustainable drying.*

1. Introduction

India produces large amounts of perishable crops, yet 20–40% are lost post-harvest due to inadequate drying, poor storage, and limited awareness of solar dryers. Many rural farmers still use open-sun drying, spreading produce on open yards, rooftops, or roadsides. This method exposes crops to weather changes that cause re-wetting, mould, discoloration, and nutrient loss, resulting in low-quality products and reduced farmer income [1].

Solar drying technology has emerged as a promising alternative to sun drying. By enclosing the drying process and harnessing solar energy, solar dryers accelerate dehydration and also protect crops from contamination. Recent advancements now combine renewable energy with automation, creating a new generation of hybrid, microcontroller-assisted, portable forced-convection solar dryers. These systems provide faster drying, improved quality retention, and reliable operation even during unfavorable weather conditions.

2. Evolution of Solar Drying Technology

2.1 Open-Sun Drying

Open-sun drying is the oldest food preservation method used by farming communities worldwide. Here, fresh farm produce is exposed to direct sunlight for several days to complete the drying process. Generally, solar radiation heats the produce and the surrounding air, gradually removing free moisture until it reaches a safe storage level. The added advantages of this method are (i) no equipment or fuel/electricity required, (ii) low cost, and (iii) widely adopted by smallholder farmers. However, this simplicity also creates major limitations that affect quality and economic value. The process fully depends on unpredictable weather conditions.

Most of the time, the low-quality dried products obtained from open sun drying if they exposed to rain, dust, insects, birds, rodents, and pollutants. For example, rain or cloudy weather can interrupt the drying process and cause fungal growth. Excessive heat may cause scorching, discoloration, and nutrient loss in dried products. In addition, uneven sunlight and airflow cause non-uniform drying, trapping moisture and accelerating spoilage during storage. Open sun drying typically takes five to seven days, increasing risks of pests, theft, and weather issues.

Generally, open-sun drying is an unreliable method for drying high-value crops, which requires the consistent quality and safety of final products [2].

2.2 Solar Dryers

To address these shortcomings, solar dryers were developed to enclose the drying environment and capture solar heat more efficiently. They are broadly classified into passive and active systems (Fig.1).

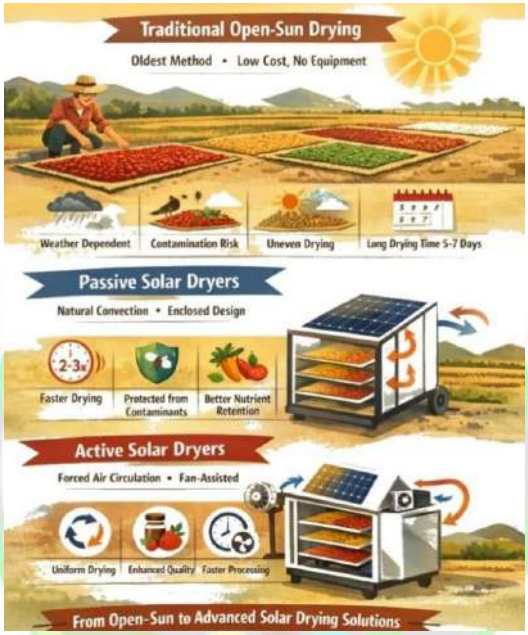

Fig.1. Evolution of solar drying technology

2.2.1 Passive Solar Dryers

It improves sun-drying by placing the food in a protected box and using warm air to dry it. Sunlight passes through a clear cover (such as glass or plastic) and heats a black plate, which then warms the air inside. The warm air rises through trays of food, removes moisture, and exits through vents, keeping the air moving without electricity.

These dryers usually operate at 50–65°C, suitable for drying fruits, vegetables, spices, and herbs while preserving quality. With a capacity of about 5–15 kg per batch, they are ideal for small farmers and household processing. Their simple construction using locally available materials keeps costs low and makes fabrication easy.

Compared to open drying, these dryers keep out dirt, bugs, and rain. Higher interior temperatures remove moisture more quickly, so drying takes less time. Indirect sunlight keeps the color, taste, and nutrients. But, air movement depends on natural heat, which can sometimes cause uneven drying. Crops can get too hot on sunny days, and the dryer works less well when it's cloudy. Without electric fans, steady sunshine is still needed.

2.2.2 Active Solar Dryers

These dryers solve the problem of slow air flow by using electric fans to move warm air through the crops. This ensures the air reaches every part of the crop, drying it more evenly and quickly. Controlling the fan helps the dryer keep a better quality.

A typical active solar dryer has a few key components. First, it uses a solar collector to heat air. Next, an insulated chamber retains heat, while a mechanical fan circulates air, and a chimney removes moist air. In addition, the fan maintains steady airflow. As a result, this helps remove moisture more efficiently and evenly from all trays.

The moving air in these dryers has several advantages. It dries things faster and more evenly, which lowers the risk that germs will grow and spoil them. Better heat control helps preserve the natural color, aroma, and special oils in spices and herbs. So, these dryers produce better-dried products for sale. New types can use sunlight with simple controls and batteries for steady drying all year [4].

3. Hybrid Microcontroller-Assisted Portable Solar Dryer

The hybrid microcontroller-assisted portable solar dryer combines solar heating, solar electricity, battery storage, and smart electronics into one compact unit. Unlike traditional solar dryers that rely only on sunshine and manual monitoring, this system is portable and intelligent. It can operate day and night, improving drying speed and product quality. A microcontroller-based control system continuously monitors temperature, humidity, and weight changes during drying. Using PID control, the system automatically adjusts airflow and temperature. This prevents overheating or under-drying, reduces the need for manual supervision, and ensures consistent drying performance [5].

4. Performance Advantages

4.1 Faster and Uniform Drying

Hybrid dryers reduce drying time by up to 70% compared with conventional solar dryers. Forced airflow ensures uniform dehydration across all trays.

4.2 Improved Product Quality

Controlled temperature and humidity help preserve (i) vitamins and antioxidants, (ii) natural colour and aroma, and (iii) essential oils in herbs and spices.

4.3 Weather Resilience

Battery backup enables drying during monsoon periods or nighttime, achieving up to 90–95% operational uptime.

5. Economic and Environmental Benefits

The adoption of hybrid solar dryers provides strong economic returns while also delivering important environmental benefits for farmers, entrepreneurs, and food processors.

5.1. Economic benefits

- Reduction in post-harvest losses
  - Minimizes spoilage, fungal growth, and improper drying losses
  - Ensures a higher proportion of harvested produce reaches the market
  - Reduces financial risk and stabilizes farmer income
- Improved product quality and market value
  - Retaining natural colour, aroma, flavour, and nutrients
  - Enables premium pricing in urban and export markets
  - Marketable products such as spice powders, herbal teas, and dried fruit snacks
- New income and business opportunities
  - Encourages rural entrepreneurship and small-scale processing units
  - Creates additional revenue streams from processed agricultural goods

- Short payback period and long-term savings
    - Modest initial investment compared to benefits
    - Payback period of approximately two years

5.2. Environmental benefits

- Reduced dependence on conventional fuels
    - Minimizes use of firewood, diesel heaters, and grid electricity
    - Reduces deforestation and fossil fuel consumption
- Lower greenhouse gas emissions
    - Uses renewable solar energy as the primary heat source
    - Contributes to cleaner air and reduced environmental pollution
- Promotion of renewable energy adoption
    - Demonstrates practical solar energy use in agriculture
    - Encourages wider acceptance of clean energy in rural communities

6. Applications

- The hybrid dryer is suitable for a wide range of users, such as smallholder farmers, farmer cooperatives, food processing units, and research laboratories.
- Typical applications include drying of fruits and vegetables, spices and herbs, medicinal plants& biomass samples.

7. Conclusion and Future Prospects

The demand for safe and high-quality food is driving the shift toward sustainable post-harvest technologies. Intelligent hybrid solar dryers enable farmers to process crops locally, reducing dependence on centralized facilities and strengthening rural value chains. Future developments, such as IoT integration, will enable real-time monitoring via smartphones, improving process control and reducing labor. Overall, the hybrid microcontroller-assisted portable solar dryer is a

significant advancement in post-harvest technology. By combining solar energy, backup power, and automation, it reduces food losses, improves product quality, and promotes sustainable and resilient agricultural development.

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NANO-ENCAPSULATION IN NUTRACEUTICALS: IMPROVING BIOAVAILABILITY OF FUNCTIONAL COMPOUNDS

Article ID: AG-VO6-I04-131

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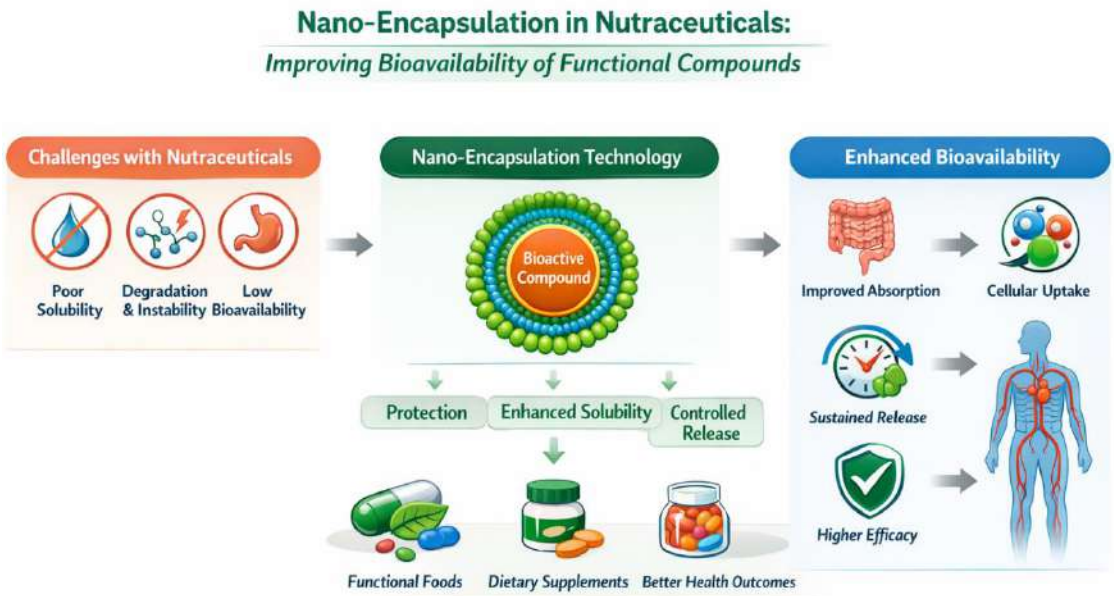
Abstract

Imagine swallowing a capsule of curcumin, the golden pigment in turmeric celebrated for its anti-inflammatory properties, only for your body to absorb less than 1% of it and consider taking a fish-oil supplement rich in omega-3 fatty acids, only to find that a large fraction degrades before it ever reaches your bloodstream. These are not hypothetical scenarios. They represent a fundamental limitation in the world of nutraceuticals: the bioavailability problem. Bioavailability refers to the fraction of an ingested compound that actually reaches systemic circulation and is available to exert a biological effect. For many of nature's most celebrated functional compounds like curcumin, resveratrol, carotenoids, polyphenols, vitamins D and E, omega-3 fatty acids, and coenzyme Q10, where oral bioavailability is notoriously poor. Their chemical structures, while conferring powerful antioxidant and anti-inflammatory activity, also make them hydrophobic (water-repelling), chemically unstable, and vulnerable to degradation by stomach acid, digestive enzymes, and intestinal metabolism long before they can be absorbed [1].

Nanotechnology is now at the forefront of efforts to change this reality. Specifically, a technique called nano-encapsulation, the packaging of bioactive compounds within nanoscale carriers, which emerged as a transformative strategy to protect fragile nutrients, improve their solubility, and dramatically enhance their uptake in the human gut. The global market for nanoencapsulation in foods and nutraceuticals reached approximately USD 3.45 billion in 2024

and is projected to grow at 8–10% annually through the coming decade [2]. This popular article explores the science behind nano-encapsulation, the types of carriers being developed, and what they mean for the future of functional foods and dietary supplements.



What Is Nano-Encapsulation?

Nano-encapsulation involves embedding an active compound called the "core" within a protective shell or matrix to form particles typically measuring between 1 and 1,000 nanometres in diameter. For perspective, a human hair is roughly 80,000 nanometres wide. At the nanoscale, materials behave differently: they have a vastly larger surface-area-to-volume ratio, which facilitates faster dissolution, improved absorption across biological membranes, and a greater interaction with cells of the gastrointestinal tract [3].

The protective shell often made from food-grade materials such as lipids, proteins, polysaccharides, or biodegradable polymers serves multiple functions. It shields the active compound from the destructive conditions of the stomach (low pH, digestive enzymes), prevents premature oxidation during food processing and storage, masks bitter or unpleasant tastes, and controls the rate and site at which the compound is released in the body. This capacity for controlled, targeted release is one of the most significant advantages of nano-encapsulation over conventional formulations [4].

Nanocarriers also have a unique ability to circumvent a major pharmacological hurdle known as the *first-pass effect* the process by which the liver metabolises orally ingested

compounds before they reach systemic circulation, substantially reducing their effective dose. By channelling nutrients through the intestinal lymphatic system (via structures such as chylomicrons or Peyer's patches), nano-formulations can partially bypass hepatic first-pass metabolism, leading to higher systemic concentrations of the active compound [2].

A Toolkit of Nanocarriers: Liposomes, Nanoemulsions, and Beyond

The field of nano-encapsulation has generated a rich variety of nanocarrier systems, each suited to different types of bioactive compounds and intended applications. The major categories are described below.

Liposomes are spherical vesicles formed from phospholipid bilayers the same type of membrane that surrounds our own cells. Their unique structure allows them to carry both water-soluble compounds in their aqueous interior and fat-soluble compounds within their lipid bilayer. Liposomal formulations have demonstrated substantially enhanced bioavailability for compounds such as curcumin and resveratrol [5]. Their biocompatibility and biodegradability make them ideal for both food and pharmaceutical applications, though they can be sensitive to temperature and pH.

Nanoemulsions are fine dispersions of oil and water stabilised by emulsifiers, with droplet sizes typically ranging from 20 to 200 nm. They are transparent or semi-transparent, highly stable, and capable of incorporating large quantities of lipophilic bioactives such as fat-soluble vitamins, carotenoids, and essential oils. Nanoemulsions have been shown to dramatically improve the oral bioavailability of poorly water-soluble compounds by increasing their apparent solubility and enhancing contact with intestinal absorptive cells [3].

Solid Lipid Nanoparticles (SLNs) consist of a solid lipid matrix (such as wax, fatty acids, or glycerides) stabilised by surfactants. SLNs offer excellent physical stability and controlled release properties, making them well suited for thermally labile compounds. They provide better stability than emulsions and are considered suitable for scale-up in industrial production [4].

Polymeric Nanoparticles are prepared from biodegradable polymers such as chitosan (derived from crustacean shells), zein (from corn), PLGA (poly lactic-co-glycolic acid), and alginate. These carriers can be fine-tuned to release their payload at specific sites in the gastrointestinal tract for example, in response to the slightly alkaline pH of the small intestine or

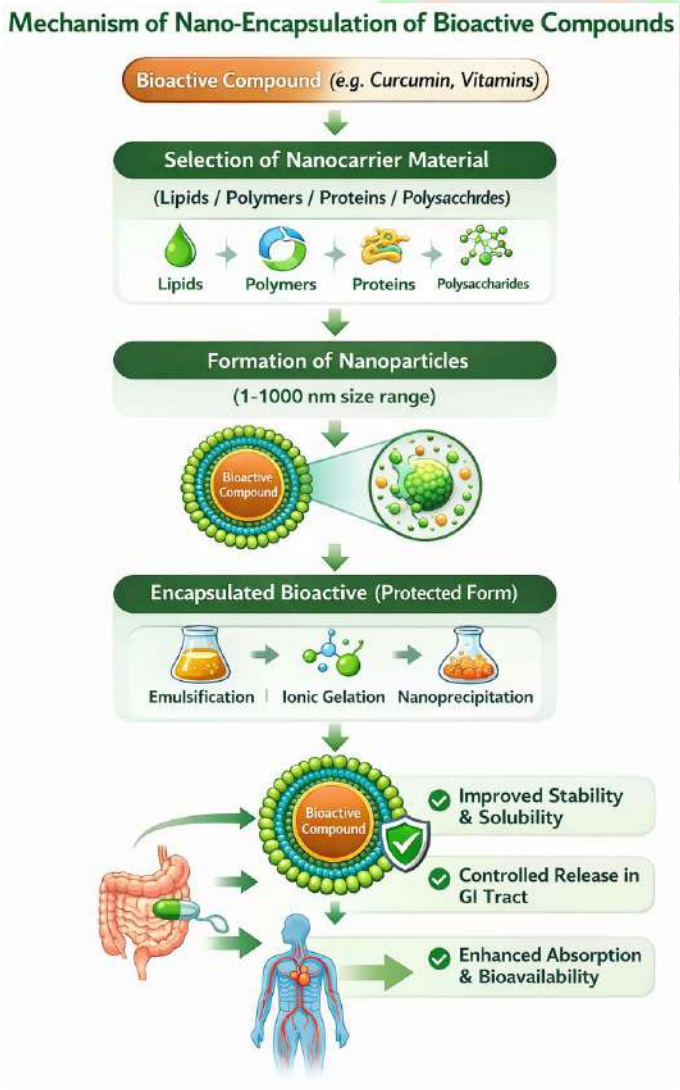
the action of gut enzymes. Chitosan, in particular, has mucoadhesive properties (it sticks to gut wall mucus), which prolongs residence time in the intestine and enhances absorption [5].

Nanogels and **nanohydrogels** are three-dimensional polymeric networks that can encapsulate both hydrophilic and hydrophobic compounds. They respond to environmental stimuli such as pH, temperature, or ionic strength a property that enables "smart" release of bioactives at the desired physiological location, such as the colon for gut health applications [7].

From Laboratory to Supplement Shelf: Key Success Stories

Curcumin — Transforming a Poorly Absorbed Spice Compound.

Curcumin, the bioactive polyphenol in turmeric (*Curcuma longa*), is one of the most studied natural compounds for its anti-inflammatory, antioxidant, anticancer, and neuroprotective properties.



Yet its oral bioavailability in conventional forms is extremely poor less than 1% due to low water solubility, poor intestinal permeability, instability at alkaline pH, and rapid hepatic metabolism [6].

Nano-encapsulation has dramatically altered this picture. Studies have shown that curcumin encapsulated in lipid-based nanoconstructs (CLEN) achieves over a million-fold increase in aqueous solubility, translating to a nearly 70-fold improvement in oral bioavailability compared with free curcumin [2]. Polymeric nanoparticles made from chitosan, PLGA, and zein have also been extensively tested, yielding significantly higher plasma concentrations and sustained release profiles. Liposomal curcumin formulations have demonstrated relative bioavailability improvements exceeding 1,300% compared to unformulated curcumin in some clinical studies, with excellent safety profiles [6]

Resveratrol -Protecting the "Red Wine Molecule."

Resveratrol, a polyphenol found in red grape skin, berries, and peanuts, has attracted enormous scientific interest for its potential cardiovascular, anti-aging, and neuroprotective effects. However, despite impressive results in laboratory studies, translating these benefits into clinical outcomes has been frustrated by its rapid metabolism and low bioavailability when taken orally it is quickly converted into less active metabolites in the gut and liver [5].

Nanoencapsulation strategies, particularly using polymeric nanoparticles (PLGA, zein) and liposomes, have been shown to provide controlled delivery, reduce rapid metabolic clearance, and significantly improve plasma levels of active resveratrol. Liposomal resveratrol formulations have demonstrated neuroprotective efficacy in animal models of Parkinson's disease. Combined nanoparticles co-encapsulating both curcumin and resveratrol have been studied for targeted cancer cell delivery, showing the ability to reduce drug dosage while enhancing anticancer effects at the tumour site [5, 6].

Omega-3 Fatty Acids Shielding Fragile Fats.

EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) from marine and algal oils are essential omega-3 fatty acids with well-documented cardiovascular, cognitive, and anti-inflammatory benefits. Their main challenge is oxidative instability: they readily undergo rancidification, producing off-flavours and losing biological activity during processing, storage, and digestion [4].

Nanoemulsion and microencapsulation technologies have been effectively used to protect omega-3 oils from oxidative degradation. Research has demonstrated that nanoemulsions co-encapsulating fish oil with polyphenols such as curcumin or resveratrol show far lower peroxide formation than plain emulsions the nanocarrier both physically isolates the lipid from oxygen and allows the polyphenols to scavenge free radicals, acting as a dual protection system [2]. This approach is already being adopted commercially, with over 68% of nutraceutical manufacturers investing in nano-delivery systems for ingredients such as omega-3 fatty acids [2].

Vitamins and Carotenoids.

Fat-soluble vitamins (A, D, E, K) and carotenoids such as lycopene, beta-carotene, lutein, and zeaxanthin are important nutraceuticals whose bioavailability is highly dependent on the co-presence of dietary fat and other formulation factors. Nanoencapsulation enables even these fat-soluble compounds to be incorporated into water-based food products and beverages while improving their bioaccessibility. Nano-formulated vitamin D has shown superior absorption compared to conventional supplements, of particular relevance given widespread vitamin D deficiency worldwide [3, 7].

The Science of Better Absorption: How Nanocarriers Work in the Gut

The mechanisms by which nanoencapsulation improves bioavailability are multiple and interrelated. Understanding them helps explain why nanoscale formulations can outperform conventional ones so dramatically.

First, by dispersing hydrophobic compounds within nanocarriers, the particles prevent aggregation and crystallisation essentially converting an insoluble substance into a colloidal suspension that can mix with digestive fluids. This massively increases the effective surface area available for dissolution and enzymatic action during digestion, a critical prerequisite for intestinal absorption [3].

Second, the small size of nanoparticles facilitates uptake through multiple intestinal routes. They can be absorbed via transcytosis across enterocytes (the absorptive cells lining the small intestine), through M-cells overlying Peyer's patches in the gut-associated lymphoid tissue, and via paracellular transport through tight junctions. Charged nanoparticles, particularly positively-charged chitosan particles, can open tight junctions temporarily, creating an additional absorption pathway unavailable to conventional formulations [4].

Third, lipid-based nanocarriers (nanoemulsions, SLNs, liposomes) are naturally processed via the same lymphatic pathways as dietary fats, incorporating themselves into chylomicrons and being transported directly into the lymphatic system thereby circumventing the hepatic first-pass effect. This route is particularly advantageous for highly lipophilic compounds that are otherwise rapidly degraded in the liver [2].

Finally, nanocarriers can be engineered for stimuli-responsive release, delivering their payload specifically in response to the pH, enzyme activity, or redox conditions at the target site (such as the small intestine, colon, or a diseased tissue). This targeted approach not only maximises bioavailability but also minimises systemic side effects and reduces the required dose [5].

Safety, Regulation, and the Road Ahead

Despite the remarkable promise of nano-encapsulation, several important challenges must be addressed before the technology reaches its full potential in everyday food and supplement products.

Safety is the most pressing concern. While the materials used in food-grade nanocarriers lipids, proteins, polysaccharides are generally regarded as safe, the behaviour of nanoparticles in the body is not always predictable. Their small size allows them to cross biological barriers that larger particles cannot, raising questions about long-term accumulation in tissues, potential immune responses, and environmental impact. Regulatory frameworks for nanotechnology in foods vary considerably across the world. The European Food Safety Authority (EFSA) and the US Food and Drug Administration (FDA) have both issued guidance on the assessment of nanotechnology-derived food ingredients, but comprehensive, globally harmonised standards are still evolving [4, 7].

Scalability is another challenge. Many nanoencapsulation techniques that perform elegantly in the laboratory such as electrospinning, layer-by-layer assembly, or nanoprecipitation are difficult and expensive to replicate at industrial scale while maintaining particle size consistency and encapsulation efficiency. However, progress is being made: technologies such as high-pressure homogenisation, microfluidics, and spray drying are increasingly bridging the gap between bench and commercial manufacturing [3].

Consumer perception also matters. Surveys suggest that many consumers are still wary of the word "nano" in their food, often conflating it with concerns about genetic modification or

synthetic chemicals — even though the carrier materials are typically natural, food-grade substances. Clear, transparent communication about what nano-encapsulation is and what it is not will be essential for market acceptance [1].

Looking ahead, researchers are exploring "smart" hybrid nanocarriers that combine the biocompatibility of natural polymers (chitosan, alginate, starch) with the structural precision of synthetic materials (PLGA, PEG, mesoporous silica). Artificial intelligence and machine learning are being deployed to accelerate formulation design — rapidly screening thousands of possible polymer-bioactive combinations to optimise encapsulation efficiency and release profiles without exhaustive laboratory iteration [5]. Personalised nanonutraceuticals, tailored to an individual's gut microbiome, metabolic profile, or genetic variants, represent an exciting frontier where nutraceutical science converges with precision nutrition [7].

Conclusion: A Nanoscale Revolution with Real-World Impact

The story of nano-encapsulation in nutraceuticals is, at its heart, a story about closing the gap between what nature offers and what the human body can actually use. Hundreds of bioactive compounds found in plants, marine organisms, and fermented foods have demonstrated profound health potential in laboratory settings yet their clinical impact has long been limited by poor bioavailability. Nano-encapsulation offers a scientifically elegant and increasingly practical solution: a protective, nanoscale shell that escorts these fragile molecules safely through the harsh environment of digestion and delivers them, intact and bioavailable, to where they are needed most.

The science is maturing rapidly. From liposomal curcumin to nanoemulsified omega-3s, from chitosan-coated vitamin D nanoparticles to stimuli-responsive resveratrol carriers, the evidence base is growing in both depth and clinical relevance. As manufacturing technologies improve, regulatory frameworks adapt, and consumer understanding deepens, nano-encapsulated nutraceuticals are poised to move from niche innovation to mainstream ingredient in the functional foods and dietary supplements of the future. The capsule you swallow tomorrow may be nanoscale and that, as the science shows, could make all the difference.

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NANOPLASTICS: A MICROSCOPIC MENACE WITH MACROSCOPIC CONSEQUENCES

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Introduction

Welcome to the intriguing world of nanoplastics - a microscopic menace with macroscopic consequences that is capturing global attention. In this blog post, we will delve into the intricate realm of these tiny plastic particles, exploring their sources, unique features, and most importantly, their profound impacts on soil, air, and aquatic systems. Join us on this journey to uncover the hidden dangers and potential solutions surrounding nanoplastics.

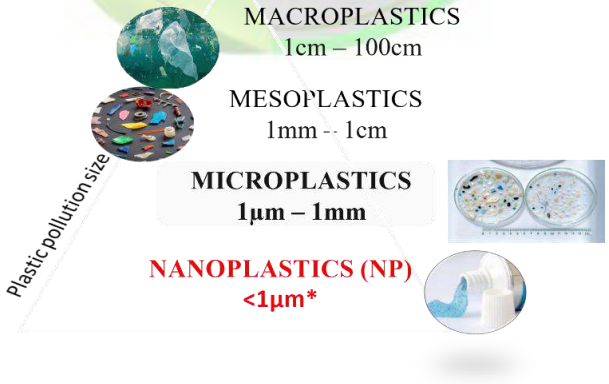

Fig 1. Various sizes of plastics

Sources and formation of nanoplastics

Nanoplastics, the minuscule plastic particles measuring less than 100 nanometers in size, are ubiquitous in our environment. These tiny fragments originate from a variety of sources. One

significant contributor is the breakdown of larger plastic debris through processes like photodegradation and mechanical abrasion. Additionally, everyday products such as personal care items and synthetic textiles release nanoplastics during their use and disposal. Industrial activities like manufacturing processes also play a role in releasing these minute particles into the environment (Shi *et al*., 2024). Moreover, nanoplastics can form through deliberate means for specific applications like drug delivery systems or coatings. The combination of these diverse sources results in nanoplastics being present in soil, water bodies, and even air around us. Understanding the varied pathways through which nanoplastics enter our surroundings is crucial for developing effective mitigation strategies to address this microscopic menace.

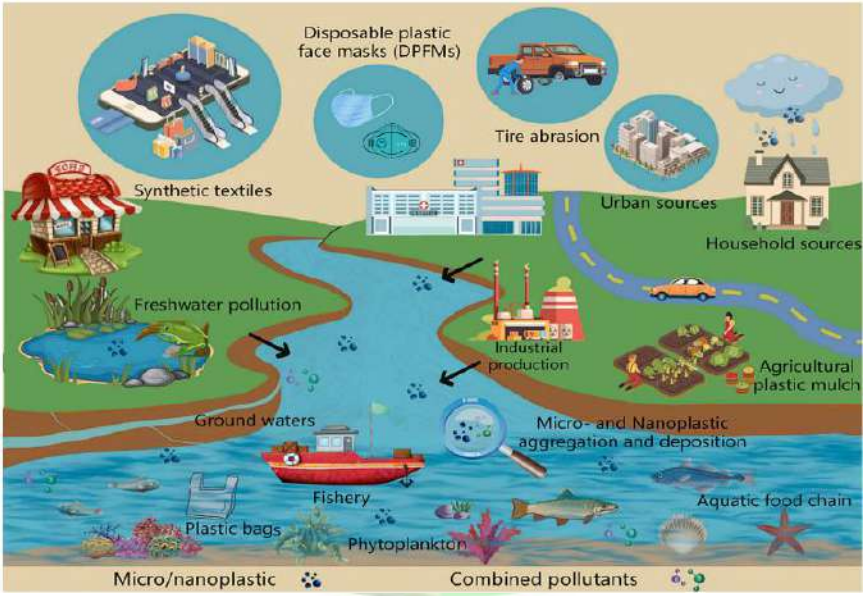

Fig 2. Source and trend of nanoplastics (Shi *et al*., 2024)

Impact on soil

Nanoplastics, despite their tiny size, have a significant impact on soil health. These minuscule particles can enter the soil through various pathways like wastewater irrigation or breakdown of larger plastic debris. Once in the soil, they can disrupt its structure and affect nutrient availability for plants. The presence of nanoplastics in soil has been linked to reduced microbial activity, which plays a crucial role in maintaining soil fertility. This disruption can lead to long-term consequences for agricultural productivity and ecosystem health. Additionally, nanoplastics can adsorb harmful pollutants present in the environment, further contaminating the soil. As nanoplastics accumulate in soil over time, there is growing concern about their potential

effects on terrestrial organisms such as earthworms and insects. The full extent of these impacts is still being researched, but it's clear that addressing nanoplastic pollution in soils is essential for safeguarding our food systems and environment (Joksimovic *et al*., 2022).

Impact on air

Nanoplastics, the tiny particles less than 100 nanometers in size, are making a big impact not only on our water systems but also in the air we breathe. These minuscule plastic particles can become airborne through various mechanisms like wind dispersion or combustion processes. Once airborne, nanoplastics can travel long distances and settle into different environments, including urban areas and remote regions. The presence of these microscopic plastics in the air raises concerns about their potential effects on human health and ecosystem resilience. Studies have shown that nanoplastics in the air can be inhaled by humans and animals, leading to possible respiratory issues and inflammation. Additionally, these tiny plastic particles can interact with other pollutants in the atmosphere, further complicating their environmental impacts. As researchers delve deeper into understanding the implications of nanoplastic pollution on air quality, it becomes increasingly clear that urgent measures are needed to mitigate this emerging threat. By addressing sources of nanoplastic emissions and implementing effective waste management strategies, we can work towards reducing the overall impact of these microscopic menaces on our precious air resources.

Impact on aquatic system

Did you know that nanoplastics have a significant impact on aquatic ecosystems? These minuscule plastic particles can easily be ingested by marine life, ranging from tiny zooplankton to larger fish and even whales. Once consumed, nanoplastics can accumulate in the tissues of these organisms, potentially causing harm to their health and disrupting the entire food chain. The presence of nanoplastics in water bodies can also lead to bioaccumulation, where toxins associated with plastics concentrate as they move up the food chain. This phenomenon not only affects marine animals but also poses a risk to human health if seafood contaminated with nanoplastics is consumed. Researchers are actively studying the long-term effects of nanoplastic pollution on aquatic environments to develop strategies for mitigation. It's crucial for us to address this issue collectively and take steps towards reducing plastic waste to protect our oceans and marine life from further harm.

Mitigation

Mitigation strategies for tackling nanoplastics pollution are crucial in safeguarding our environment. One approach involves implementing proper waste management systems to prevent plastic products from breaking down into smaller particles. Recycling and upcycling initiatives can also help reduce the amount of plastic waste entering ecosystems. Furthermore, promoting sustainable alternatives to single-use plastics can decrease the overall production and consumption of plastic materials. Encouraging the use of biodegradable packaging options and eco-friendly products is a step in the right direction towards mitigating nanoplastics contamination (Pérez-Reverón *et al*., 2023).

Education and awareness campaigns play a significant role in informing individuals about the potential risks associated with nanoplastics. By raising public consciousness, we can foster behavioral changes that contribute to minimizing plastic pollution at its source. Collaboration between governments, industries, researchers, and communities is essential for developing innovative solutions to address nanoplastics pollution effectively. Working together towards a common goal of environmental preservation is key in mitigating the impact of these microscopic menaces on our planet.

Conclusion

Nanoplastics are a rapidly emerging environmental concern with far-reaching implications. These microscopic particles, smaller than microplastics, possess unique properties that make them particularly challenging to detect and mitigate. The sources of nanoplastics range from the breakdown of larger plastic debris to the direct release of engineered nanoparticles. The impact of nanoplastics on soil, air, and aquatic systems is concerning. In soil, they can affect nutrient uptake by plants and potentially enter the food chain. In the air, nanoplastics can be inhaled and pose risks to human health. In water bodies, they can accumulate in organisms and disrupt ecosystems. Mitigating nanoplastic pollution requires a multi-faceted approach involving research into detection methods, regulation of plastic production and disposal practices, as well as public awareness campaigns to reduce plastic consumption. As we strive towards a more sustainable future, addressing the issue of nanoplastic pollution will be crucial in safeguarding our environment for future generations. Let's work together to tackle this microscopic menace with macroscopic consequences before it's too late.

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EFFECT OF PROBIOTICS AND PLANT EXTRACTS ON GROWTH PERFORMANCE AND SURVIVAL OF *BOMBYX MORI*

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Abstract

Sericulture is an eco-friendly agro-based industry that plays a vital role in rural employment and sustainable textile production. However, silkworm rearing is significantly affected by diseases caused by microbial pathogens, leading to reduced cocoon quality and economic losses. The present study evaluates eco-friendly disease management strategies using probiotics and plant extracts to enhance silkworm health and productivity. Silkworms (*Bombyx mori*) were reared under controlled conditions and subjected to four treatments: control, probiotic supplementation, plant extract treatment, and a combination of both. Neem (*Azadirachta indica*) and tulsi (*Ocimum sanctum*) extracts were used due to their antimicrobial properties, while *Lactobacillus bulgaricus* served as the probiotic agent. Results indicated a significant improvement in larval weight and survival rate in treated groups compared to control. The combined treatment showed the highest survival rate (96%) and improved larval growth (3.9 g), demonstrating a synergistic effect. The findings suggest that integrating probiotics with plant-based extracts offers a sustainable, cost-effective, and environmentally safe alternative to chemical disease control in sericulture. This approach enhances silkworm immunity, reduces disease incidence, and promotes sustainable silk production practices, benefiting rural farmers and contributing to eco-friendly agricultural systems.

Key words: *Bombyx mori, Morus alba, Sericulture,Probiotics , Plant extracts , Silkworm rearing , Silkworm immunity*

1. Introduction

Sericulture, the scientific rearing of silkworms (*Bombyx mori*) for silk production, is an important agro-based industry contributing to rural livelihoods and sustainable textile production. It provides employment opportunities, particularly for small and marginal farmers, and plays a significant role in women empowerment and economic development. As a low-investment and high-return activity, sericulture is widely adopted in developing countries like India.

The success of sericulture largely depends on several environmental and biological factors such as temperature, humidity, mulberry leaf quality, rearing hygiene, and silkworm strain. Among these, disease incidence remains a major challenge affecting productivity and quality of silk. Silkworms are highly susceptible to diseases such as pebrine (caused by *Nosema bombycis*), grasserie (viral), flacherie (bacterial/viral), and muscardine (fungal). These diseases can drastically reduce larval survival, cocoon yield, and silk quality, leading to significant economic losses for farmers.

Traditional disease management strategies often rely on chemical disinfectants and antibiotics, which may leave harmful residues and negatively impact the environment. Therefore, there is a growing need for eco-friendly and sustainable alternatives to ensure safe and efficient silkworm rearing.

Plant extracts such as neem (*Azadirachta indica*) and tulsi (*Ocimum sanctum*) are known for their antimicrobial and immunomodulatory properties. Similarly, probiotics like *Lactobacillus bulgaricus* can enhance gut health and improve resistance to pathogens. The integration of these natural agents offers a promising strategy for sustainable disease management in sericulture.

This study aims to evaluate the effectiveness of probiotics and plant extracts, individually and in combination, in improving silkworm growth performance and survivability. The findings contribute to the development of eco-friendly sericulture practices that align with sustainable agricultural and environmental goals.

2. Objectives

1. To evaluate the impact of probiotic supplementation and plant extracts on silkworm health, growth, and survival.
2. To assess their individual and combined effects in disease control.

3. To develop an eco-friendly, sustainable strategy for improving silkworm rearing efficiency and reducing disease incidence in sericulture systems.

3. Materials and Methods

Silkworm eggs (*Bombyx mori*) were collected from local sericulture farmers in the Kanakapura region. The larvae were reared under controlled laboratory conditions using standard rearing trays lined with paraffin and foam sheets. Fresh mulberry (*Morus alba*) leaves were used as the primary feed. Plant materials including neem (*Azadirachta indica*) and tulsi (*Ocimum sanctum*) leaves were collected from the college garden.

Fig 1: Neem and Thulasi Leaves

Fig 2:Egg spread and Hatched Larvae

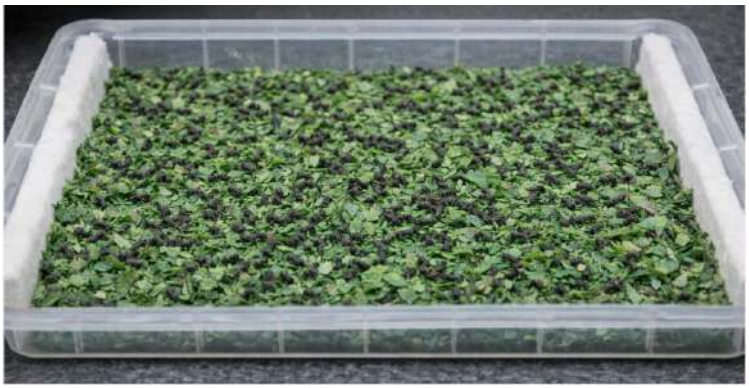


Fig 3: Mulching

The leaves were thoroughly washed with tap water followed by distilled water to remove contaminants. The equal quantity of cleaned leaves(1:1) were ground using a sterile mortar and pestle. The homogenate was filtered through muslin cloth to obtain crude plant extracts.

The probiotic culture, *Lactobacillus bulgaricus*, was obtained from the microbiology laboratory. The culture was grown in LBS broth and diluted with distilled water to prepare a sprayable solution. Feed enrichment was carried out by dipping mulberry leaves in plant extract and allowing them to dry under shade. The probiotic solution was sprayed on the leaves immediately before feeding.

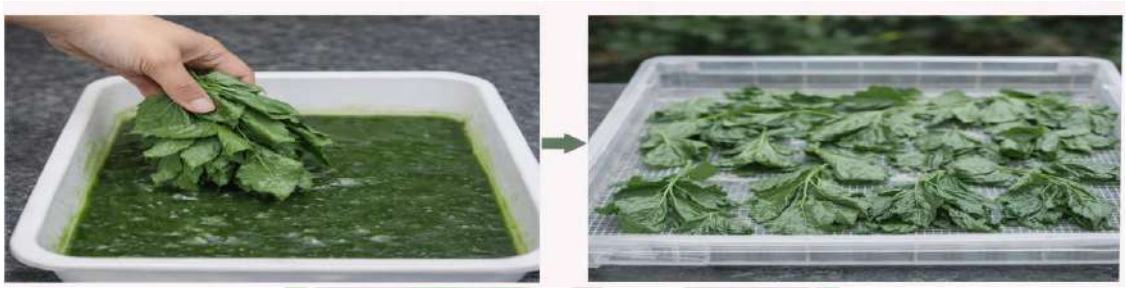


Fig 4: Treatment of Mulbery leaves with plant extracts

Fig 5: *Lactobacillus bulgaricus*

The experiment consisted of four treatment groups:

- T0: Control (normal feed)
- T1: Probiotic-treated feed
- T2: Plant extract-treated feed
- T3: Combined probiotic and plant extract treatment

Each group consisted of 50 larvae. The larvae were reared for a fixed period under similar environmental conditions. Observations were recorded for larval weight, survival rate, and general health. Larval weight was measured using a digital balance, and survival rate was calculated based on the number of larvae surviving until the final stage. The experimental design allowed comparison of individual and combined effects of treatments on silkworm performance.

4. Results

4.1 Effect of Treatments on Larval Growth

The effect of probiotic and plant extract supplementation on larval growth was evaluated by measuring the average larval weight across different treatment groups (Table 1).

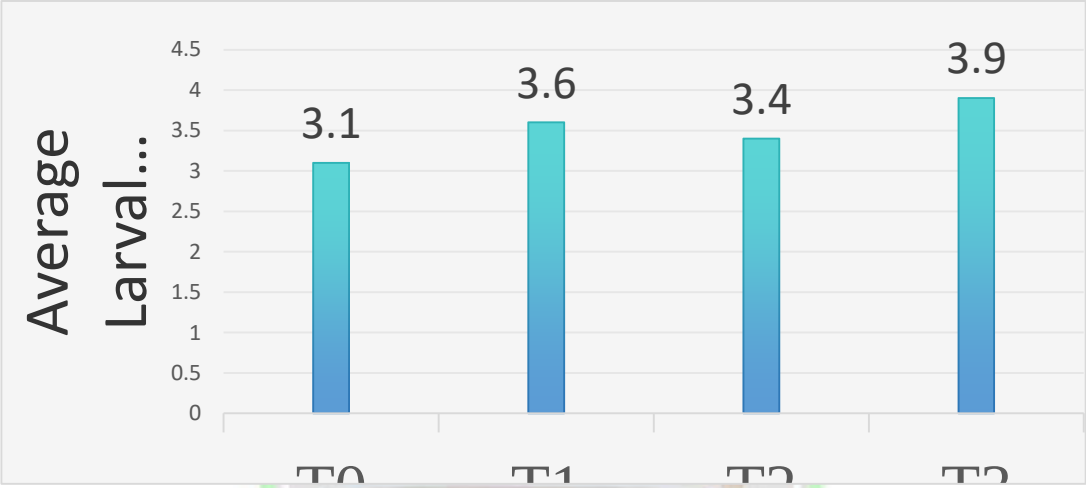
Table 1. Average larval weight under different treatments

Treatment	**T0 (Control)**	**T1 (Probiotic)**	**T2 (Plant Extract)**	**T3 (Combined)**
Weight (g)	3.1	3.6	3.4	3.9

Fig 6 Larvae fed with Probiotics

Fig 7 Larvae fed with with Plant extracts

Fig 8 Larvae fed with the combination of Probiotics and Plant extracts



Graph 1 Effect of Probiotic and plant extracts combination on larvae weight

This results indicate a clear improvement in larval weight in all treated groups compared to the control. The highest mean larval weight was recorded in the combined treatment (T3: 3.9 g), followed by probiotic treatment (T1: 3.6 g) and plant extract treatment (T2: 3.4 g).

The increase in larval weight in T1 suggests that probiotic supplementation enhances nutrient assimilation and metabolic activity. Similarly, the improvement observed in T2 indicates the beneficial role of plant extracts in maintaining larval health. The maximum weight observed in T3 demonstrates a synergistic interaction between probiotics and plant extracts.

4.2 Effect of Treatments on Survival Rate

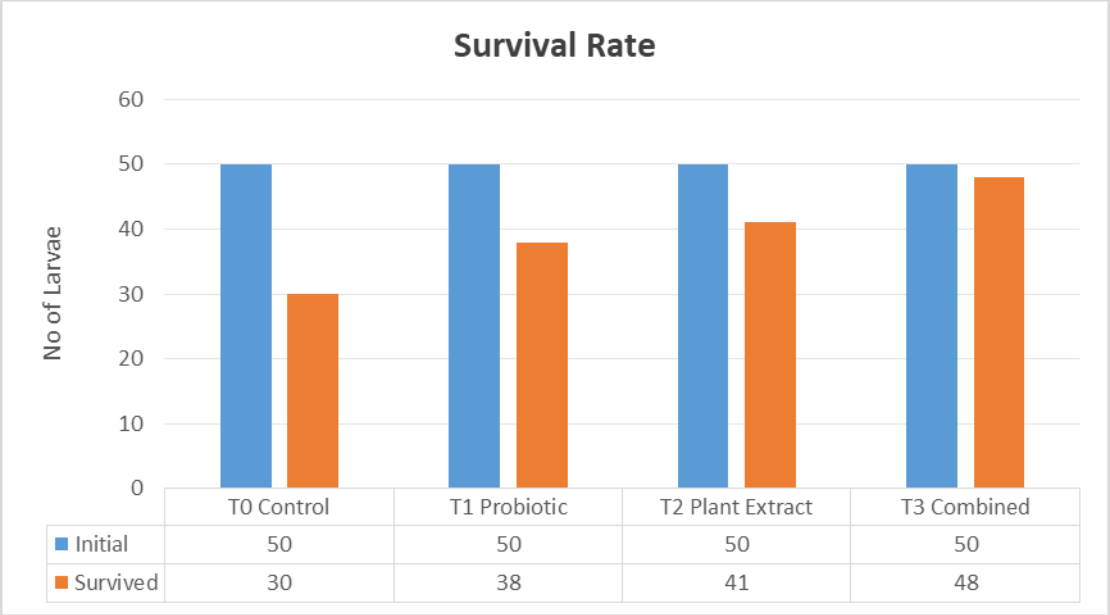
Table 2. Survival rate of silkworm larvae under different treatments

Treatment	Initial number	Survived	Survival (%)
T0 Control	50	30	60%
T1 Probiotic	50	38	76%
T2 Plant Extract	50	41	82%
T3 Combined	50	48	96%

A significant improvement in survival rate was observed in all treatment groups compared to the control. The control group (T0) recorded the lowest survival rate (60%), indicating higher susceptibility to environmental stress and disease.

Probiotic-treated larvae (T1) showed an increased survival rate of 76%, reflecting improved physiological resistance. Plant extract treatment (T2) further enhanced survival to 82%, likely due to antimicrobial properties of neem and tulsi.

The combined treatment (T3) demonstrated the highest survival rate of 96%, indicating a strong synergistic effect. This suggests that probiotics and plant extracts together provide both internal (gut health) and external (pathogen control) protection to silkworms.



Graph 2 : Survival rate of Larvae

4.3 Comparative Analysis of Treatments

Comparative evaluation of all treatments reveals a consistent trend where the combined treatment (T3) outperformed individual treatments (T1 and T2) and control (T0) in both growth and survival parameters.

- **Growth enhancement:** T3 > T1 > T2 > T0
- **Survival rate:** T3 > T2 > T1 > T0

This pattern confirms that while probiotics primarily improve growth performance, plant extracts mainly contribute to disease control, and their combination maximizes overall silkworm health.

4.4 Observational Findings

During the rearing period, noticeable differences were observed among treatment groups:

- Larvae in T3 appeared more active, healthy, and uniform in size
- Reduced signs of disease and mortality were observed in treated groups
- Control larvae showed comparatively slower growth and higher mortality

4.5 Overall Outcome

The experimental results clearly demonstrate that eco-friendly treatments significantly enhance silkworm performance. The combined application of probiotics and plant extracts resulted in:

- **25% increase in survival compared to control (96% vs 60%)**
- **Higher larval biomass accumulation**
- **Improved overall health and resistance**

These findings validate the effectiveness of probiotic–plant extract integration as a sustainable approach for silkworm rearing and disease management.

5. Discussion

The results of this study clearly demonstrate the effectiveness of eco-friendly interventions in improving silkworm health and productivity. Among the treatments, the combined application of probiotics and plant extracts showed the most significant improvement in both larval weight and survival rate, indicating a synergistic interaction between the two.

The increase in larval weight in probiotic-treated groups can be attributed to improved gut health and nutrient absorption. Probiotics such as *Lactobacillus bulgaricus* are known to enhance digestion, produce beneficial metabolites, and suppress pathogenic microorganisms in the gut. This leads to better growth performance and overall health of silkworm larvae.

Plant extracts from neem and tulsi exhibited strong antimicrobial properties, which likely contributed to reduced pathogen load and lower disease incidence. Neem contains bioactive compounds such as azadirachtin, while tulsi possesses essential oils and phenolic compounds known for their antibacterial and antifungal activities. These properties help in controlling common silkworm diseases such as flacherie and muscardine.

The combined treatment resulted in the highest survival rate (96%), significantly higher than control (60%). This indicates that while probiotics improve physiological health, plant extracts provide external protection against pathogens. Together, they create a comprehensive defense system for silkworms.

These findings are consistent with previous studies highlighting the benefits of probiotics and plant-based treatments in sustainable agriculture. The results support the adoption of eco-friendly disease management strategies in sericulture, reducing reliance on chemical treatments. Furthermore, the use of locally available plant materials and simple probiotic formulations makes this approach cost-effective and accessible for rural farmers. It aligns with sustainable agricultural practices and contributes to environmental conservation.

6. Conclusion

The study confirms that eco-friendly treatments significantly enhance silkworm survival and growth. The combined use of probiotics and plant extracts proved most effective, offering a sustainable and environmentally safe approach for disease management in sericulture. This strategy supports improved productivity and sustainable silk production.

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ENHANCING DAIRY PRODUCTIVITY THROUGH A MULTI-CROP FODDER PRODUCTION SYSTEM

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Abstract

Dairy farming plays an important role in improving the livelihood of rural households in India; however, inadequate availability of quality fodder remains a major constraint affecting livestock productivity. The present article highlights the demonstration of a multi-crop fodder production model aimed at ensuring year-round availability of nutritious green fodder and improving dairy animal productivity. The model integrates high-yielding fodder crops such as hybrid Napier, fodder sorghum, hedge lucerne, and Agathi within a limited land area to provide balanced nutrition for dairy animals. The demonstration was conducted under semi-intensive farming conditions involving ten farmers in two villages. Results indicated that the adoption of the multi-crop fodder system increased average milk yield from 8.1 to 9.4 litres per animal per day, representing an improvement of about 12.2 per cent. Improvements in milk fat and SNF content were also observed. Economic analysis showed higher net returns and benefit–cost ratio compared to the conventional single fodder system, indicating the economic viability of the model.

Keywords: Dairy productivity, multi-crop fodder system, green fodder production, milk yield, nutritional management, dairy cattle, fodder diversification, farm profitability.

Introduction

Livestock farming plays an important role in the rural economy of India by providing food, employment, and income security to millions of small and marginal farmers. Among various livestock enterprises, dairy farming has become one of the most dependable sources of daily income for rural households. India currently ranks first in global milk production and contributes significantly to the world's dairy sector. However, the productivity of dairy animals

in the country remains relatively low compared with many developed nations, mainly due to the shortage of quality feed and fodder. Feed accounts for nearly **60–70 per cent of the total cost of milk production**, making it the most critical component of dairy management (Kumar *et al*., 2022). India faces a significant deficit in fodder resources, with shortages of about **30–35 per cent green fodder, 10–12 per cent dry fodder, and nearly 35 per cent concentrate feed ingredients** (Singh *et al*., 2023). These shortages directly affect the productivity, health, and reproductive performance of dairy animals. Small and marginal farmers often have limited landholdings and cannot allocate large areas exclusively for fodder cultivation. As a result, they depend largely on crop residues and purchased feed, which may not provide balanced nutrition.

Concept of the Multi-Crop Fodder Model

The **10-cent fodder model**, equivalent to approximately **0.04 hectares**, is a compact and efficient fodder production system designed primarily for smallholder dairy farmers. The model integrates several fodder crops in a planned layout so that different crops mature at different times, thereby ensuring continuous availability of fodder.

In the demonstration, the following fodder crops were included:

- Hybrid Napier grass (*Pennisetum purpureum x Pennisetum glaucum*)
- Fodder sorghum (*Sorghum bicolor*)
- Hedge lucerne (*Desmanthus virgatus*)
- Agathi (*Sesbania grandiflora*)

These crops were selected because of their high biomass production, nutritional value, adaptability to tropical climatic conditions, and complementary growth patterns. Hybrid Napier grass is widely recognized as one of the most productive perennial fodder grasses in tropical regions. It is capable of producing **high green biomass yields ranging from 250 to 350 tonnes per hectare annually under proper management** (Reddy *et al*., 2022). The grass is highly palatable, rich in nutrients, and suitable for multiple harvests throughout the year.

Fodder sorghum is another important fodder crop due to its rapid growth, high biomass production, and tolerance to drought conditions. Multi-cut sorghum varieties allow several harvests within a growing season, providing consistent fodder supply (Kumar and Suresh, 2021). Leguminous fodder crops such as hedge lucerne and Agathi are valuable components of the model because they contain high levels of protein and improve soil fertility through biological nitrogen fixation.

These legumes enhance the overall nutritive value of the fodder system and support better milk production in dairy animals (Sharma *et al*., 2023).

Demonstration Details

The demonstration of the **multi-crop fodder model** was conducted under semi-intensive dairy farming conditions during the year 2025. The programme aimed to evaluate the effectiveness of diversified fodder production in improving dairy productivity and farmer income.

The key details of the demonstration are as follows:

Enterprise: Large animals (dairy cattle)

Thematic area: Nutritional management

Number of villages: 2

Number of farmers involved: 10

To ensure successful adoption of the technology, several extension activities were conducted. These included:

- One farmer training programme on fodder production and feeding management
- Five field visits for monitoring crop growth and providing technical guidance

Farmers were trained on land preparation, planting techniques, crop management, harvesting intervals, and proper feeding of fodder to dairy animals.

Impact on Milk Production and Milk Quality

The performance of the multi-crop fodder model was evaluated by comparing milk production and milk quality parameters before and after adoption of the technology. The results demonstrated significant improvement in dairy productivity.

The average milk yield of dairy animals increased from **8.1 litres per day to 9.4 litres per day** after adopting the multi-crop fodder system. In contrast, animals fed with fodder from a conventional single-crop system showed only a marginal increase from **8.0 litres to 8.2 litres per day**. Overall, the multi-crop fodder model resulted in approximately **12.2 per cent increase in milk yield**. This improvement can be attributed to the availability of balanced and nutritious fodder throughout the year.

In addition to increased milk yield, improvements were also observed in milk quality parameters such as fat and solids-not-fat (SNF) content. The fat percentage increased from **4.1 per cent to 4.6 per cent**, while the SNF content improved from **7.2 per cent to 7.9 per cent**.

These improvements in milk composition indicate better nutritional intake and digestive efficiency in dairy animals. Previous studies have also reported that diversified fodder systems enhance feed intake, nutrient utilization, and milk production in dairy cattle (Patel *et al*., 2024).

Economic Benefits of the Technology

Apart from improving milk production, the multi-crop fodder model also generated higher economic returns for farmers. Economic analysis revealed that the cost of fodder cultivation under the multi-crop system was slightly higher than that of the conventional system due to the inclusion of multiple crops.

However, the increase in milk yield significantly improved overall income.

The economic results are summarized below:

System	Gross Cost (₹)	Gross Income (₹)	Net Return (₹)	B:C Ratio
Multi-crop fodder model	4,300	16,920	12,620	2.93
Single fodder system	3,400	12,177	8,777	2.58

The **benefit-cost ratio of 2.93** obtained from the multi-crop fodder model clearly indicates that the system is economically viable and profitable for dairy farmers. Similar findings have been reported by several researchers who observed that integrated fodder production systems significantly enhance economic returns and reduce feed costs in dairy enterprises (Singh *et al*., 2023).

Advantages of the Multi-Crop Fodder Model

The 10-cent multi-crop fodder model offers numerous advantages, particularly for smallholder farmers with limited land resources.

1. Year-Round Availability of Green Fodder

By integrating different fodder crops with varied harvesting intervals, the model ensures continuous supply of fresh fodder throughout the year.

2. Improved Milk Yield and Quality

Balanced nutrition from diversified fodder crops improves milk production and enhances milk composition.

3. Efficient Use of Small Land Areas

The model enables farmers to produce sufficient fodder within a small land area of only 10 cents.

4. Reduced Feed Cost

Availability of home-grown fodder reduces dependence on purchased feed and concentrates.

5. Improved Soil Fertility

Leguminous fodder crops enrich the soil with nitrogen, improving soil health and sustainability.

6. Climate Resilience

Diversification of fodder crops reduces the risk of crop failure and ensures stable fodder supply even under variable climatic conditions. Such integrated fodder production systems have been recommended as an effective strategy for enhancing livestock productivity in smallholder farming systems (Sharma *et al*., 2023).

Farmers' Feedback

Farmers who participated in the demonstration expressed positive feedback regarding the technology. According to the participating farmers, the multi-crop fodder model ensured consistent availability of green fodder throughout the year. This reduced their dependence on purchased fodder and improved feeding practices. Many farmers also reported improvements in animal health, body condition, and milk production. The observed **12.2 per cent increase in milk yield** encouraged farmers to adopt the technology on a larger scale. The technology was found particularly beneficial for **small and marginal farmers**, as it required only a small land area and minimal additional investment.

Conclusion

The demonstration of the **10-cent multi-crop fodder model** clearly demonstrated its potential to improve dairy productivity and farmer income. By integrating high-yielding fodder crops such as hybrid Napier, fodder sorghum, hedge lucerne, and Agathi, the system ensures continuous supply of nutritious fodder throughout the year. The adoption of this model resulted in **increased milk yield, improved milk quality, and higher economic returns**, making it a sustainable and practical solution for smallholder dairy farmers. Promotion of this technology through farmer training programmes, demonstrations, and extension activities can significantly improve fodder availability and strengthen dairy farming systems in rural areas. Widespread adoption of such innovative fodder production models will contribute to enhancing livestock productivity and improving the livelihoods of farming communities.

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ZINC – AN IMPORTANT MICRONUTRIENT IN CROP PRODUCTION

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Introduction

Essential plant micronutrients (iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl)) are trace elements and crucial for enzyme activity, photosynthesis, and structural integrity, though needed in lesser quantity. They prevent deficiencies like stunted growth and leaf yellowing, improving yield and quality.

Among micronutrients, zinc (Zn) is important and required for the metabolism of plants, enzyme function, and ion transport. Consequently, inadequate Zn availability in soil is a main consideration for plant nutrition, resulting in a significant loss in production and grain nutrient content. Zinc exits naturally in rocks. The amount of zinc present in the soil depends on the parent materials of that soil. Sandy and highly leached acid soils generally have low plant available zinc. Mineral soils with low soil organic matter also exhibit zinc deficiency. In contrast, soils originating from igneous rocks are higher in zinc. Plants take up zinc as the divalent ionic form (Zn^{2+}) and chelated-zinc.

Functions of zinc:

1. Zink plays an important role as a constituent of alcohol dehydrogenase and galactose oxidase engines.
2. It regulates auxin content and reproductive process of plant.
3. Required for synthesis of tryptophane.
4. Important role in photosynthesis and nitrogen metabolism.

Deficiency symptoms of zinc:

- Terminal growth is first affected.

- Yellow and bronze colour developed on older leaves.
- Decreases leaf size and mal formation of leaves which is known as little leaf.
- Shorten internodes which gives rosette appearance of leaves.
- Interveinal chlorosis and often necrosis.
- flower setting and fruit development are delayed.
- Accumulation of amine and amino nitrogen in plants.

Zinc deficiency in rice:

- Zinc deficiency in rice is called Khaira disease.
- The symptoms of Khaira disease is
- Poor stand and establishment of plants which causes poor growth and tillering.
- The crop appears sickly after 4 to 6 days weeks after transplanting.
- Basal and Midrib bleaching of 3rd and 4th leave from the top after 2 to 4 weeks after transplanting.
- Dark rusty spots appear on upper leaf margins in older and matured leaves.
- A general characteristic yellowing of crop which do not turn to green colour after application of Nitrogen fertilizers.
- Strong matured plants develop its characteristic greyish appearance.
- Poor road development which shows durty black colour and in severe cases become spongy and later roots will die

Zinc deficiency symptoms in maize:

- Zinc deficiency in Maize is called as white bud
- The symptoms are
- Chlorosis development on 3rd leaf and later spread of chlorosis to leaves sheath, leave nodes and purple pigmentation develops.
- During night time leaves excrete various fluids which dries up daytime and gives up appearance of salt encrustation.

In cocoa zinc deficiency is called sickle leaf and in citrus, zinc deficiency is called mottle leaf.

Factors affecting availability of zinc in soils:

1} Soil pH: Zinc availability decreases with pH increases. pH induced zinc deficiency occur in pH range of 6 to 8, if PH more than 7.5, pH,

Zn concentration negatively charged ions known as zincate ion.

Optimum pH 5.5 – 6.5 for availability of Zn.

2) $CaCO_3$ content: Zn deficiency occurs in calcareous soil because $CaCO_3$ adsorbs Zn which is very strong. Maximum Zn retention by $CaCO_3$ occur at 2.5% in case of calcareous soils and 1.5% in red soils.

3) Clay minerals: Zn is fixed in clay minerals like bentonites, illite and Kailonite. The adsorption is directly related to CEC of clays & hydrous oxides. In this clay minerals Zn is adsorbed by replacing Mg ions in crystal lattice.

4) Interaction with other nutrients: Cu, Fe & Mn inhibits Zn uptake by plants because they compete same size of ion adsorption.

5) Phosphorus: High P content / application of excess P fertilizers induces Zn deficiency because P accumulation increases with similarly Zn availability. There is a definite P:Zn ratio to obtain optimum yields, aby change in this ratio will affect the uptake of Zn.

6) Sulphates: Soils with So_4^{-2} and application if S fertilizers will increase solubility and availability of Zn and there by increases Zn availability.

7) Nitrogenous fertilizers: Application of acid forming N fertilizer will increases native and applied Zn. Whereas neutral and basal fertilizers decrease the uptake of Zn by plants.

8) Flooding: In flooding or submergence, in acid soils the Zn level decreases due to increase pH and also formation of less soluble mineral like franklinite that is Zn and Fe oxide ($ZnFe_2O_4$).

Conditions cause Zn deficiency in soils

- Soil are derived from granite & shales
- Acid leaching sandy soils, Alkaline soils
- Application of large quality of undecomposed & party decomposed organic manures.
- Soil containing low Si: Mg ratio
- High P fertilization
- Overliming of acid soils & calcareous soils
- Low lying and water logged conditions.
- Continuous flooding of soils season after season
- Mono cropping of paddy.
- Severe coil spells
- Recently levelled fields.

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THE RISE OF ORGANIC FOOD CULTURE

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Introduction

In recent years, the way of people pursuing food has changed dramatically. Consumers are no longer just looking for taste and convenience; but increasing concerned about health, safety and sustainability. This shift has led to the growing popularity of organic food products. From vegetables and fruits to dairy and packaged goods, organic options are becoming more visible in local markets and supermarkets alike.

But what exactly is driving this trend? Why are people more willing to spend extra on organic food? And what challenges still prevent organic food from becoming a mainstream choice? Let's explore the changing consumer mindset and the growing importance of organic food in today's world.

Understanding Organic Food

Organic food refers to products that are grown and processed without the use of synthetic fertilizers, pesticides, genetically modified organisms (GMOs), or artificial additives. The focus on natural farming helps maintain soil health, biodiversity, and ecological balance.

For many consumers, organic food is not just a consumption – it became a lifestyle choice. They associate with better health, environment protection, and ethical farming practices. This perception has played a major role in influencing buying behavior.

Why Consumers are choosing Organic

The biggest reason behind the rise of organic food consumption is health awareness. Increasing cases of lifestyle diseases such as diabetes, obesity, and heart-related issues, people are becoming more cautious about what they eat, hence organic food is seen as a safer and healthier alternative.

Another important factor is concern about chemicals and pesticides. Consumers worry about long-term effects of consuming foods that contains chemical residues. Organic food, being free from harmful substances, provide a sense of security and trust.

Environmental consciousness also plays a crucial role. Modern consumers are more aware of climate change, pollution, and sustainable living. Organic farming practices are considered eco-friendly, as they reduce soil degradation and water contamination so, this makes consumers feel contribution towards a better planet.

Additionally, taste and quality influence buying decisions. Many people believe that organic food tastes fresher and more natural. This perception, is complete accurate or not, strongly impacts consumer preference.

The role of Income and lifestyle

Even though the awareness about organic food is increasing, its consumption is still influenced by factors such as income and lifestyle. Organic products are slight expensive than conventional ones, which limits their accessibility to certain sections of society.

Urban consumers, especially those with higher income levels, are more likely to purchase organic food regularly. More exposed information takes place through digital platforms, social media, and health campaigns. On the other hand, middle- and low-income groups often restrict the purchase by price. Busy professionals may prefer convenience over careful food choices, while health-conscious individuals are more willing to invest time and money in organic options.

Challenges in the Organic market

Despite its popularity, market faces several challenges. The most significant barrier is high cost. Organic farming itself requires more labor and time leading to higher production costs. Another challenge lack of awareness and trust. Still consumers are unsure about what “organic” really means, questions arise like whether the products are genuinely organic or just labeled as for marketing purposes.

Limited availability is also an issue. In many areas, organic products are not easily accessible. Consumers may need to visit specific stores or reply on online platforms, which can be convenient. Lastly, inconsistent quality and certification standards, without proper regulation and transparency, it becomes difficult for consumers to make informed choices.

The Influence of Marketing and Digital Platforms

This plays a major role in reaching the consumer end. Attractive packaging, clear labeling, and effective branding greatly influence consumer decisions. Words like “Natural”, “chemical-free” and “eco-friendly” appeal strongly to modern buyers.

Digital platforms have further accelerated this trend. Social media, online reviews, and influencer marketing have made organic food more visible and appealing. Consumers often rely on online information before making a purchase, and positive word-of-mouth can significantly boost sales.

E-commerce platforms have also made it easier to access organic products, especially in urban areas. With doorstep delivery and detailed product descriptions, online shopping has become a convenient option for health-conscious consumers.

A Shift towards Sustainable living

The growing demand for organic food reflects a shift towards sustainable living. Consumers today are more mindful of their choices and their impact on the environment. Organic food aligns with this mindset by promoting responsible consumption and ethical production.

This shift is not just a passing trend it represents a long-term change in consumer behaviour. As awareness continues to grow, more people are likely to adopt organic food as part of their daily lives.

The Road Ahead

The future of organic food looks promising, but there is still a long way to go. To make organic products more accessible, efforts must be made to reduce costs, improve supply chains, and increase awareness. Governments, businesses, and farmers all have a role to play. Better policies, improved certification systems, and educational campaigns can help build trust and encourage wider adoption. For consumers, the choice of organic food is not just about personal health - it is about supporting a healthier planet and a sustainable future.

Conclusion

The rise of organic food products highlights a significant change in consumer behaviour. People are becoming more conscious of what they eat and how it affects their health and the environment. While challenges such as cost and accessibility plays a major part. Organic food is no longer a niche market - it is steadily becoming a part of everyday life. As awareness grows and systems improve, it has the potential to transform not just individual diets, but the entire food industry.

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FROM SOIL TO SOUL: REVIVING EARTH THROUGH SUSTAINABLE FARMING AND PLANT PHYSIOLOGY

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Introduction

On a quiet April morning, as the first rays of sunlight touch the fields, a farmer bends down, takes a handful of soil, and gently crumbles it between his fingers. What he holds is not just soil—it is life, memory, and the future. Every year, on April 22, the world observes **Earth Day**, reminding us that the health of our planet begins with the soil we nurture and the crops we grow. Agriculture is not merely an occupation; it is the foundation of ecological balance and human survival.

Over the years, modern agriculture has achieved remarkable increases in productivity. However, this progress has come at a cost. Excessive use of chemical fertilizers, pesticides and unsustainable practices has led to soil degradation, declining microbial activity, reduced fertility and increased vulnerability of crops to drought and environmental stress. The soil, once rich and vibrant, is slowly losing its vitality. The earth is speaking to us through these changes—what remains is whether we are willing to listen and act.

Plants are not passive organisms; they are dynamic, living systems that respond continuously to their environment. The science of plant physiology helps us understand how plants grow, absorb nutrients, utilize water and respond to stress conditions. Photosynthesis, the fundamental process by which plants convert sunlight into energy, depends heavily on nutrient availability and healthy soil conditions. When soil health declines, this process becomes less efficient, ultimately affecting crop productivity. Similarly, plants regulate water through tiny pores called stomata. Under drought conditions, these stomata close to conserve water, but this

also reduces growth. Healthy root systems, supported by good soil conditions, enhance nutrient uptake and improve plant resilience against stress.

Integrated Nutrient Management (INM)

In this context, Integrated Nutrient Management (INM) emerges as a sustainable and practical solution. It represents a balanced approach that combines organic manures such as farmyard manure and compost, biofertilizers like beneficial microorganisms, and chemical fertilizers in appropriate proportions. This integrated approach restores soil health, enhances microbial activity, improves nutrient availability and strengthens the physiological efficiency of plants. It also increases the ability of crops to withstand drought and other stresses. INM is not merely a farming technique—it is a philosophy that emphasizes harmony between nature and agriculture.

Farmers are the true guardians of the earth. Their decisions directly influence soil health, water conservation and biodiversity. This Earth Day, the message to farmers is simple yet powerful: feed the soil, not just the crop; use water wisely; diversify cropping systems; and trust natural processes. Small changes in farming practices can lead to significant improvements in sustainability and productivity. When farmers adopt eco-friendly practices, the entire ecosystem benefits.

Role of agricultural extension

Equally important is the role of agricultural extension in bridging the gap between scientific knowledge and field application. Scientific advancements become meaningful only when they reach the farmer. Extension agencies must intensify efforts through farmer training programs, field demonstrations, soil testing campaigns and awareness initiatives. Promoting the use of organic inputs, biofertilizers and balanced fertilization practices can transform farming systems and improve livelihoods. The responsibility of protecting the Earth does not rest solely with farmers. Every individual in society has a role to play. Supporting sustainable agriculture, reducing food waste, conserving water and planting trees are simple yet impactful actions. Environmental conservation is a shared responsibility that requires collective commitment.

Conclusion

As we reflect on the significance of Earth Day, we must envision a future where soils are healthy, crops are resilient and farmers are empowered. Such a future is not distant—it is achievable through informed decisions and coordinated efforts. The connection between soil,

plant and human life is inseparable. By understanding plant physiology and adopting sustainable practices like integrated nutrient management, we can restore ecological balance and ensure food security for generations to come.

Let us remember: when we heal the soil, we heal the Earth; and when we support farmers, we secure our future.

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INDIA'S STARTUP BOOM: FROM POLICY SUPPORT TO AGRITECH INNOVATION

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Abstract

India's startup ecosystem has experienced significant growth over the past decade, supported by strong government initiatives, digital transformation, and increasing entrepreneurial participation. This article examines the current scenario of startups in India, with a particular focus on the role of policy support mechanisms such as Startup India and its associated financial schemes. It further explores the composition of the startup ecosystem and highlights the emergence of agritech as a key sector driving innovation in agriculture. Agritech startups are leveraging advanced technologies such as artificial intelligence, data analytics, and digital platforms to address long-standing challenges in farming, supply chains, and market access. The study also outlines major government initiatives promoting agritech development and identifies key areas of innovation within the sector. Overall, the article emphasizes the transition of India's startup ecosystem towards sustainability, technological advancement, and inclusive growth.

Keywords: Startup ecosystem, Agritech startups, Innovation, Government schemes, Digital transformation

Introduction

India has emerged as one of the world's fastest-growing startup ecosystems, driven by strong policy support, increasing digital adoption, and a surge in entrepreneurial spirit. Since the launch of the Startup India initiative in 2016, the country has witnessed a remarkable transformation in how businesses are created, funded, and scaled. The initiative promotes a

startup culture by offering tax incentives, fast-tracking intellectual property rights, and improving ease of doing business, along with financial support through schemes such as the Fund of Funds for Startups (FFS), Startup India Seed Fund Scheme (SISF), and Credit Guarantee Scheme for Startups (CGSS).

At present, India stands as the third-largest startup ecosystem globally, with over 1.7–2 lakh recognized startups, generating significant employment and contributing to economic growth. The ecosystem is now moving beyond rapid expansion towards sustainable and profitability-driven growth, with increasing participation from Tier-2 and Tier-3 cities and growing focus on technology-driven sectors such as artificial intelligence, fintech, and agritech. Despite challenges like funding constraints and market competition, the current position of startups in India reflects a mature, resilient, and innovation-oriented ecosystem.

Key Financial Support Schemes under Startup India

Startup India Seed Fund Scheme (SISF)

Under this scheme, a corpus of Rs 945 Cr will be provided for a period of four years starting from 2021-22. Startups will be provided financial assistance for proof of concept, prototype development, product testing, market and commercialization. Seed funding will be provided to eligible startups through eligible incubators across India. Startup India Seed Fund Scheme, various startups in India. Around 2231 startups are funded, out of which 135 are agri startups, including agri-tech, agro-chemicals, animal husbandry, food processing, food technology, and organic farming. In Tamil Nadu, 220 startups are supported under the Startup India Seed Fund Scheme, out of which 22 are agri-startups. SISF is distributed to startups through incubators. Technology Business Incubator, Tamil Nadu Agricultural University, is one of the incubators authorized to provide SISF to startups.

Fund of Funds (FoF) Scheme

The FoF for Startups with a fund of Rs 10,000 crore was approved and established in June 2016. To provide a much-needed boost to the Indian startup ecosystem and enable access to domestic capital, the scheme has been rolled out in the 14th and 15th Finance Commission cycles, with contributions being made based on the progress of implementation.

95+ Alternative Investment Funds (AIFs) are supported under the Department for Promotion of Industry and Internal Trade (DPIIT)'s Start-up Fund. 750+ startups have already been funded by these Alternative Investment Funds (AIFs).

Credit Guarantee Scheme for Startups (CGSS)

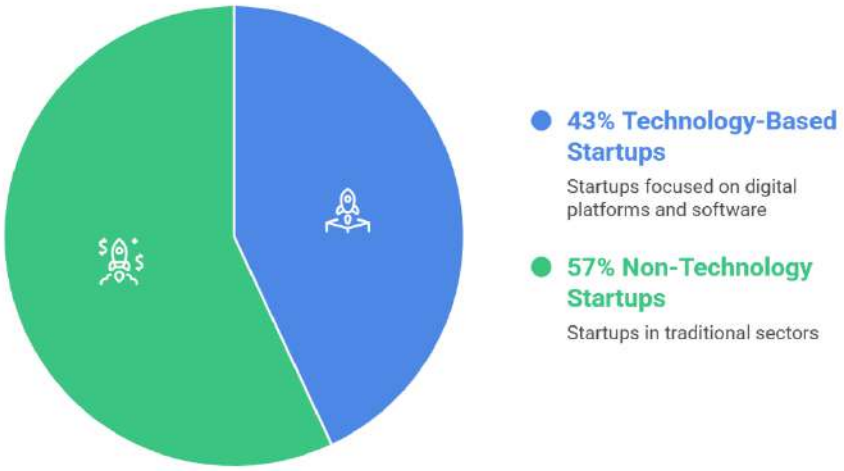
The establishment of CGSS is aimed at providing loan guarantees for loans disbursed to DPIIT-approved startups by Scheduled Commercial Banks, Non-Banking Financial Companies (NBFCs) and Venture Debt Funds (VDFs). Investment Funds

Startup India Investor Connection

Startup India Investor Connect is a platform that connects startups with investors to facilitate investment opportunities through AI-based matchmaking. Through this, entrepreneurs can directly reach out to multiple investors using a single app and pitch their startup idea. Startup India Investor Connect has registered 6955 investors and 6214 startups have responded.

Composition of the Indian Startup Industry

The Indian startup ecosystem comprises both technology and non-technology enterprises. Out of around 10,000 startups, about 43% (4,300) are technology-based, while 57% (5,700) belong to non-technology sectors. Nearly 800 new tech startups emerge annually, indicating strong growth in innovation-driven areas, while non-technology startups continue to hold a slightly larger share overall.



Agritech Startups

Agritech is a term used for agricultural technology, which uses technology to improve agriculture and farming across various value chains. In India, agritech continues to grow with startups using innovation and digital technologies such as precision farming, quality management, manufacturing, supply chain/market connectivity and digital traceability. Currently (as of September 24, 2024), there are 6,354 agriculture DPIIT-approved startups in India,

including 3,732 agritech startups. Through government-led initiatives like Startup India, efforts have been made to promote the growth of an ecosystem in which the agritech sector is a key one. In the 2023 Budget, the 'Agriculture Accelerator Fund' was introduced to promote agricultural start-ups launched by young entrepreneurs in rural areas and the agricultural credit target was increased to Rs. 20 lakh crore with a focus on animal husbandry, dairying and fisheries (Budget. 2023).

Government initiatives for Agritech startups

Agricultural Infrastructure Fund - Ministry of Agriculture

With the launch of the Agriculture Infrastructure Fund, trained and established farmers have an opportunity to set up a new unit or scale up the operations of an existing one. With credit guarantees, incentives and interest subsidy, lending institutions can provide loans with low risk to previously disadvantaged agripreneurs. With a dedicated funding source, agripreneurs can try to innovate in the agriculture sector using new age technologies like IoT, AI etc.

Nabventures

An equity fund that invests in early to mid-stage companies in agriculture, food, rural businesses and agri/rural financial services. The fund invests in asset-light business models, innovation/technology, and solutions to big problems in agriculture, food and rural development through innovative means.

PM Formalization of Micro Food Processing Enterprises Scheme (PM FME Scheme)

The Ministry of Food Processing Industries (MoFPI), in collaboration with State UT Governments, has launched the All India Centrally Funded Prime Minister's Scheme for Micro Food Processing Enterprises (PMFME Scheme) to provide financial, technical and commercial support for the upgradation of existing micro food processing enterprises.

Major Sectors for Agritech stratups

Precision Agriculture

One of the key areas where agritech startups are making a significant impact is precision agriculture. Precision agriculture leads to more precise use of resources such as water, fertilizers, and pesticides, leading to increased efficiency and reduced environmental impact. This not only increases crop yields by up to 30% but also promotes sustainable agricultural practices, a key aspect in combating climate change.

Online markets

Focusing on providing farm inputs and agricultural equipment to farmers, they sell fertilizers, seeds, farm tools, and other inputs through online marketplaces and mobile apps. Many of these startups have created marketplaces that analyze crop-related problems and provide specific solutions.

Data-driven agricultural solutions

Many startups have started taking care of the final stage of distribution of products through technology and predicting the supply and demand of inputs based on AI and data-driven decisions. This data-driven approach helps farmers anticipate challenges, plan better, and ultimately improve their crop yields. For a country like India, where unpredictable weather often poses a threat to agriculture, such predictive capabilities are a game-changer.

Supply Chain Technology

Many farmers in India face challenges in reaching the right markets and getting a fair price for their produce. AgriTech startups have created platforms that connect farmers directly with buyers, cutting out middlemen and ensuring equitable distribution of profits. They achieve this through mobile and web-based applications. This not only increases farmers' income but also promotes transparency in the agricultural supply chain.

Machine-based quality management

In addition to all this, there has also been progress in the field of quality management, which uses machine-based image analytics to assess the quality of products. One of the most common examples of this is when someone orders their groceries online, some startups are using blockchain technology to provide end-to-end visibility so that they can know everything about the ordered items.

Conclusion

India's startup ecosystem has become dynamic and resilient, contributing significantly to economic growth, innovation, and employment. Supported by government initiatives and investor participation, it is now shifting towards sustainable and profitability-driven growth. Agritech startups, in particular, are transforming agriculture by improving productivity, supply chains, and farmer incomes through technology. Despite existing challenges, the ecosystem shows strong potential for future growth, especially in promoting inclusive and rural development.

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Volume: 06 Issue No: 04

KELP FORESTS AS CLIMATE STABILIZERS: BIODIVERSITY CONSERVATION & CARBON SEQUESTRATION

Article ID: AG-VO6-I04-139

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Abstract

Kelp forests, dominated by large brown algae of the order *Laminariales*, are among the most productive and ecologically significant marine ecosystems, occupying extensive coastal regions worldwide. These underwater forests provide critical ecosystem services, including habitat provision, shoreline protection, nutrient cycling, and substantial contributions to global fisheries and coastal economies. Structurally complex, kelp forests support high biodiversity and play a vital role in maintaining marine ecological balance. Importantly, they contribute to climate change mitigation through high rates of primary productivity and carbon sequestration. A significant proportion of kelp biomass is exported to deep-sea environments, where carbon can be stored long-term, enhancing the oceanic carbon sink. Additionally, kelp photosynthesis helps regulate seawater chemistry by reducing ocean acidification. Despite their importance, kelp forests are increasingly threatened by climate change, marine heatwaves, pollution, and overgrazing by herbivores such as sea urchins, leading to widespread ecosystem degradation. In response, various restoration strategies including transplantation, seeding, grazer control, and artificial reef deployment have been developed and implemented globally. Emerging approaches such as selective breeding and microbial enhancement offer promising future solutions. This study highlights the ecological, economic, and climatic importance of kelp forests and

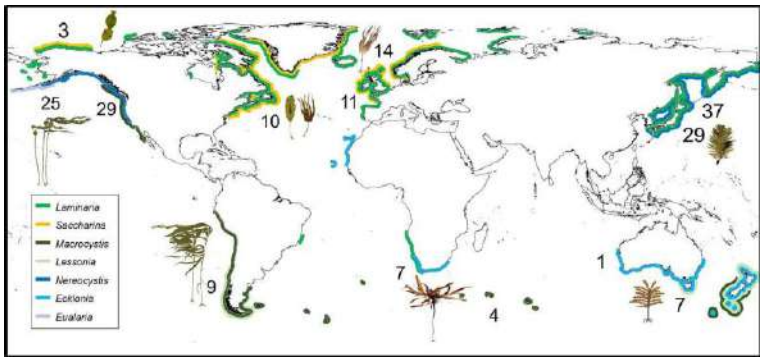
emphasizes the urgent need for conservation and restoration efforts to ensure their sustainability in a changing global environment.

Introduction

Kelp forests, often referred to as the "green lungs of the ocean," occupy nearly one-quarter of the world's coastlines. These ecosystems are dominated by large brown algae belonging to the order *Laminariales*, which function as key foundation species in marine environments. Kelp forests are among the most productive ecosystems globally, comparable to intensively managed agricultural lands and tropical rainforests in terms of primary productivity. Typically found at depths ranging from 0 to 50 meters, kelp forests form dense underwater canopies similar to terrestrial forests, consisting of both canopy and understory layers. These systems play a vital role in carbon cycling by absorbing and storing large amounts of carbon dioxide, ranking as the third most productive ecosystem worldwide. Economically, kelp forests contribute significantly, with an estimated global value of approximately US $684 billion annually through fisheries, tourism, and other ecosystem services. Kelp thrives under specific environmental conditions, including hard substrates such as rocks, sufficient light availability, and nutrient-rich waters, particularly those influenced by oceanic upwelling. Morphologically, kelp consists of three main parts: the holdfast (anchor), stipe (stem-like structure), and blade (photosynthetic organ). Some species also possess gas-filled structures called pneumatocysts, which provide buoyancy and enhance light capture.

Distribution

Kelp forests are predominantly distributed in temperate and polar coastal regions across the globe. Major genera include *Laminaria* (Atlantic and East Asia), *Ecklonia* (Australia, New Zealand, South Africa), and *Macrocystis* (Pacific and Southern Oceans). The northeastern Pacific Ocean, particularly from California to Alaska, exhibits the highest species diversity of kelp.



Life Cycle

Kelp exhibits a complex life cycle involving both sexual and asexual reproduction. The dominant stage is the sporophyte, which produces spores through specialized reproductive tissues known as sori. These spores settle and develop into microscopic gametophytes, which differentiate into male and female forms. Male gametophytes produce sperm, while female gametophytes produce eggs. Fertilization results in a diploid zygote, which develops into a juvenile sporophyte. This grows into a mature kelp plant, completing the life cycle.

Ecological and Economic Importance

Kelp forests provide numerous ecosystem services, including shoreline protection, nutrient cycling, and support for commercial fisheries. They serve as habitats for diverse marine organisms such as fish, lobsters, and abalone. Historically, kelp has played a significant role in human societies. It has been used as food in Asian countries for centuries and has applications in agriculture, medicine, and industry. Kelp-derived alginate is widely used in food processing, pharmaceuticals, and bioengineering. Additionally, kelp forests contribute to oxygen production and carbon dioxide removal, further emphasizing their ecological importance.

Role in Climate Change Mitigation

Kelp forests play a crucial role in mitigating climate change through carbon sequestration and regulation of ocean chemistry. Firstly, kelp exhibits rapid growth and high biomass production, contributing significantly to global carbon fixation. Although most kelp grows on rocky substrates where carbon storage is limited, a substantial portion (40–80%) detaches and is transported to deeper ocean environments, where it can be sequestered in sediments. Secondly, kelp photosynthesis reduces ocean acidification by absorbing dissolved inorganic carbon and increasing seawater pH. Carbon export occurs in two forms:

- Dissolved Organic Carbon (DOC)
- Particulate Organic Carbon (POC)

These forms contribute to the biological carbon pump, which transports carbon from surface waters to deeper ocean layers. Studies estimate that macroalgae sequester approximately 153 Tg of carbon annually in deep-sea sediments, surpassing traditional blue carbon ecosystems such as mangroves and seagrasses. Despite their potential, kelp forests alone cannot meet global carbon

reduction targets but can contribute significantly when combined with conservation and aquaculture strategies.

Threats to Kelp Forests

Kelp forests are currently declining worldwide due to both local and global stressors. Key threats include:

- Climate change and rising sea temperatures
- Marine heatwaves
- Pollution and sedimentation
- Overgrazing by sea urchins
- Overfishing of predator species

Elevated temperatures can exceed kelp's physiological tolerance limits, leading to population decline. Additionally, increased herbivory due to expanding sea urchin populations has resulted in the formation of "urchin barrens," where kelp forests are completely destroyed. These losses have significant ecological and economic consequences, including declines in fisheries and biodiversity.

Restoration of Kelp Forests

Efforts to restore kelp forests have been ongoing for over 300 years across multiple countries. Modern restoration initiatives involve governments, researchers, and local communities. Marine Protected Areas (MPAs) have proven effective in reducing human impacts and supporting ecosystem recovery. Global initiatives such as the United Nations Decade of Ecosystem Restoration (2021–2030) aim to enhance restoration efforts worldwide.

Restoration Methodologies

Transplantation

Kelp individuals are physically attached to substrates such as rocks or artificial structures. While effective, this method is labor-intensive and costly.

Seeding

This involves dispersing spores or juvenile stages into the environment. However, high mortality rates limit its success.

Grazer Control

Control of herbivores such as sea urchins is achieved through removal or exclusion techniques.

Artificial Reefs

Artificial substrates are introduced to promote kelp growth in areas lacking suitable natural habitats.

Future Restoration Strategies

Future approaches may include:

- Selective breeding of climate-resilient kelp strains
- Genetic conservation through seed banks
- Use of beneficial microbial associations
- Deployment of autonomous technologies for large-scale restoration

Effective management strategies must also address pollution, overfishing, and climate change to ensure long-term sustainability.

Conclusion

Kelp forests are highly productive and ecologically valuable marine ecosystems that provide essential services, including biodiversity support, carbon sequestration, and climate regulation. Despite facing significant threats, ongoing restoration efforts offer hope for their recovery. Given their critical role in mitigating climate change and supporting marine life, kelp forests should be recognized and managed as ecosystems of global importance.

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BANANA BASED BY- PRODUCT AS SUSTAINABLE RAW MATERIALS FOR BIODEGRADABLE PACKAGING

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Introduction

India generates nearly 9.46 million tonnes of plastic waste annually, of which about 3.78 million tonnes cannot be recycled or diverted from landfills, leading to severe environmental impacts. A major share of this non-recyclable waste consists of non-biodegradable single-use plastics used in food packaging (Nagarajan et al., 2022). Marine ecosystems are especially susceptible to plastic pollution, which poses significant risks to marine life and can ultimately enter the human food chain through bioaccumulation. Tackling these environmental challenges calls for a holistic approach to polymer/plastic production, use, and disposal, with a strong focus on sustainable alternatives and responsible waste management practices. Also rising environmental awareness among the public and regulatory authorities is driving the adoption of biodegradable and eco-friendly packaging materials.

Petrochemical-based, non-renewable materials are widely preferred in commercial food packaging industries; however, their extensive use generates large amounts of non-biodegradable waste, adversely affecting ecosystem health. This highlights the urgent need to develop technologies based on sustainable and renewable alternative resources (Nithya,2023). The banana plant is a

perennial monocotyledon, primarily cultivated for its fruit. Asia is the largest producer of bananas, and India leads with 33-35 million metric tonnes production annually. After harvesting its fruit, remaining parts often going to waste, and these parts are rich in cellulose, hemicelluloses and lignin. Banana pseudostem is a source of fiber, having limited application in the textile industry. The large volume of by products generated after banana harvest like pseudostem, peels, leaves, peduncle etc (figure 1) can be effectively utilized in the production of packaging materials, offering a sustainable approach for waste valorization and reduction.

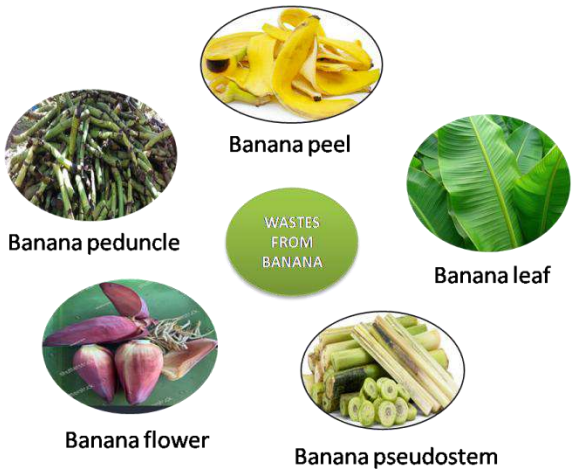

Figure 1. Type of by products from banana

Numerous researchers have extensively explored the development of packaging materials using lignocellulosic by-products derived from sources such as coconut, banana, sugarcane, jute, carrageenan, *Grewia optiva* flower biomass, orange fibers, corn fibers, hemp lignocellulosic nanowhiskers, abaca, sisal, pineapple, straw, and rice husk (Vinay2024). Utilizing lignocellulosic material from agricultural wastes for making packaging materials has several advantages.

Why Banana by products for Packaging?

It is rich in cellulose, hemicelluloses, lignin and natural fibers. The compositions of various by products materials are given in the table 1.

Table 1. Compositions

Sl. No.	Content	Value	Reference
Banana fiber			
1	Cellulose	50 – 60 %	Patil *et al*., 2024
2	Hemicellulose	25 – 30 %	
3	Lignin	12 – 18 %	
4	Pectin	3 – 5 %	
5	Fat and wax	3 – 5 %	
6	Moisture	10 – 11 %	Brahma *et al*., 2024
Banana pseudostem			

1	Cellulose	31.27 %	Vinay,et al., 2024
2	Hemicellulose	14.98 %	
3	Lignin	24 %	
Banana leaves			
1	Cellulose	26 %	Vinay, et al., 2024
2	Hemicellulose	17 %	
3	Lignin	24 %	

Types of Biodegradable Packaging from Banana by products

- **Banana fiber based packaging**

Fiber extracted from banana pseudostem exhibits good mechanical strength along with biodegradable properties, making it a promising material for sustainable applications. Banana pseudostem (BPS) contains approximately 31.27% cellulose and 14.98% hemicellulose, making it a suitable raw material for fiber extraction and its subsequent application in the packaging industry. Grease-proof paper, paper, film, laminates, nanocrystals and nanofiber can be made from banana fiber. Banana pseudostem cellulose extracted from fiber can be used for making packaging films (Vinay et al., 2024). Also, fiber mixed with banana peel wastes and plant starches or with other binding materials can develop into eco-friendly bio-composite sheets (figure 2). Fiber extracted from banana peduncle also used for making packaging materials.

Types of packaging materials produced from fiber

Figure 2. Biofilm production process (Sachcha et al., 2024 & Abera et al., 2024)

- **Paper and paperboards:** Used for wrapping, cartons, and carry bags
- **Molded pulp products:** Plates, trays, and cushioning materials
- **Biodegradable films:** Often blended with starch or other biopolymers

Composites: Reinforced packaging materials with improved strength

- **Banana Peel-Based Bioplastics**

Banana peel fiber or powder with suitable additives/binders like polyvinyl alcohol and glycerol can be developed into packaging materials. Banana peel and its extracts have been identified as a suitable filler to starch matrices to improve the properties of packaging material.

Types of packaging materials from peel:

- Starch extracted from peels can be utilized to produce bioplastic films.
- Pectin extracted from banana peels can be incorporated into food packaging materials to enhance film-forming ability and improve biodegradability.
- Banana peels can be utilized as a rich source of cellulose and nanocellulose for the development of wrapping papers

In addition to using starch and lignocellulosic components of banana peels for biodegradable packaging production, recent research has explored banana peel extracts (BPE) as functional additives in bioplastics to impart additional value-added properties (Jayasinghe et al., 2024).

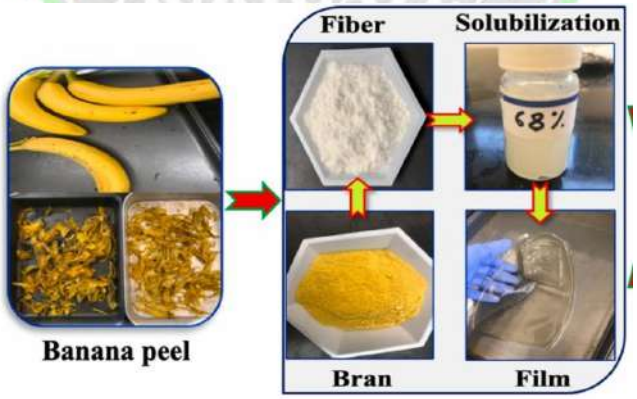

Figure 3. Biodegradable ackaging films from banana peel fiber (Hoque, et al., 2024)

- **Composite Materials**

Dried banana fibers, when combined with suitable binders such as natural rubber solution and chitosan solution, can be developed into banana fiber composites. These composites possess high tensile strength, low density, and biodegradable nature, making them suitable for use in automotive components (such as panels and dashboards), construction materials (including

roofing and doors), and various consumer products. They are often combined with other natural fibers, such as jute, or reinforcing particles like nanoclay to further enhance their mechanical strength and performance properties.

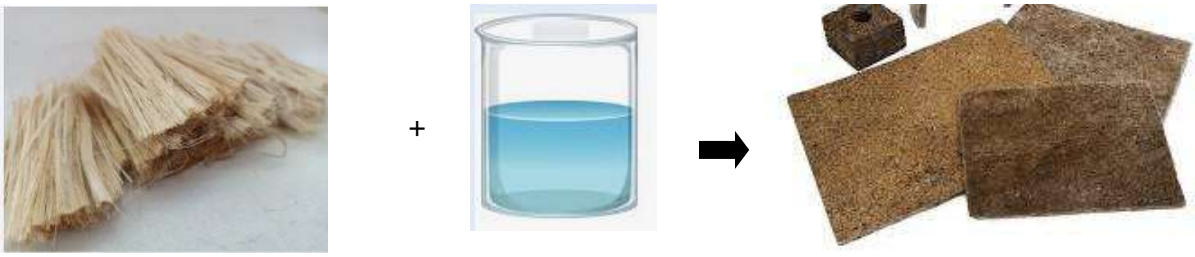

Figure 4. Banana leaves as packaging materials

Banana leaves are commonly used as a packaging material in most tropical and subtropical countries (Figure 4) . Their large surface area, flexibility, and waxy coating make them suitable for various packaging applications. Key applications (Figure 5) are given below

- **Food wrapping:** Used to wrap rice, snacks, sweets, and street foods, providing a natural barrier and enhancing aroma.
- **Plates and containers:** Leaves are shaped into plates, bowls, or cups for serving and packaging food.
- **Takeaway packaging:** Increasingly used as an eco-friendly alternative to plastic wraps and containers.
- **Lining material:** Used as a lining in boxes or trays to prevent direct contact and improve hygiene.
- **Steam cooking wraps:** Commonly used for steaming foods, helping retain moisture and flavor.

Figure 5. Key applications of banana leaves

Environmental and Economic Benefits

- Reduction in plastic waste
- Biodegradable and compostable
- Waste valorization
- Additional income for farmers
- Lower carbon footprint
- Supports circular economy

Challenges and limitations

Banana-based packaging materials are highly moisture-sensitive, which can weaken their structure and reduce durability, particularly under humid conditions. They also exhibit lower strength and flexibility compared to conventional plastics. Although eco-friendly, their production costs are relatively higher. Additionally, large-scale production remains challenging due to the need for advanced processing infrastructure.

Conclusion

The demand for sustainable and eco-friendly packaging materials is rapidly increasing across both industrial and domestic sectors worldwide. Banana cultivation, widely practiced in tropical and subtropical regions, generates large quantities of by products such as leaves, pseudostems, and peels, which have significant potential for use in food packaging applications. Despite certain limitations, it has strong potential to become a game-changer in sustainable packaging by reducing environmental pollution and promoting circular economy practices. To fully realize this potential, collaboration among researchers and industries is essential for developing scalable, efficient, and standardized solutions.

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BREEDING FOR DISEASE RESISTANCE IN DAIRY ANIMALS: A SUSTAINABLE APPROACH FOR HEALTHY MILK PRODUCTION

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Introduction

Dairy farming is one of the most important agricultural activities supporting rural livelihoods and food security in India. Healthy dairy animals are essential for consistent milk production, improved fertility and better farm income. However, infectious and metabolic diseases continue to pose a major challenge to dairy farmers, leading to economic losses and reduced productivity. In this context, breeding for disease resistance in dairy animals has emerged as a sustainable and long-term solution to improve herd health and milk production.

The Need for Disease-Resistant Dairy Animals

Diseases such as mastitis, foot-and-mouth disease, bovine tuberculosis, parasitic infections, and metabolic disorders significantly reduce milk yield and reproductive efficiency. Farmers often spend large amounts on veterinary treatment, medicines, and preventive care. Frequent disease outbreaks not only increase production costs but also reduce animal lifespan and profitability.

Developing dairy animals that naturally resist diseases can reduce dependence on antibiotics and veterinary interventions. Disease-resistant animals remain healthier, produce more milk, and require less medical care, making dairy farming more profitable and environmentally sustainable.

Understanding Disease Resistance

Disease resistance refers to the ability of an animal to prevent infection or reduce the severity of disease. It is mainly controlled by the animal's immune system and genetic makeup.

Some animals naturally possess stronger immunity and better adaptability to environmental stress.

Scientists generally classify disease resistance into three types:

- **Resistance** – ability to prevent infection
- **Tolerance** – ability to withstand disease effects
- **Resilience** – ability to recover quickly after infection

These characteristics help animals maintain productivity even under disease pressure and challenging environmental conditions.

Major Diseases Targeted in Dairy Breeding

Breeding programs in dairy cattle mainly focus on economically important diseases that affect milk production and animal health. Among these, mastitis is considered the most important disease because it directly affects milk quality and quantity. Selection for low somatic cell count and good udder health is widely practiced to improve mastitis resistance.

Other important diseases targeted in breeding programs include:

- Foot and Mouth Disease (FMD)
- Bovine Tuberculosis
- Paratuberculosis (Johne's disease)
- Gastrointestinal parasitic infections
- Metabolic disorders like ketosis and milk fever

Improving resistance to these diseases helps maintain herd health and reduce economic losses.

Methods of Breeding for Disease Resistance

Traditional Selection

Traditionally, farmers selected animals based on their health and performance. Healthy animals with good milk yield, strong body condition, and low disease incidence were chosen for breeding. Although this method is simple and practical, it takes a long time to achieve significant improvement.

Genetic Selection

Modern breeding programs use pedigree and performance records to identify animals with better immunity and disease resistance. Scientists have discovered that certain genes play an important role in immune response, particularly in the **major histocompatibility complex (MHC)** region, which helps animals fight infections. By selecting animals with favorable

immune-related genes, breeders can gradually improve disease resistance in dairy herds.

Genomic Selection

Genomic selection is a recent advancement in dairy cattle breeding. It uses DNA markers to identify disease-resistant animals at an early age, even before they start producing milk. This method increases selection accuracy and reduces the time required to improve herd health.

Genomic tools help in:

- Early identification of superior animals
- Improved disease resistance
- Better milk production
- Reduced breeding cost in the long term

This technology is now being adopted in many advanced dairy breeding programs worldwide.

Molecular and Modern Technologies

Recent developments in biotechnology, including genome editing and molecular breeding, offer new opportunities to develop disease-resistant animals. Technologies like CRISPR and gene-based selection can improve immune response and resistance to specific diseases.

Although these technologies are still under development, they hold great promise for the future of dairy farming.

Benefits to Dairy Farmers

Breeding for disease resistance offers several advantages to farmers and the dairy industry:

- Reduced disease incidence
- Lower veterinary and treatment costs
- Increased milk yield and quality
- Improved fertility and reproduction
- Reduced antibiotic usage
- Better animal welfare
- Higher farm profitability
- Sustainable dairy production

Healthy animals require less management effort and provide stable income to farmers, making dairy farming more reliable and efficient.

Challenges in Implementation

Despite its benefits, breeding for disease resistance faces certain challenges:

- Disease traits are complex and controlled by many genes
- Lack of proper disease recording in farms
- Environmental influence on immunity
- High cost of genomic technologies
- Limited awareness among farmers

To overcome these challenges, proper data recording, farmer training, and government support are essential.

Future Prospects

The future of disease resistance breeding in dairy animals is promising. Integration of genomics, epigenetics, and artificial intelligence will help develop highly resilient dairy cattle. Indigenous breeds such as Sahiwal, Gir, and Tharparkar already show strong natural disease resistance and can be utilized in breeding programs.

With continued research and technological advancement, disease-resistant dairy animals can ensure sustainable milk production, improved farmer income, and better animal health.

Conclusion

Breeding for disease resistance is a practical and sustainable approach to improve dairy animal health and productivity. By combining traditional selection methods with modern genomic and molecular technologies, the dairy sector can develop healthier and more productive animals. This will reduce disease burden, increase milk production, and strengthen the rural economy.

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TRANSFORMING COMMERCIAL HORTICULTURE THROUGH PROTECTED CULTIVATION: A STRATEGIC INTERVENTION BY THE NATIONAL HORTICULTURE BOARD

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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 and Farmers Welfare. It is registered as a society under the Societies Registration Act, with its headquarters in Gurugram. At present, NHB has 29 field offices located across the country. **The present Managing Director of NHB is Shri. Kapil Meena, IAS.**

Shri Kapil Meena, IAS.

The Board's key objectives include the development of production clusters and hubs for integrated hi-tech commercial horticulture, promotion of post-harvest management and cold chain infrastructure, ensuring the availability of quality planting material, and encouraging the adoption of modern technologies, tools, and techniques. NHB also promotes the establishment of projects under protected cultivation (such as playhouses and net houses) on a project-based approach. Its vision is to develop hi-tech commercial horticulture in identified regions, transforming them into vibrant hubs of horticultural activity that drive overall sectoral growth.Activities:- Projects under protected cover on project mode including components viz planting material, plantation, irrigation, fertigation, mechanization, etc for projects having area over 4000 sq metre.

NHB Assisted Project Protected Cultivation photos

Crops eligible:

a. Flowers:

Name of the Flower crop	**Project Cost Rs lakh/ 4000 sq mtre**
Anthurium	80.00
Orchids	80.00
Gerbera.	75.00
Carnation	75.00
Rose	70.00
Lilium	70.00
Chrysanthemum	70.00

b. Vegetables: (High value vegetables)

Name of the Vegetable crop	Project Cost Rs lakh/ 4000 sq mtre
Coloured Capsicum	55.00
Tomato	55.00
Cucumber.	55.00

Pattern of assistance: Credit linked back-ended subsidy @ 50% of the total project cost limited to Rs 100.00 lakh per project as per admissible cost norms for green houses, shade net house, plastic tunnel, anti-bird /hail nets & cost of planting material etc.

Norms for Technology Add on components and other essential components of Integrated Commercial Horticulture project

S. No	. Item	Description	Admissible Cost Revised
1	Cost of Land*#	Admissible only if purchased newly but not before one year from date of sanction of loan.	Actual or up to 10 % of Eligible Project Cost (EPC) (Excluding cost of Land and Development) whichever is less subject to m
2	Land Development*#	Includes cost of Land leveling, digging of pits, fencing, gates etc.	Actual or up to 15% of Eligible Project Cost (EPC) (Excluding cost of Land and Land Development) whichever is less subject to maximum of Rs. 60,000/- per acre.
3	I Cultivation	Includes cost of Planting	As per MIDH (NHM) cost

	expenses*#	material, cost of input (labour, fertilizer and manures, pesticides etc).	norms on prorata basis.
4	Irrigation infrastructure excluding micro irrigation * #	Irrigation infrastructure like tubewell/bore well/open well, pipeline, water harvesting structure, water tank etc, admissible only if newly created with loan component.	Actual or upto Rs.60,000/- per acre for open field cultivation. Rs.4.80 lakh per project in case of protected cultivation. Component–wise cost norms will be as under: Tube-well – up to Rs. 3.00 lakh per unit Water harvesting structure- @ Rs.100/- CuM with use of minimum 300 microns plastic films or RCC lining. Cost of non lined ponds/tanks will be 30% less. Pipe line-Rs 150/- per running meter only from source (min. 4" diameter) of irrigation to production unit
5	Civil Infrastructure * #	Includes Functional Pack House/ On farm collection unit and labour quarter.	1. Functional Pack house @ Rs. 4.80 Lakh/unit with size of 9 x 6 Meter (Prorate basis for lower size) as per NCCD guideline. 2. Labour Quarter/Storeroom @ Rs. 24,000/- per acre maximum up to 3.60lakh.

6	Vermi Compost unit * #	Permanent structure and HDPE vermibed.	Rs.72,000/-per unit for permanent structure and Rs.12,000/-for HDPE vermibed 96cft (12'x4'x2') and ISO 15907:2010
7	Bed Preparation Cost in the cases requiring Soil replacement #	Protected Cultivation projects only in cases involving removal and replacement of top soil by red soil or cultivation is done on media/ Pots/Concrete bed.	Rs.120/-per Sq. m.
8	Cost of Poly house with drip & fogger system #	Protected Cultivation (as per NHB specification)	@ Rs 1000/ Sq Mtr
9	Horticulture Mechanization* # ##	Power/hydraulic operated machine/ tools including small farms tractor with Rotavator/equipment's etc. Machineries Identified by NHB under farm mechanization component may be considered for subsidy in standalone mode	As per SMAM Norms
	#Protected Cultivation, within overall cost ceiling ## Over and above overall cost ceiling		

Rose

Gerbera **Cucumber**

Coloured Capsicum **Gerbera**

Revision in the scheme guidelines of NHB, including its implementation design, documentation and sanctioning process

The scheme guidelines of NHB including its implementation design, documentation and sanctioning process etc. have further been reviewed and with the approval of competent authority, it has been decided to effect major changes w.e.f. 01.01.2023. NHB will do away with two stage system of IPA and GoC. Now IPA will not be needed for availing benefit under the Scheme of NHB and applicant will apply straightaway for Grant of Clearance (GoC) to NHB after sanction of term loan by bank. The term loan sanctioned within 3 months from the date of online GoC application to NHB shall be treated valid, however, disbursement of term loan and

start of project will be allowed only after issuance of GoC by NHB. GoC will be valid for 3 months for getting disbursement of first instalment of term loan and start of project. Accordingly, the applications in NHB will be dealt in the following manner

1. IPA system will be discontinued from 15.03.2023 and thereafter NHB shall accept applications only for Grant of Clearance with required documents. IPA/GoC applications received prior to the same will be considered as per existing system.
2. The processing of GoC application will be completely digital, including examination and sanctioning. The platform will be augmented with the timeline monitoring systems, so that every step can be monitored as per the pre-set target timelines and alerts can be sent to the processing officer/applicant at regular intervals and escalation matrix can be put in place based on ageing analysis of pendency at officer level.
3. Before making a new GoC Application online on the Web-Portal of NHB, the applicant will have to register after Aadhar authentication through OTP verification. Applicant will be given an option at NHB portal and in case loan for the proposed project is sanctioned under Agri-Infra Fund (AIF) Scheme, the entire loan data of the applicant will be captured as such from AIF portal through API and only remaining details would be required to be filled in by the applicant online and saved at NHB Portal to complete the GoC application of NHB. In case loan is not sanctioned under AIF, the complete application form will have to filled up by the applicant.
4. NHB has prescribed a new short template for DPR and Bank appraisal note (Annexure-I). The template is indicative, and applicant/bank must ensure that the components mentioned in the template are invariably included in DPR or appraisal note.
5. The applicant will have to submit following documents along with the application for grant of clearance: - a. Details Project Report (DPR) and the information suggested in the NHB's prescribed template will only be mandatory. b. Project Land Document along with non-encumbrance certificate c. Bank Sanction letter d. Bank Appraisal Note e. Undertaking (will be part of Application Form in the prescribed format)
6. After application is submitted, an email will be sent to the applicant along with a reply/confirmation link to the financing bank. Concerned bank need to confirm the

authenticity of documents online. Based on the confirmation of documents, e.g. bank sanction letter, appraisal note and land documents etc., NHB will issue GoC.

7. Queries on GoC applications, if any, will be communicated to the applicant Bank automatically by system/email by the concerned division within 15 days from the date of receipt of hard copy of the application/documents/bank documents and get the reply from applicant/bank within 15 days and place the application to the approving authority for decision. GoC will be issued by NHB within a period of two months positively.
8. Subsidy claim documents will also be submitted by bank/applicant online.
9. NHB shall be timely relying upon financing banks for the examination of project documents.

For more details, visit www.nhb.gov.in

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HOW FOUNDERS' THINKING SHAPES AGRIBUSINESS SUCCESS?

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Abstract

This article examines how the thinking patterns of founders influence the success of agribusiness startups. While factors such as capital, infrastructure and market conditions are often emphasized, the role of decision-making remains less visible but equally important. The article explains how founders interpret information, assess risks and respond to changing market signals, ultimately shaping business outcomes. It highlights common thinking patterns such as reliance on past experience, overestimation of product potential, excessive caution and limited attention to consumer trends. Drawing from the agribusiness context, the discussion shows how similar market conditions can lead to different results based on how founders think and act. The article concludes by emphasizing the need for adaptive and informed decision-making in a rapidly evolving agricultural sector.

Keywords: Agribusiness startups, Managerial cognition, Entrepreneurial decision-making, Founder behaviour

Introduction

Why do some agribusiness startups grow steadily while others struggle, even when they operate in the same region and handle similar products? Success is often linked to visible factors such as capital, weather, or market fluctuations. While these certainly play a role, they do not fully explain why outcomes differ so widely. A less obvious but powerful factor is how founders think and make decisions. In agribusiness, where uncertainty is constant and information is

rarely complete, a founder's interpretation of situations can shape results in meaningful ways. Two entrepreneurs may face identical conditions yet move in completely different directions, not because of resources but because of how they read and respond to those conditions. This article examines how such thinking patterns influence the path of agribusiness startups and why they deserve more attention.

Understanding Thinking Patterns in Simple Terms

In management, the way decision makers process and interpret information is often described as managerial cognition. Put simply, it refers to how founders recognize opportunities, evaluate risks and decide on actions. Agribusiness decisions are rarely straightforward. Founders must deal with fluctuating prices, production uncertainties, supply chain issues and evolving consumer demands. In such situations, choices are shaped not just by data but also by experience, assumptions and personal judgment. These underlying thought processes influence what founders pay attention to, what they overlook and how they act.

Common Thinking Patterns in Agribusiness Startups

1. Reliance on Past Experience

Many founders draw heavily from farming or trading experience. While this provides a strong base, it can also restrict new thinking. Methods that worked earlier may not always suit current market realities. For example, depending entirely on local mandi channels may limit growth when urban consumers are increasingly looking for branded or value added products. Founders who are willing to rethink traditional approaches often uncover new market opportunities.

2. Overestimating Product Potential

Another common tendency is the belief that a good or healthy product will naturally attract buyers. This assumption can lead to scaling operations too quickly without proper market validation. A startup producing millet based snacks may invest heavily in production capacity expecting rapid demand growth. Without a clear understanding of consumer preferences, pricing limits or distribution challenges, this can lead to financial strain. A more effective approach is to test demand on a smaller scale before expanding.

3. Excessive Caution

Some founders take the opposite approach and become overly cautious. They hesitate to explore new channels such as online platforms, direct to consumer models or institutional sales.

While caution helps avoid immediate risks, too much hesitation can result in lost opportunities. In a dynamic market, waiting for complete clarity often means entering too late.

4. Limited Attention to Market Signals

In some cases, founders focus strongly on production efficiency while paying less attention to consumer trends. This creates a gap between what is produced and what the market actually wants. With increasing demand for low sugar, organic or chemical free products, startups that respond to these shifts are better positioned than those that continue with undifferentiated bulk sales.

Real World Relevance in Agribusiness

These patterns are not abstract. They are visible across many agribusiness models. Consider two ventures dealing with traditional rice. One continues bulk sales through intermediaries. The other invests in branding, smaller packaging and direct marketing to urban consumers. Over time, the second venture is likely to achieve better margins and stronger customer relationships. The difference lies not in resources but in how the founders approached the same opportunity.

Why This Matters Today

Agribusiness is changing rapidly. Consumers are increasingly focused on health, quality and traceability. Digital platforms are creating new market access points while competition continues to intensify. In this environment, relying only on traditional methods is no longer sufficient. Founders must continuously interpret new information and adjust their strategies. The ability to question assumptions, identify emerging trends and act in time has become a key advantage. Those who remain rigid in their thinking may struggle to sustain growth.

Practical Takeaways for Founders

Although external challenges cannot be fully controlled, founders can improve how they approach decisions:

- **Test before scaling** Validate demand before making large investments
- **Understand the end consumer** Look beyond intermediaries to actual buyer preferences
- **Explore new channels** Use digital platforms and direct sales opportunities
- **Revisit assumptions** Regularly question beliefs about pricing and demand
- **Blend experience with new insights** Combine traditional knowledge with evolving trends

These steps support more adaptive and informed decision making.

Conclusion

Agribusiness success is often explained through visible factors such as capital and infrastructure. However, an equally important influence operates beneath the surface. The way founders think plays a critical role. Thinking patterns shape how opportunities are identified, how risks are managed and how strategies are executed. In a sector defined by uncertainty, this internal process becomes a key driver of outcomes. As agribusiness continues to evolve, founders who develop flexible and responsive ways of thinking will be better positioned to navigate challenges and build sustainable enterprises.

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LEVERAGING SOCIAL MEDIA FOR AGRICULTURAL OUTREACH ACTIVITIES

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Abstract

Social media has become an important tool for communication in the agricultural sector. Farmers need timely information regarding crop production, plant protection, weather conditions, market trends and government support programmes. In many areas, conventional extension methods alone are not sufficient to reach all farmers quickly. Social media platforms provide an opportunity to share knowledge with a large audience in a short time. These tools help strengthen communication between farmers, scientists, extension personnel and institutions. The present article discusses the use of social media in agricultural outreach activities, commonly used platforms, their benefits and existing challenges.

Keywords: Social Media, Agricultural Extension, Farmers, Communication and crop production

Introduction

Agriculture is one of the major sectors supporting the economy and rural livelihoods in India. Farmers regularly require updated knowledge on improved cultivation practices, pest and disease management, livestock care, weather changes, market opportunities, and government welfare schemes. Agricultural extension services play an important role in transferring such knowledge from research institutions to the farming community. Traditionally, this information has been delivered through farm visits, field demonstrations, meetings, training programmes, and printed materials. Although these approaches remain valuable, they often face limitations in

reaching a large number of farmers within a short period. (Bhattacharjee, S and Saravanan, R.(2016).

Rapid growth in digital technology has opened new possibilities for agricultural communication. According to the Telecom Regulatory Authority of India (TRAI) Annual Report 2023–24, India recorded more than 969 million internet subscribers, reflecting significant expansion of digital access across both rural and urban areas. Increased smartphone usage and internet availability have encouraged farmers to use online platforms for information and communication. (TRAI Annual Report 2023–24)

As a result, social media platforms such as WhatsApp, Facebook, YouTube, Instagram and X are now widely used to share agricultural advisories, weather forecasts, pest alerts, training materials, market information and success stories. These platforms enable faster interaction between farmers and experts. Therefore, leveraging social media has become an effective and practical approach for agricultural outreach activities in the present era.

Social Media

Social Media has been defined as websites which allow profile creation and visibility of relationships between users (Boyd & Ellison, 2008); web-based applications which provide functionality for sharing, relationships, group conversation and profiles. (Kietzmann et al., 2011).

Social media refers to internet-based platforms that allow people to create exchange and discuss information in digital form. Users can communicate through written messages, photographs, audio clips, videos and live interactions. Unlike one-way communication methods, social media supports active participation and two-way discussion among users.

In the agricultural sector, social media has become useful for spreading awareness, sharing technical knowledge, promoting innovations and connecting farmers with extension agencies and markets. It has created a simple and convenient medium for information exchange.

Table 1 : Types of Social Media Platforms Used in Agriculture

Type of Platform	Examples	Major Use
Social Networking Sites	Facebook, Instagram	Community interaction, awareness creation, farmer networking, sharing success stories, promotion of agricultural products

Messaging Platforms	WhatsApp, Telegram	Instant advisory services, pest alerts, weather updates, market price sharing, group discussions with farmers
Video Sharing Platforms	YouTube	Demonstration of farming practices, online training, machinery handling guidance, organic farming education
Microblogging Sites	Twitter	News updates, government announcements, policy information, market trends, weather alerts
Blogs and Websites	WordPress, Agri Portals	Detailed technical guidance, research information, crop production practices, downloadable learning materials

Use of Popular Social Media Tools in Agricultural Outreach

In recent years, social media has become increasingly important in the agriculture sector with major platforms like Facebook, Twitter and YouTube being widely used for farming & extension related activities. Additionally, WhatsApp has emerged as a popular tool for extension networks to communicate & interact with farmers, experts & farmers.

Facebook

Facebook is widely used by agricultural organisations, universities, farmer groups and extension centres. Through pages and groups, information related to training programmes, awareness campaigns, success stories, new technologies and government schemes can be shared with many users at once. It also helps build online farming communities where farmers can interact with each other.

WhatsApp

WhatsApp has become one of the most practical communication tools in rural areas because it is simple to use on mobile phones. Extension workers create groups to send advisory messages, pest warnings, weather forecasts, and market price details. Farmers can also share field photographs and receive expert guidance immediately.

YouTube

YouTube provides an effective method of visual learning. Farmers can watch instructional videos related to seed treatment, nursery management, organic farming, compost preparation, irrigation systems, livestock care and machinery handling. Practical demonstrations through video are often easier to understand than written instructions.

Instagram

Instagram is useful for sharing photographs and short videos related to innovative farming methods, protected cultivation, organic products and successful farm enterprises. It is also useful for promoting agricultural products and agribusiness ventures.

Twitter

Twitter is commonly used by institutions, departments and experts to publish quick updates regarding policies, market trends, weather alerts and public announcements. It enables rapid communication with a broad audience.

Advantages of Social Media in Agricultural Extension

- Enables rapid sharing of agricultural information.
- Reduces communication and extension delivery cost.
- Reaches farmers in different locations at the same time.
- Photos and videos improve learning and practical understanding.
- Farmers can directly contact experts and get quick solutions.
- Helps share successful farming experiences among communities.
- Encourages farmers to adopt modern technologies and innovations.
- Useful during emergencies such as pest attacks, floods and droughts.

Challenges in Using Social Media

- Internet connectivity is poor in some remote rural areas.
- Not all farmers have smartphones or digital devices.
- Some farmers have limited digital knowledge and skills.
- False or misleading information may spread quickly online.
- Language barriers can reduce proper understanding.
- Local language content is not always available.
- Dependence on mobile data may create access problems.
- Proper guidance and information verification are necessary.

Conclusion

Social media has significantly changed the way agricultural information is communicated. It offers a fast, low-cost, and interactive method for connecting farmers with scientists, extension officers, institutions and markets. Platforms such as WhatsApp, Facebook, YouTube, Instagram and Twitter have become valuable tools for training, awareness creation,

advisory services, and market linkage. With better digital literacy, reliable internet facilities and responsible use of information, social media can further strengthen agricultural outreach activities and support sustainable rural development.

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CLOSING THE GAP IN RURAL DEVELOPMENT: WHAT PROJECT MANAGEMENT CAN DO BETTER

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Abstract

Rural development projects play a crucial role in improving livelihoods, reducing poverty, and promoting inclusive growth. However, many such initiatives fail to achieve their intended objectives due to persistent challenges such as inadequate planning, weak coordination among stakeholders, inefficient resource utilization, and limited monitoring mechanisms. This article examines the underlying reasons why rural development projects often miss the mark and highlights the gaps in traditional implementation approaches. Drawing on insights from project management principles, the paper argues that the integration of structured techniques such as systematic planning, scheduling, risk management, and performance monitoring can significantly enhance project efficiency and effectiveness.The discussion emphasizes the importance of incorporating project management specialists alongside Subject Matter Specialists (SMS) to ensure better coordination, accountability, and outcome-oriented execution. By aligning technical expertise with managerial discipline, rural development initiatives can achieve improved transparency, timely completion, and measurable impact. The article concludes that adopting project management frameworks and tools is essential for strengthening the design and delivery of rural development projects, ultimately leading to more sustainable and scalable outcomes.

Keywords: Gap, Project Management, Rural development, SMS.

Introduction

Walk through any rural district in a developing country and you'll find the ruins of good

intentions: half-built market stalls, irrigation channels that never carried water, agricultural training centers that trained no one (Institute of Civil Engineers and Development Consultants, 2025)

The problem isn't a shortage of funding or goodwill. It's a shortage of project management discipline the structured application of tools, techniques, and principles that turn ambitious plans into tangible results (AgEcon Search, 2024)

The Gap Between Plans and Reality

Rural development and agricultural extension projects face a unique set of challenges. They operate in remote locations with poor infrastructure, engage communities that have often been burned by failed interventions before, and must navigate complex webs of local politics, cultural norms, and seasonal cycles. A project that works in one village may fail spectacularly in the next.

Yet many of these projects are still designed in distant offices, managed by staff with no formal training in project management, and implemented without clear timelines, budgets, or accountability structures. The result is predictable: cost overruns, missed deadlines, scope creep, and communities left worse off than before.

What Professional Project Management Brings to the Table

Project management isn't just about Gantt charts and spreadsheets. At its core, it's a systematic way of thinking about how to move from where you are to where you want to be while managing uncertainty, resources, and stakeholders along the way.

1. Clear Scope Definition Preventing "Mission Drift"

One of the most common failures in social sector projects is scope creep the gradual expansion of a project's objectives beyond what was originally planned. A water supply project becomes a sanitation project becomes a community health project becomes... nothing, because resources are spread too thin.

Work Breakdown Structures (WBS) force project teams to define exactly what they will and won't deliver. Every activity is mapped, every deliverable specified. This doesn't mean projects can't adapt but changes happen through a formal change control process, not through informal conversations that nobody documents.

2. Realistic Scheduling Respecting Agricultural Cycles

Agricultural extension projects that ignore planting and harvest seasons are doomed

before they begin. Farmers won't attend training during peak labor periods. Inputs delivered after the planting window are useless.

Network diagrams (Critical Path Method and PERT) help project managers visualize task dependencies and identify which activities must happen in sequence. A Gantt chart overlaid on an agricultural calendar immediately reveals scheduling conflicts that would otherwise surface too late to fix.

3. Stakeholder Mapping Knowing Who Matters

Rural development projects involve a dizzying array of stakeholders: farmers, local leaders, government extension officers, NGOs, input suppliers, credit institutions, and sometimes competing development agencies. Each has different interests, influence, and expectations.

Stakeholder analysis matrices help project managers identify who needs to be consulted, who needs to be kept informed, and who has the power to derail the project if ignored. This isn't cynical politics it's pragmatic planning that prevents costly conflicts later.

4. Risk Management Planning for What Goes Wrong

Droughts happen. Pest outbreaks happen. Political changes happen. The question isn't whether projects will face unexpected challenges, but whether they're prepared for them.

Risk registers document potential threats, estimate their likelihood and impact, and assign responsibility for mitigation actions. A project that has already thought through what it will do if the rainy season fails, or if a key government partner is transferred, can respond quickly instead of scrambling. (Anabela Tereso et al., 2019)

5. Monitoring and Evaluation Learning What Works

The social sector has historically been better at measuring activities (trainings held, inputs distributed) than outcomes (yields increased, incomes improved). Project management frameworks demand both.

Earned Value Management (EVM) tracks whether a project is on schedule and on budget relative to what it has actually accomplished not just what it has spent. Logical frameworks (log frames) link inputs to activities to outputs to outcomes, making it clear what assumptions must hold for the project to succeed. (David Baccarini, 1999)

Participatory Approaches and Project Management: Not Enemies

A common objection is that formal project management is incompatible with participatory development that it imposes rigid, top-down structures on communities who

should be driving their own development.

This is a false dichotomy. Participatory Rural Appraisal (PRA) and Rapid Rural Appraisal (RRA) the gold standards for community engagement can be integrated directly into project management frameworks. PRA tools like community mapping, wealth ranking, and seasonal calendars generate the data needed for realistic planning. Community members can participate in developing the Work Breakdown Structure, identifying risks, and monitoring progress (Riley & Fielding, 2001).

The Skills Gap And How to Close It

The uncomfortable truth is that most rural development projects are managed by subject matter experts agronomists, veterinarians, social workers who have never been trained in project management. The involvement of a project management specialist, working in coordination with Subject Matter Specialists (SMS), can enhance efficiency and lead to more effective and timely achievement of project goals.

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FROM FIELDS TO FEEDS: HOW AI, SOCIAL MEDIA, AND AGRISTACK ARE TRANSFORMING AGRICULTURE IN RURAL INDIA

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Abstract

Agriculture remains a cornerstone of India's economy, yet challenges such as shrinking landholdings, labour constraints, and increasing food demand necessitate a transition toward technology-driven approaches. This paper examines the evolution of agricultural extension from conventional face-to-face systems (Extension 1.0) to advanced, digital, and artificial intelligence (AI)-enabled models (Extension 4.0). The integration of social media platforms, AI technologies, and digital infrastructures such as AgriStack and Bharat-VISTAAR has transformed extension into a participatory, real-time, and farmer-centric knowledge system. Social media facilitates rapid information dissemination, peer-to-peer learning, and community engagement, while the emergence of agri-influencers has fostered a trust-based knowledge economy grounded in authenticity and experiential learning. AI-driven tools enhance decision-making by providing timely insights on weather forecasting, crop management, pest surveillance, and market trends. Initiatives such as Bhashini further bridge linguistic and digital divides, improving accessibility and inclusivity in advisory services. However, challenges including misinformation (infodemics) and digital fatigue remain critical concerns. The study concludes that the future of agricultural extension lies in integrating digital innovation with inclusive, collaborative knowledge networks, where farmers actively participate as both knowledge users and co-creators.

Keywords: Agri Stack, Artificial Intelligence, Digital Agricultural Extension, Social Media

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 (Akter et al, 2026). India's agricultural extension system is being transformed through the integration of artificial intelligence, social media, and digital infrastructures like AgriStack. The adoption of social media in agriculture has significantly changed the way farmers, academics, and policymakers communicate and share knowledge (Priya et al., 2022). As digital technologies such as artificial intelligence (AI), machine learning (ML), and robots have transformed agricultural techniques, social media platforms have emerged as key hubs for information exchange and collaborative efforts (Prusty et al., 2025).

The role of social media in agriculture is particularly significant concerning the dissemination of real-time information such as weather forecasts, crop management techniques, pest control strategies, and market trends (Mounika et al., 2025; Peddi et al., 2025). Farmers can also get updates in real time, which can improve farmers'better decision-making capacities (Mounika et al., 2025). Simultaneously, social media platforms such as WhatsApp and YouTube have emerged as important channels for peer-to-peer learning, knowledge exchange, and community engagement. These platforms allow farmers not only to access expert information but also to share experiences, raise queries, and collaboratively innovate (Sahoo et al., 2024). Researchers and institutions have also used social media to work together on research projects that cross borders in order to promote technological advances in agriculture (Periginji, 2025; Saha et al., 2025). This transformation is further reinforced by a shift from fragmentary advisory mobile applications and toward an integrated digital ecosystem based on Digital Public Infrastructure (DPI).

The Union Budget 2026-27 allocated over ₹150 crore to scale Bharat-VISTAAR, an AI-driven extension platform that integrates with AgriStack, the national digital database of farmers, land records, and agricultural information (NITI Aayog, 2025). AgriStack aims to link farmer databases with service providers to improve service delivery efficiency, transparency, and targeting (NITI Aayog, 2021). This evolving ecosystem represents a significant shift away from traditional top-down extension approaches toward a more participatory, inclusive, and farmer-centric digital knowledge system in India (Meena et al., 2025).

Evolution of Extension

The agricultural extension system in India has evolved through multiple stages in response to technological progress and changing farmer needs. Extension 1.0 was characterized by field visits and in-person demonstrations, where extension workers directly interacted with farmers. This phase relied heavily on face-to-face communication and practical demonstrations to transfer knowledge. Extension 2.0 marked the introduction of mass media tools, including radio, television, and printed bulletins. These platforms enabled wider dissemination of agricultural information, although communication largely remained one-way. With the expansion of mobile connectivity and internet access, Extension 3.0 emerged, focusing on digital advisory services and mobile applications (Periginji et al., 2025). This phase improved the speed and accessibility of information delivery, allowing farmers to receive timely guidance. India is now transitioning into Extension 4.0, which integrates social media platforms and artificial intelligence-based systems to create connected learning environments. Unlike earlier models, this phase emphasizes a two-way flow of knowledge among researchers, agribusinesses, extension agents, and farmers, moving beyond the traditional *lab-to-land* approach. A key feature of Extension 4.0 is the development of digital communities of practice (Rajasri et al., 2025). These communities enable farmers to share local knowledge, exchange experiences, and collectively evaluate new technologies. Such interoperable networks make extension systems more flexible and responsive within increasingly complex agri-food systems (Nanda et al., 2025).

In this transformation, social media plays a crucial role by providing farmers with real-time information on weather, market prices, pest outbreaks, and government schemes (Akter et al, 2026). Additionally, these platforms support webinars, live demonstrations, and continuous

learning, enhancing farmers' capacity to adapt and innovate. They also allow extension professionals to engage directly with farmers, ensuring that advisory services are more personalized and need-based (Sahoo et al., 2024).

The Rise of the "Agri-Influencer" and the Trust Economy

One of the most notable developments in digital agriculture is the emergence of so-called *agri-influencers*. The rise of the agri-influencer involves farmers, agri-entrepreneurs, and rural youth utilizing platforms such as YouTube, Instagram, and WhatsApp to share authentic farming experiences and advice (Ghosh et al., 2025). Farmers are increasingly placing their trust in these peers, as they offer practical, relatable, and visible knowledge derived from shared experiences under similar conditions. This emergence fosters a trust economy based on authenticity and the practical value of information, rather than mere official authority. The concept is elucidated through four key pillars:

1. **Authentic Voice & Personal Brand:** Agri-influencers gain trust by sharing genuine stories from their farms, showcasing both successes and failures with consistency and transparency, allowing farmers to relate more to individuals than institutions.
2. **Peer-to-Peer Education:** Knowledge sharing occurs among farmers rather than solely from experts. Practical "how-to" videos provide locally relevant advice, rooted in shared experiences, making it easier for farmers to implement the advice given.
3. **Community & Social Engagement:** Agri-influencers foster interaction through comments, Q&A sessions, and live discussions, creating feedback loops that support learning among farmers. This approach promotes a community atmosphere rather than one-sided broadcasting.

4.Integrated Technology & Data Trust: Trust is further established through transparent collaborations, verified information, and ethical practices. Farmers become increasingly reliant on credible platforms and influencers that exhibit honesty and accountability in their communication and practices.

Research on the role of social media in agricultural advisory services further supports this shift. Social media platforms enable users to create, share, and exchange agricultural knowledge within interactive online communities, thereby strengthening linkages among stakeholders in agricultural innovation systems (Bhattacharjee & Raj, 2016). These platforms not only accelerate information dissemination but also encourage dialogue, feedback, and peer validation.

As a result, a new "trust economy" is emerging in agriculture—one in which influence is shaped less by formal institutional authority and more by authenticity, relatability, and practical relevance. In this evolving system, credibility is earned through consistent, experience-based knowledge sharing rather than official designation.

Potential of Social Media in Agricultural Extension

Social media has transformed agricultural extension from a top-down, expert-led system into a more interactive, farmer-centered knowledge network. Platforms like YouTube, Facebook, Instagram, and WhatsApp enable faster, wider, and more participatory dissemination of agricultural information.

1. Rapid Information Dissemination: Instant sharing of extension messages such as weather alerts and pest outbreaks, especially in emergencies.
2. Cost-Effective Delivery: Reduces travel, manpower, and logistics costs while reaching a wider audience compared to traditional methods.
3. Farmer-to-Farmer Learning: Facilitates sharing of practical experiences and local innovations, improving context-specific information adoption.
4. Multimedia-Based Learning: Uses videos and images to simplify complex agricultural practices for farmers, especially those with lower literacy.
5. Real-Time Interaction and Feedback: Establishes a two-way communication system, allowing farmers to ask questions and share field issues directly.
6. Building Digital Communities: Online groups enhance continuous engagement, knowledge exchange, and collective problem-solving among farmers.

7. Market Linkages and Price Awareness: Provides access to real-time market prices and buyer-seller connections, improving decision-making.
8. Promotion of Innovations: Accelerates the spread of new technologies through viral content and influencer networks.
9. Empowerment of Youth and Women: Offers rural youth opportunities as agri-entrepreneurs and women farmers access to vital information and decision-making.

Artificial Intelligence and Its Uses in Agriculture

AI is revolutionizing agriculture by transforming data into actionable insights for farmers through the analysis of satellite imagery, weather forecasts, soil data, and crop patterns. It supports decisions on sowing, input usage, and harvest timing while providing early warnings on pests and diseases. The key applications include:

1. Soil Health Diagnostics: Using deep learning and image recognition, AI monitors soil health via satellite and drone imagery, allowing farmers to promptly address nutrient deficiencies without laboratory tests.

2. Climate-Responsive Crop Monitoring: In India, AI analyses climate data to predict rainfall and temperature shifts, offering real-time advice on sowing and irrigation, while enabling the identification of pests and crop diseases through advanced monitoring systems. This is crucial for rainfed agriculture, helping mitigate climate risks and crop losses.
3. Farm Mechanization Efficiency: AI improves the efficiency of farming machinery through image classification and machine learning, enhancing tasks such as precision weeding, early disease detection, and automated harvesting. This innovation reduces

labour dependency and optimizes resource usage in horticulture through continuous crop monitoring.

4. Price Realization for Farmers: AI addresses price discovery issues in the agricultural supply chain, enabling better market intelligence and coordination. By utilizing predictive analytics from extensive agricultural datasets, farmers can make informed decisions about crop choices and sales timing, thus improving their share of the consumer price and reducing distress sales.

The implementation of AI in agriculture has facilitated market access and price efficiency for approximately 1.8 million farmers across 12 states, showcasing its significant impact on the sector.

Reimagining Agricultural Extension through AgriStack

AgriStack is a key component of the Digital Agriculture Mission, providing farmers with a unique digital identity (Farmer ID) connected to land records, animal ownership, crop cultivation, and benefits received, allowing for safe identification and access to agricultural services. With the integration of real-time data from digital crop surveys, AgriStack enables extension services to offer timely advice on sowing, irrigation, pest control, and harvesting, thereby improving decision-making and reducing farm-level risks. The platform enhances the targeting of government schemes, ensuring that subsidies, insurance, and other benefits are accurately delivered to farmers without duplication or delay. Additionally, AgriStack supports the integration of advanced technologies such as AI, facilitating predictive analytics, early warning systems, and climate-smart advisories. Extension messages can be rapidly shared via digital platforms like WhatsApp and YouTube, which increases outreach and farmer engagement. Overall, AgriStack transforms agricultural extension from a broad, top-down system to a more focused, technology-driven approach that enhances productivity, transparency, and service delivery in rural India.

Bridging India's Digital Divide: Bhashini and Bharat-Vistaar in 2026

The *digital divide* means the gap between people who have easy access to digital technologies (internet, smartphones, digital services). The introduction of modern technologies in agricultural extension is changing the magnitude and efficiency of advisory services. The Bharat-VISTAAR platform is one of the largest initiatives of India to develop an AI-based extension ecosystem (NITI Aayog, 2025). Bharat-Vistaar represents the expansion of digital

infrastructure into rural and remote areas. It focuses on Expanding internet connectivity, improving access to smartphones and digital tools and Bringing government and private digital services to villages. This ensures physical and technological reach to last-mile users.

The three-layer architecture of Bharat-VISTAAR:

1. Demand Layer - Voice-First Interface: Farmers use smartphones or feature phones to communicate with the system.
2. Network Layer - AI and Data Analytics: AgriStack, satellite images, weather predictions, and crop advice databases are combined to handle farmer enquiries via artificial intelligence.
3. Supply Layer - Verified Knowledge Sources: The system's replies are based on verified information from ICAR institutions, agricultural universities, and extension organisations (ICAR, 2025).

Another important part of this ecosystem is Bhashini, a language translation platform in India that uses AI. Bhasyini is able to eliminate the linguistic barriers that made digital advisory services limited in the past due to the fact that it facilitates real-time translation of the Indian languages. Collectively, the technologies are forming a phygital model of extension where digital intelligence supplements the physical extension networks. Bhashini helps bridge the language barrier in India's digital ecosystem between citizens and digital platforms in their native language. This ensures that language is no longer a barrier to accessing technology.

Infodemics and Digital Fatigue: Challenges of the Digital Agriculture

Digital agriculture has greatly improved access to information for farmers through mobile apps, AI-based advisory systems, and social media platforms. However, it has also created emerging challenges. An infodemic refers to the overabundance of information—both accurate and misleading—that makes it difficult for users to identify trustworthy guidance. In agriculture, farmers often receive conflicting advice on crop management, fertilizers, and pest control through platforms like YouTube and WhatsApp. Such misinformation can negatively affect decision-making and productivity (WHO, 2020; Tandoc et al., 2018). Wrongful advertising of fake products, misleading methods of farming may go viral quickly with the help of viral videos and unproven messages. Furthermore, the amount of digital information might cause a sense of digital fatigue when the farmer cannot figure out which sources are reliable and which are not. Research on the topic of social media in the agricultural advisory services suggests that the

absence of information authenticity on the Internet is a significant limitation of the digital extension systems (Bhattacharjee and Raj, 2016). With the expansion of systems like AgriStack, the volume of agricultural data and advisories is increasing. While this improves access to knowledge, it also intensifies the risk of information overload if not properly managed.

Institutionalizing Social Media in Agricultural Communication

Based on the growing importance of digital communication, Indian agricultural institutions have begun to institutionalize their social media practices to improve outreach and knowledge sharing (Badavath et al., 2025). This shift reflects a recognition that platforms like YouTube, WhatsApp, and Facebook are no longer informal tools, but essential components of modern agricultural extension.

The ICAR Communications Policy and Strategy (2025) emphasizes integrated digital outreach and encourages institutions within the National Agricultural Research and Education System to adopt coordinated communication systems (ICAR, 2025). This ensures that scientific information is shared consistently and effectively across multiple digital platforms.

Under the "One Organization – One Narrative" approach, institutions such as Krishi Vigyan Kendras (KVKs), agricultural universities, and research institutes are expected to maintain active and unified digital communication channels. This helps bridge the gap between scientific research and farmers by delivering clear, consistent, and accessible agricultural knowledge.

Overall, institutionalizing social media strengthens agricultural extension by improving the reach, reliability, and coordination of digital communication, making scientific knowledge more accessible to farmers in real time.

Policy Corner: Budget 2026 Highlights

- ✓ ₹150 crore allocated for scaling Bharat VISTAAR AI extension platform
- ✓ Integration of AgriStack digital farmer databases
- ✓ Expansion of multilingual AI services through Bhashini
- ✓ Strengthening digital advisory services and data-driven extension

Conclusion

Digitization in agriculture signifies a profound redefinition of knowledge production, distribution, and application within agricultural systems. Social media platforms have evolved into dynamic ecosystems allowing farmers to engage directly with experts, markets, and policymakers, notably serving as a vital interface within India's digital public infrastructure.

Initiatives like the Digital Agriculture Mission and AgriStack establish a scalable foundation for delivering targeted services to farmers. The integration of Artificial Intelligence, through tools such as Bharat-VISTAAR and Kisan e-Mitra, facilitates real-time advisory services and makes expert insights accessible, particularly in remote areas, enhancing decision-making.

AI systems for monsoon forecasting and pest surveillance, exemplified by the National Pest Surveillance System, enable farmers to mitigate climatic and biological risks while improving resilience. However, the effectiveness of these advancements hinges on the ability of agricultural researchers and institutions to adapt to the new communication landscape, recognizing farmers as active knowledge creators rather than passive recipients. The challenge lies in expanding access to information and promoting inclusive digital communities that foster collective innovation. Ultimately, the future of Indian agriculture will rely on synergistic networks of producers and knowledge generators collaboratively developing solutions within a shared digital framework, transcending mere technological implementation.

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IOT-BASED SMART IRRIGATION SYSTEMS: A PATHWAY TO SUSTAINABLE AND CLIMATE-RESILIENT AGRICULTURE

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Introduction

Agriculture is the largest consumer of freshwater globally, accounting for nearly 70% of total withdrawals. In countries like India, where agriculture is highly dependent on monsoon rainfall and groundwater resources, efficient water management is critical for ensuring food security and environmental sustainability. However, traditional irrigation practices such as flood irrigation or fixed scheduling often result in over-irrigation, nutrient leaching, soil degradation, and depletion of aquifers. With increasing climate variability, including erratic rainfall patterns, prolonged droughts, and rising temperatures, there is an urgent need for precision-based irrigation systems that optimize water use efficiency. In this context, Internet of Things (IoT)-based smart irrigation systems have emerged as a promising technological intervention. These systems integrate sensors, communication networks, cloud computing, and automation to provide real-time, data-driven irrigation management. IoT-based irrigation represents a shift from conventional practices to “smart agriculture,” where decisions are guided by continuous monitoring and analytics rather than intuition. This technology aligns with the broader goals of sustainable intensification, climate-smart agriculture, and digital transformation in farming systems.

2. Concept and Architecture of IoT-Based Smart Irrigation

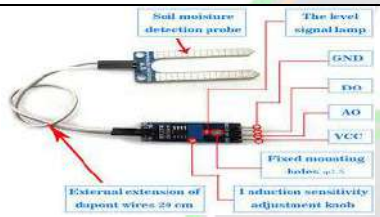
2.1 Concept of IoT in Agriculture

The Internet of Things (IoT) refers to a network of interconnected physical devices embedded with sensors and software that collect and exchange data over the internet. In agriculture, IoT enables real-time monitoring of soil, crop, and environmental conditions, facilitating informed decision-making. Smart irrigation is one of the most impactful applications of IoT, focusing on optimizing water delivery based on crop needs and environmental conditions.

2.2 System Architecture

An IoT-based smart irrigation system typically comprises four layers:

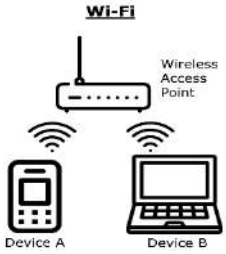
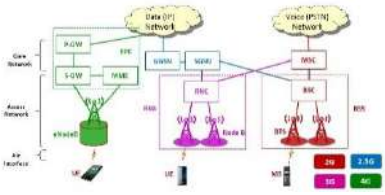
2.2.1 Sensing Layer: This layer includes sensors that collect field data, including:

S. No	Common sensors	Usages
1.	 **Soil moisture sensors**	Measure the amount of water present in the soil as a percentage of volume in the root zone. They help determine when irrigation is needed to avoid both water stress and over-irrigation.
2.	**Soil temperature sensors**	Monitor soil temperature, which influences seed germination, root growth, and microbial activity. This data helps optimize irrigation timing and crop management under varying climatic conditions.
3.	**Ambient temperature and humidity sensors**	Record air temperature and relative humidity surrounding the crop canopy. These parameters are used to estimate evapotranspiration and crop water requirements.

4.	 **Rainfall sensors**	Detect and measure the amount of precipitation received in a specific area. They help prevent unnecessary irrigation by adjusting schedules based on natural rainfall.
5.	 **Light intensity sensors**	Measure the amount of solar radiation or light available for photosynthesis. This information helps assess plant growth conditions and indirectly influences irrigation needs.

2.2.2 Communication Layer:

Data collected from sensors is transmitted through communication technologies such as:

S. No	Communication Layer	Working Nature
1.	 **Wi-Fi**	Provides high-speed wireless data transmission over short distances using local internet networks. Suitable for farms with nearby routers or controlled environments like greenhouses.
2.	 **GSM/3G/4G/5G:**	Uses cellular networks to transmit data over long distances without the need for local internet infrastructure. Ensures reliable connectivity in remote agricultural fields with mobile network coverage.

3.	 **LoRa (Long Range communication)**	A low-power, long-range communication technology designed for transmitting small data packets over several kilometers. Ideal for large farms as it enables battery-powered sensors to operate for extended periods.
4.	 **NB-IoT (Narrowband IoT)**	A low-power wide-area network (LPWAN) technology that operates on cellular infrastructure for efficient data transmission. Offers strong indoor coverage, low energy consumption, and reliable connectivity for IoT devices in agriculture.

2.2.3 Processing Layer (Cloud/Edge Computing):

The data is processed using cloud platforms or local microcontrollers. Advanced systems use machine learning algorithms to analyze historical and real-time data for predictive irrigation scheduling.

2.2.4 Application and Control Layer:

This layer includes user interfaces (mobile apps or dashboards) and actuators such as pumps and solenoid valves. Based on processed data, irrigation is automatically controlled or remotely managed by farmers.

3. Working Principle of Smart Irrigation Systems

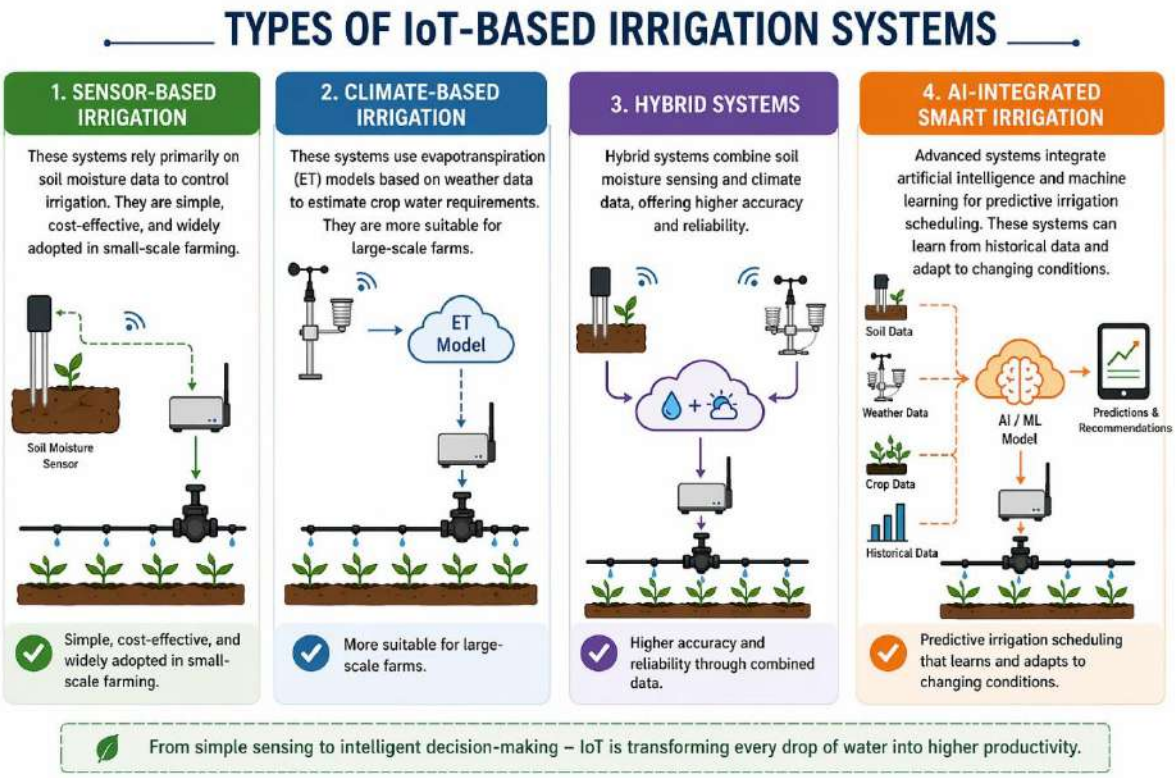
The functioning of IoT-based irrigation systems involves continuous monitoring, analysis, and automated response:

- Soil moisture sensors detect water availability in the root zone.
- Weather sensors monitor climatic variables such as temperature, humidity, and rainfall.
- Data is transmitted to a central system where algorithms evaluate crop water requirements.
- If soil moisture falls below a predefined threshold, irrigation is triggered automatically.
- Irrigation stops when optimal moisture levels are reached.

- Advanced systems incorporate weather forecasts to delay irrigation if rainfall is expected.

This closed-loop system ensures precise water application, reducing wastage and improving crop health.

4. Types of IoT-Based Irrigation Systems



5. Benefits of IoT-Based Smart Irrigation

- **Enhanced Water Use Efficiency:** IoT systems can reduce water usage by 30–50% by delivering precise amounts of water directly to the root zone. This is particularly important in water-scarce regions.
- **Increased Crop Productivity:** Maintaining optimal soil moisture levels ensures better plant growth, improved nutrient uptake, and higher yields.
- **Energy Savings:** Reduced irrigation frequency leads to lower energy consumption for pumping water, thereby decreasing operational costs.
- **Labor Efficiency:** Automation reduces the need for manual monitoring and irrigation, saving time and labor costs.
- **Real-Time Monitoring and Decision Support:** Farmers can access real-time data through mobile applications, enabling remote monitoring and control.

- **Environmental Sustainability:** Efficient irrigation minimizes runoff, reduces soil erosion, and prevents nutrient leaching, contributing to sustainable agriculture.

6. Applications in Crop Production

IoT-based irrigation systems have been successfully applied in various cropping systems:

- ✓ **Field Crops:** Cotton, wheat, and maize benefit from optimized irrigation scheduling.
- ✓ **Horticultural Crops:** Fruits and vegetables require precise water management, making them ideal for smart irrigation.
- ✓ **Greenhouses:** Controlled environments allow integration of IoT for precise irrigation and fertigation.
- ✓ **Plantation Crops:** Crops like sugarcane and coffee benefit from automated irrigation systems.

7. Challenges and Constraints

- ➢ Despite its advantages, the adoption of IoT-based irrigation systems faces several challenges:
- ➢ **High Initial Cost:** The cost of sensors, controllers, and communication infrastructure can be prohibitive, especially for smallholder farmers.
- ➢ **Connectivity Issues:** Reliable internet connectivity is often lacking in rural areas, limiting system performance.
- ➢ **Technical Complexity:** Farmers may require training to operate and maintain IoT systems effectively.
- ➢ **Data Management and Security:** Handling large volumes of data and ensuring data privacy are emerging concerns.
- ➢ **Power Supply Issues:** IoT devices require a continuous power supply, which may be challenging in remote areas.

8. Future Prospects

The future of IoT-based irrigation is closely linked with advancements in digital agriculture:

- **Integration with Artificial Intelligence:** AI can enhance predictive irrigation and optimize resource use.
- **Use of Drones and Remote Sensing:** Satellite and drone data can provide spatial variability insights for site-specific irrigation.
- **Blockchain Technology:** Ensures secure data management and transparency.

- **Low-Cost Sensor Development:** Reducing costs will improve accessibility for small farmers.
- **Government Policies and Support:** Subsidies and training programs can accelerate adoption.

The integration of IoT with precision agriculture technologies will play a crucial role in addressing global challenges such as water scarcity, climate change, and food security.

9. Conclusion

IoT-based smart irrigation systems represent a paradigm shift in agricultural water management. By leveraging real-time data, automation, and advanced analytics, these systems enable precise and efficient irrigation practices. They not only improve crop productivity and resource use efficiency but also contribute to environmental sustainability and climate resilience. While challenges such as cost, connectivity, and technical complexity remain, ongoing technological advancements and policy support are expected to drive widespread adoption. For countries like India, where agriculture is both a livelihood and a critical economic sector, IoT-based irrigation offers a viable solution for achieving sustainable and efficient water management.

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UNVEILING THE POTENTIAL APPLICATION OF DRONES IN AGRICULTURAL SECTOR

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Introduction

The global population is consistently growing, with projections indicating it will reach 9 billion by 2050. Consequently, the demand for agricultural products is on the rise. Meeting the increasing food requirements has become an urgent priority. Agriculture, a pivotal sector, faces numerous challenges, with labor scarcity being a notable issue. Additionally, factors like extreme weather events, inadequate and inefficient use of fertilizers, as well as health concerns stemming from chemical applications, further complicate the agricultural landscape. Climate change exacerbates these challenges, significantly impacting food security. Currently, over 815 million people suffer from chronic hunger, with 64 percent of them located in Asia. To sustain a population of nine billion, food production needs to increase by nearly 50 percent by 2050. However, essential resources such as land and water are becoming increasingly scarce

Farming communities and those engaged in agriculture must adjust their practices to address challenges such as climate change. In this context, information and communication technology (ICT)-driven tools and technologies play a crucial role in improving decision-making by providing accurate, reliable, and timely information. To tackle the challenges in agriculture, there is a need to explore and adopt emerging technologies. The advancements in monitoring, supervision, management, and control systems have ushered in a new era, rendering many

traditional agricultural practices obsolete. The integration of new technologies falls under the umbrella of "precision farming," which involves applying agronomic variables in the right place, at the right time, and with precise control over the quantity of inputs or crop production. FAO and ITU, in collaboration with various partners, have joined efforts to confront agricultural challenges by leveraging sustainable ICTs. Unmanned aircraft has emerged as a valuable technique for swift and non-invasive analysis of factors like air quality, physical properties of soil components, and crop growth

Drone basic concept

A recent advancement in agriculture involves the growing utilization of small unmanned aerial vehicles (UAVs), commonly referred to as drones. Drones, being remotely controlled aircraft without an on-board human pilot, hold significant potential in agriculture by facilitating evidence-based planning and spatial data collection. Despite certain inherent limitations, these technologies offer valuable data that can inform policies and decisions. Drones find applications in various sectors, including the military, humanitarian relief, disaster management, and agriculture. The combination of aerial perspectives with analytic tools capable of interpreting data and images into actionable information represents a groundbreaking development. However, addressing concerns related to privacy, safety, and security is crucial for the sustainable integration of these technologies.

Drones and agriculture

Drones are revolutionizing agriculture, enabling farms and agricultural businesses to enhance crop yields, save time, and make informed land management decisions for long-term success. Farmers face various challenges, including water access, climate changes, soil quality, pests, and variable growing seasons. High-level drone technology addresses these issues, providing fast and efficient solutions. Agricultural drones offer valuable data for improved decision-making on crop yields, livestock health, soil quality, nutrient levels, weather conditions, and more. This data enables farmers to create precise maps of issues and implement reliable solutions. The agriculture industry, known for embracing technological trends, sees drones as the next wave to meet future demands. The United Nations, including the World Food Programme and FAO in collaboration with Google, has experimented with drones in humanitarian crises and agriculture, emphasizing their usefulness in quick and accurate data collection for effective policies and interventions. The use of drones is expanding rapidly in various areas, including

crop production, early warning systems, disaster risk reduction, forestry, fisheries, and wildlife conservation.

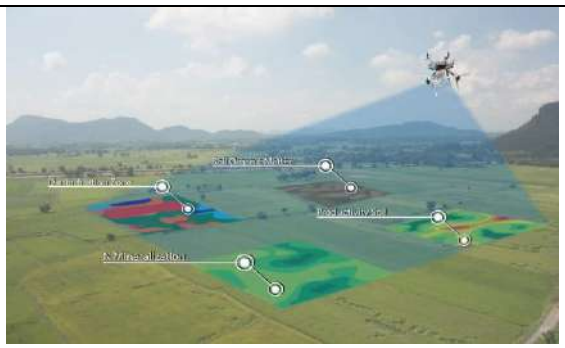
Applications of drone in agriculture

Soil and field analysis: Throughout each phase of the crop cycle, drones can be employed to gather valuable data. Generating 3D maps of current soil conditions enables the monitoring of soil quality, nutrient levels, and areas with limited soil vitality. This data assists farmers in identifying optimal patterns for planting, crop management, and soil care. Continuous monitoring facilitates the efficient use of water resources and better management of crop nutrient levels.

Seed planting: Drone planting is an emerging technology that is not yet widely adopted, but certain companies are exploring its potential. Manufacturers are testing customized systems that can launch seed pods into prepared soil. Startups in the drone industry, such as Drone Seed, play a key role in developing innovative drone technologies for ecological and agricultural purposes. This adaptable drone technology has the potential to be utilized in various types of farms, leading to reduced planting times and labor costs overall.

Crop spraying and spot spraying: This operation holds significant importance in the crop life cycle, as regular fertilization and spraying are essential for maintaining high yields. Traditionally, these tasks were carried out manually, using vehicles, or occasionally via airplanes in certain regions. These methods are not only inefficient and labor-intensive but also quite expensive. Drones can be equipped with sizable reservoirs for fertilizers, herbicides, or pesticides. Utilizing drones for crop spraying proves to be safer and more cost-effective. Furthermore, drones can operate autonomously, following programmed schedules and routes.

Crop mapping and surveying: Drone technology offers a significant advantage in large-scale crop and acreage monitoring. Unlike the past reliance on costly satellite or plane imagery, drones provide real-time footage and time-based animations with enhanced precision. Drone mapping and surveying allow for informed technology decisions based on up-to-date data, eliminating the reliance on outdated imagery or guesswork. Employing near-infrared (NIR) drone sensors enables the assessment of plant health by analyzing light absorption, providing a comprehensive overview of overall farm health. Agriculture drones facilitate the collection of crucial information, including crop and plant health, land distribution based on crop type, crop life cycle, and detailed GPS maps of the current crop area.

	
Soil and field analysis	**Seed planting**
Crop spraying and spot spraying	**Crop mapping and surveying**

Drone Irrigation: Irrigation has long been a challenge for farmers, especially with extensive irrigation systems covering vast distances. Drones equipped with thermal cameras offer a solution by identifying irrigation issues or areas experiencing insufficient or excessive moisture. This information enables farmers to optimize crop layout, enhance drainage, follow natural land runoff patterns, and prevent water pooling that could harm delicate crops. Addressing water and irrigation problems is not only cost-effective but also crucial for safeguarding crop yields. Drone surveying plays a proactive role in detecting these issues before they escalate into significant challenges. Recent research from Australia is opening up promising possibilities for the utilization of drones in agriculture. Given the growing impact of climate change on drought conditions, the development of more effective irrigation solutions is crucial. Drones equipped with microwave sensing technology can capture precise soil health information, including moisture levels, without interference from plants. This capability allows for the optimal distribution of water in a field, promoting resource conservation and efficient irrigation practices.

Real-time livestock monitoring: Drones equipped with thermal imaging cameras provide a streamlined solution for livestock management. This technology enables a single operator to

monitor livestock more frequently and with reduced time and staff requirements. The drone operator can promptly check on the herd, identifying injured or missing livestock and monitoring birthing activities. Drones efficiently perform what was once a costly and time-intensive task of keeping a constant eye on the herd. Additionally, thermal imaging helps detect potential threats from livestock predators, providing a significant advantage for farmers. The widespread adoption of drone technology in agriculture has brought about transformative changes, enhancing efficiency in various farming operations. From crop monitoring, planting, and livestock management to crop spraying, irrigation mapping, and more, high-tech drones play a crucial role in modern farming. These devices empower farmers and drone pilots to leverage real-time data, eliminating guesswork and enabling them to optimize yields and enhance overall crop production.

Irrigation monitoring and management	**Real-time livestock monitoring**
Drone Pollination	**Solar Panel Inspection**

Drone Pollination: The agriculture sector is exploring and developing innovative uses for drones, with some still in the testing and development phase. A notable example is the concept of pollinating drone technology, which has gained attention, particularly in the Netherlands and Japan. Researchers are working on small drones designed to pollinate plants without causing

harm. The ongoing goal is to advance these drones into autonomous pollinators capable of working independently and monitoring crop health without constant operator instructions.

Solar Panel Inspection: Globally, farms are increasingly adopting renewable energy sources, such as solar panels, to fulfill their energy requirements. The installation of expansive solar farms in agriculture not only guarantees a stable power supply but also leads to substantial reductions in energy costs. AI-powered drones play a crucial role in streamlining the inspection process of solar panels, significantly cutting down on time and expenses. These agricultural drones are employed for routine monitoring of solar panels, enabling the early identification of any potential defects in the grid before they pose a risk to the entire system.

Conclusion

Drones present numerous advantages for farmers in agriculture, including heightened efficiency, enhanced yields, and reduced costs. Despite concerns like potential job loss and a lack of knowledge hindering widespread adoption, initiatives in rural India aim to address these challenges and encourage drone use in agriculture. Farmers need to comprehend the technology's potential benefits and receive adequate training and support for effective utilization. In summary, the adoption of drone technology in agriculture holds transformative potential, revolutionizing crop management and boosting yields. While challenges exist, ongoing initiatives aim to overcome them, supporting farmers in embracing this technology.

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CLINICAL MANAGEMENT OF KETOSIS IN A POST-PARTURIENT DAIRY COW: A CASE REPORT

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Abstract

A five-year-old dairy cow presented with reduced feed intake, decreased milk yield, slimy feces and incoordination of gait 20 days after normal calving. Clinical examination and history suggested **Bovine Ketosis**, a common metabolic disorder in early lactation associated with negative energy balance (Melendez and Serrano, 2024). The animal was treated with intravenous 20% dextrose solution along with supportive therapy including Isoflud, Tribivet and E-Booster supplementation. Following treatment, the cow showed marked improvement in appetite, coordination and milk production. The case highlights the importance of early diagnosis and prompt metabolic therapy in the successful management of ketosis in dairy cattle.

Keywords: Dairy cow, ketosis, early lactation, negative energy balance, metabolic disorder

Introduction

Metabolic disorders are common in high-producing dairy cows during early lactation due to increased nutrient demands and metabolic adaptations occurring during the transition period (Melendez and Serrano, 2024). Among these disorders, **Bovine Ketosis** is frequently observed within the first few weeks after calving (Huang *et al*., 2024). The condition occurs when the energy requirement for milk production exceeds dietary energy intake, leading to excessive mobilization of body fat and accumulation of ketone bodies in blood and tissues (Suthar *et al.*, 2021). Ketosis results in reduced milk yield, anorexia, digestive disturbances and occasionally nervous manifestations such as incoordination and abnormal gait (Melendez and Serrano, 2024). Early recognition and appropriate therapy are essential to restore metabolic balance and prevent economic losses in dairy farms (Cainzos *et al*., 2022). The present report describes the successful clinical management of ketosis in a post-parturient dairy cow.

Case History and Clinical Examination

A five-year-old dairy cow was presented with a history of reduced feed intake and decreased milk yield. The animal had calved normally 20 days earlier. The owner reported gradual decline in appetite, reduced milk production and passage of slimy dung. On clinical examination, the cow appeared dull and weak. The animal showed mild incoordination while walking. Milk yield had decreased considerably compared to the previous days. No signs of fever or systemic infection were observed. The vital parameters including temperature, pulse and respiration were within normal limits. Based on the history of early lactation, reduction in feed intake, decline in milk yield and neurological signs such as incoordination, the condition was suspected to be **Bovine Ketosis**, which commonly occurs during early lactation due to negative energy balance (Melendez and Serrano, 2024).

Diagnosis

Diagnosis was made based on:

- Early lactation stage (20 days postpartum)
- Reduced appetite and feed intake
- Decreased milk production
- Digestive disturbances (slimy feces)
- Neurological signs such as incoordination

These findings were consistent with clinical ketosis commonly observed in dairy cattle during early lactation (Huang *et al*., 2024).

Treatment and Management

The animal was treated with metabolic supportive therapy to restore energy balance.

Treatment administered:

- **20% Dextrose (Inj. D20):** 2 litres administered intravenously to correct hypoglycaemia and provide immediate energy (Melendez and Serrano, 2024).
- **Inj. Isoflud:** 5 ml administered intramuscularly to stimulate metabolism and support liver function.
- **Inj. Tribivet:** 15 ml administered intramuscularly as vitamin B-complex supplementation to improve metabolic activity and nerve function.
- **E-Booster:** 1 litre administered orally as an energy supplement to improve metabolic status and help correct negative energy balance (Cainzos *et al*., 2022).

Additionally, the owner was advised to provide good quality green fodder, adequate concentrate feed and mineral mixture supplementation to improve the dietary energy intake of the animal, which plays an important role in preventing metabolic disorders during early lactation (Suthar *et al*., 2021).

Outcome and Follow-up

The animal showed gradual improvement following treatment. Feed intake improved within a few days and the incoordination while walking gradually subsided. The consistency of feces returned to normal and the general condition of the cow improved. After one week of treatment and supportive nutritional management, the cow completely recovered. Milk production gradually increased and returned to its normal level. The animal resumed normal feeding behaviour and showed no further clinical signs of Bovine Ketosis.

Discussion

Ketosis is one of the most common metabolic diseases affecting dairy cows during early lactation (Melendez and Serrano, 2024). The condition occurs due to negative energy balance when energy demand for milk production exceeds dietary supply (Huang et al., 2024). Under such conditions, excessive mobilization of body fat leads to increased production of ketone bodies such as β-hydroxybutyrate, acetoacetate and acetone (Suthar *et al*., 2021). Clinical signs typically include anorexia, reduction in milk yield, dullness and digestive disturbances (Melendez and Serrano, 2024). In some cases, nervous signs such as incoordination and abnormal behaviour may occur. Intravenous administration of glucose solutions remains one of the most effective treatments for rapid correction of hypoglycaemia and restoration of metabolic balance (Chirivi *et al*., 2023). Energy supplementation and improved feeding management help reduce the severity of negative energy balance and promote recovery in affected animals (Cainzos *et al*., 2022).

Conclusion

The present case demonstrates that early diagnosis and prompt treatment using intravenous glucose, metabolic stimulants and oral energy supplementation can effectively manage ketosis in dairy cows. Proper nutritional management and monitoring during early lactation are essential to prevent the occurrence of ketosis and maintain optimum milk production.

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POWER IN EVERY LEAF: THE RISE OF MICROGREENS

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Abstract

Microgreens are young, tender seedlings harvested within 7–14 days after germination, known for their exceptional nutritional value, vibrant color, and intense flavor. They are rich sources of vitamins (A, C, E, and K), minerals, antioxidants, and bioactive compounds, often containing significantly higher nutrient concentrations than their mature counterparts. Due to their rapid growth cycle, minimal space requirements, and ease of cultivation, microgreens have gained increasing importance in urban agriculture, kitchen gardening, and commercial production systems. Their consumption contributes to improved human health by enhancing immunity, reducing inflammation, and lowering the risk of chronic diseases such as cardiovascular disorders and cancer. Additionally, microgreens support sustainable agriculture practices as they require less water, fewer inputs, and can be grown in controlled environments using soil or hydroponic systems. This study highlights the nutritional importance, cultivation practices, and potential applications of microgreens as functional foods for future food security and sustainable development.

Key words: Microgreens, Nutrient-dense food, Sustainable agriculture, Antioxidants

Introduction

Microgreens cultivation has emerged as a modern, sustainable, and highly rewarding approach to urban and small-scale agriculture. These young, tender seedlings of vegetables, herbs, and grains are harvested just 7–21 days after germination, at a stage when they are packed with intense flavor, vibrant color, and concentrated nutrients. In recent years, microgreens have

gained immense popularity among health-conscious consumers, chefs, and researchers due to their rich content of vitamins, minerals, antioxidants and bioactive compounds—often significantly higher than their mature counterparts.

The cultivation of microgreens is simple, cost-effective, and requires minimal space, making it ideal for indoor farming, kitchen gardening, and commercial production. Unlike conventional crops, microgreens can be grown year-round using trays, natural or artificial light, and basic growing media such as soil, cocopeat, or hydroponic systems. Their short growth cycle not only ensures quick returns but also reduces water usage and eliminates the need for heavy fertilizers or pesticides, contributing to eco-friendly and sustainable agricultural practices.

From a nutritional perspective, microgreens such as radish, mustard, broccoli, sunflower, and pea shoots are considered "functional foods" due to their potential role in preventing lifestyle-related diseases. Additionally, their appealing texture and intense taste make them a valuable ingredient in salads, sandwiches, soups and gourmet dishes.

With increasing awareness about healthy diets, urban farming, and sustainable food systems, microgreens cultivation is gaining recognition as a promising venture for students, entrepreneurs, and farmers alike. It represents a perfect blend of nutrition, innovation and sustainability—making it not just a trend, but a future-forward agricultural practice

What Are Microgreens?

Microgreens are the seedlings of vegetables and herbs harvested just after the first true leaves appear. They are different from sprouts and baby greens:

- **Sprouts** are germinated seeds eaten with roots and grown in water.
- **Microgreens** are grown in soil or growing medium and harvested above the root.
- **Baby greens** are older than microgreens and take more time to grow.

Common microgreens include:

- Radish
- Mustard
- Broccoli
- Pea shoots
- Sunflower
- Fenugreek (methi)
- Coriander

Each type has a unique taste, ranging from spicy to mild and sweet.

Nutritional Importance of Microgreens

Microgreens are often called "superfoods" because of their high nutritional value. Studies have shown that microgreens can contain 4–40 times more nutrients than mature plants.

Key Nutrients:

- Vitamins (A, C, E, K)
- Minerals (iron, calcium, magnesium)
- Antioxidants
- Fiber

Health Benefits:

- Boost immunity
- Improve digestion
- Reduce risk of chronic diseases
- Support heart health
- Help in detoxification.

Advantages of Microgreens Cultivation

1. Short Growth Period

Microgreens can be harvested within 1–3 weeks, providing quick results.

2. Low Space Requirement

They can be grown in trays, containers, or even small kitchen spaces.

3. Minimal Investment

Only basic materials like seeds, trays, and growing medium are required.

4. Water Efficient

Microgreens need less water compared to traditional crops.

5. No Need for Chemicals

They can be grown organically without pesticides or fertilizers.

6. Year-Round Production

Indoor cultivation allows production in all seasons.

Materials required for growing Microgreens

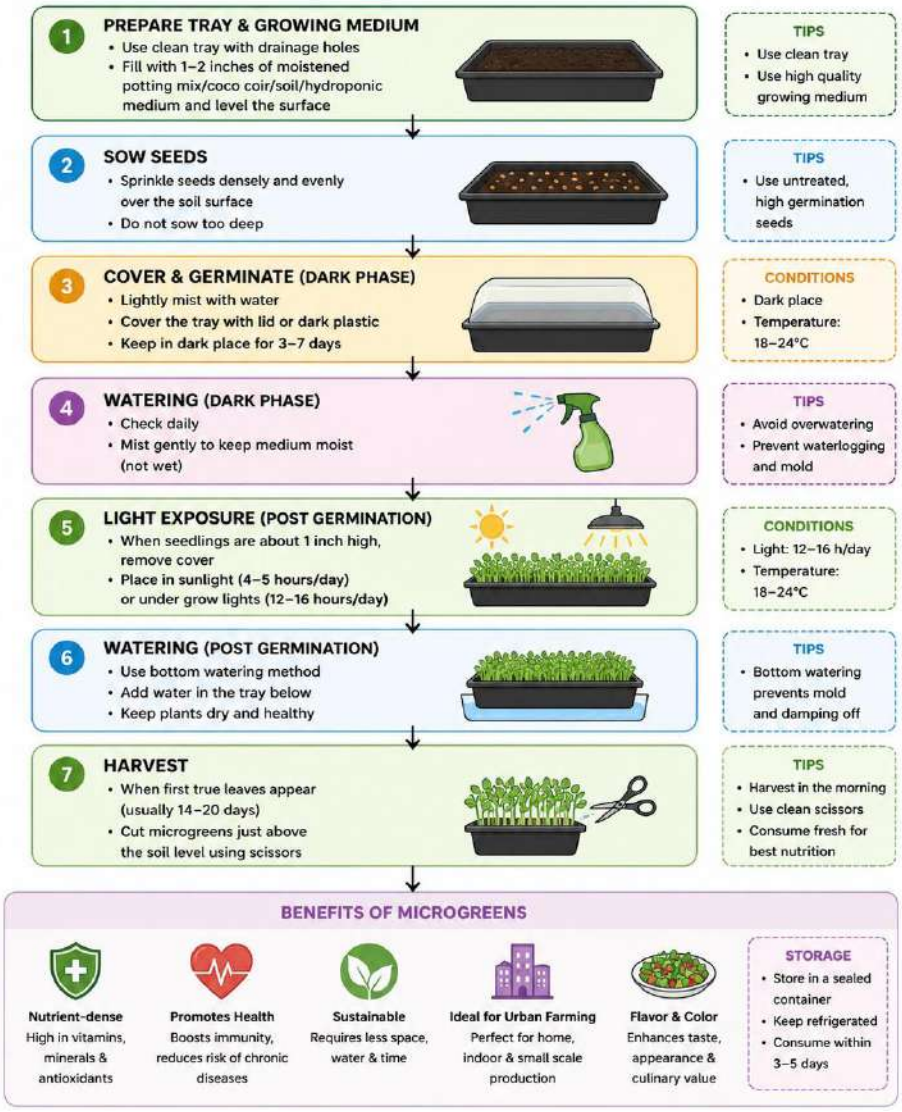
To start microgreens cultivation, you need:

- Good quality seeds (untreated)

- Growing trays or containers
- Growing medium (soil, cocopeat, or tissue paper)
- Water spray bottle
- Light source (sunlight or LED light)

Cultivation of Microgreens

1. **Prep the Soil:** Fill the tray with 1-2 inches of moistened potting mix and flatten the surface.



1. **Sow Seeds:** Sprinkle seeds densely and evenly over the soil.
2. **Cover and Germinate:** Lightly spray the seeds, then cover the tray with a lid or dark plastic to keep them in the dark for 3–7 days, encouraging germination.

3. **Watering (Blackout Phase):** Check daily and mist with water to keep the soil moist but not wet.
4. **Light Exposure:** Once seeds sprout and are about 1 inch high, remove the cover and place the tray in a sunny window (4–5 hours of sunlight) or under grow lights.
5. **Watering (Post-Germination):** Switch to bottom-watering (pouring water into a holding tray underneath) to keep the plants dry and prevent mold.
6. **Harvest:** When the first set of true leaves appear (usually 14–20 days), use scissors to cut the microgreens just above the soil level.

Care and Maintenance for Microgreens Production

- Avoid Overwatering: Too much water causes mold.
- Soaking**:** Soak larger seeds like peas and sunflowers for 4-12 hours before planting.
- Weight: Place a weight (like another tray) on top of the seeds during germination to encourage stronger roots.
- Storage: Consume immediately for best nutrition, or store in the refrigerator in a sealed container for a few days.
- Use Untreated seed and maintain clean tray to avoid fungal growth.

Economic Importance

Microgreens cultivation can be a profitable small-scale business. Due to high demand in urban areas, restaurants, and health markets, they can be sold at a premium price.

Income Opportunities:

- Local markets
- Supermarkets
- Online sales
- Direct supply to hotels and restaurants

Students and young entrepreneurs can start microgreens farming with low investment and earn additional income.

Microgreens in Sustainable Agriculture

Microgreens contribute to sustainable agriculture in several ways:

- Reduce carbon footprint
- Promote urban farming
- Use less water and resources

- Encourage organic production

Conclusion

Microgreens are a powerful example of how small innovations can create big impacts. With their high nutritional value, quick growth, and ease of cultivation, they offer a practical solution for healthy living and sustainable farming. Whether grown for personal use or commercial purposes, microgreens represent the future of smart agriculture. As awareness continues to grow, microgreens are not just a trend but a promising opportunity for improving nutrition, income, and environmental sustainability.

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ANTIMICROBIAL RESISTANCE IN AQUACULTURE: A GROWING CONCERN

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Abstract

Aquaculture has grown to be among the most rapidly expanding food production sectors worldwide. As much as this has significantly contributed to food security and proper nutrition, frequent disease outbreaks have been accompanied by the misuse of antibiotics and development of antimicrobial resistance (AMR). AMR has become a major threat to both aquatic animals and humans alike due to its far-reaching consequences on aquatic ecosystems, public health, and economic development. This paper examines the major factors that promote antimicrobial resistance in aquaculture and possible transmission routes from aquatic organisms to human populations. Some of the important considerations include the over-reliance on antimicrobial drugs, mismanagement of diseases and antibiotics, and environmental contamination. The mechanisms underlying resistance development will also be explained alongside the role of aquatic ecosystems as important sources of antibiotic-resistant bacteria and their genes. In addition, possible transmission routes through seafood consumption will be outlined as well as possible solutions to the AMR problem. Some of the possible alternatives include the use of probiotics, vaccinations, biosecurity, and farm management. Overall, this article presents a "One Health" approach to address the challenges of AMR within the aquaculture sector.

Introduction

The field of aquaculture has developed into one of the world's fastest-growing industries producing food products. Aquaculture contributes up to fifty percent of all the fish that people eat across the globe. Unfortunately, increased cases of diseases due to such rapid growth have forced the sector to utilize more antibiotics in treating diseases. As a result, antimicrobial

resistance (AMR) has increased dramatically and become a considerable health threat to the planet, food safety, and environmental sustainability. Aquatic habitats serve as sources for bacteria with resistant genes and resistance pathways, thus posing an important One Health concern associated with aquaculture, affecting humans, animals, and the environment (Caputo et al., 2022; Watts et al., 2017)

Antimicrobial Resistance (AMR)

The term antimicrobial resistance describes the capacity of microorganisms like bacteria, viruses, and fungi to withstand medicines used to eradicate them. It results from genetic mutation or by acquiring resistance genes through processes like transformation, transduction, and conjugation. In aquaculture environments, the existence of different microbial communities, coupled with their regular exposure to antimicrobials, facilitates the growth and propagation of AMR microorganisms. The AMR microorganisms thrive in water bodies and may pass on their resistance genes to other microorganisms, including human disease-causing organisms (Watts et al., 2017).

Aquaculture Expansion and Antibiotic Use

With an increase in aquaculture intensity with respect to density of fish stocks and output needs, there is an increase in prevalence of diseases and need for antibiotics. These antibiotics are commonly fed to large populations as opposed to individuals. Research shows that aquaculture is responsible for some proportion of the global usage of antimicrobials, with some species being administered higher amounts of antibiotics per unit biomass than terrestrial livestock. This widespread usage results in selective pressure favoring antibiotic resistance among bacteria populations (Schar et al., 2021).

Causes of AMR in Aquaculture

There are multiple causes of AMR in aquaculture environments. One of the main causes includes the widespread and preventive use of antibiotics without diagnosis. Poor management practices in fish farms, such as overcrowded tanks and poor water quality, exacerbate the prevalence of diseases and the need for antibiotics. Also, antibiotics in feeds cause the discharge of the drug into the environment without metabolism, which causes selection for antibiotic resistance. Besides, the presence of pollutants, such as heavy metals in aquaculture environments, contributes to the selection of antibiotic-resistant microorganisms (Watts et al., 2017).

Dispersal of Antimicrobial Resistance in Water Bodies

Antimicrobial resistance in aquaculture is not limited to the confines of the farm environment but diffuses through several interrelated channels. The use of open systems for aquaculture permits direct contact between the cultured species, the water around them, the soil, and the wildlife within the water body, which aids in the dispersal of the resistant bacteria and the resistant genes. Research indicates that up to 70–80% of the antibiotics introduced into the water body are eventually eliminated and persist within the aquatic habitat, thus providing a selective pressure on the microbial population.

Antimicrobial Resistance Hotspots and Global Trends

Several studies performed at a global level have concluded that there are hotspots for antimicrobial resistance in aquaculture in regions like Asia. Countries including China and India are hotspots due to the presence of intensive farming and high antibiotic usage. According to a meta-analysis study, it was observed that one-third of antimicrobial substances utilized in aquaculture possessed resistance above 50%. In addition, the pathogens that show resistance include Vibrio species, Aeromonas species, and Escherichia coli species. The conclusion drawn from these observations is that AMR poses a significant threat throughout various aquatic ecosystems.

Antibiotic-Resistant Bacterial Genera Prevalent in Aquaculture

There exist several bacterial genera that are common to the field of aquaculture, which have become resistant to a wide range of antibiotics, making them difficult to treat. In particular, Vibrio spp. and Aeromonas spp. are some of the most common genera that show resistance to antibiotics, followed by Streptococcus, Edwardsiella, and E. coli. Antibiotics against which resistance is acquired include critical ones, such as tetracyclines, sulfonamides, macrolides, and β-lactams (Caputo et al., 2022; Schar et al., 2021).

Public Health Relevance

There are several public health concerns related to AMR in the aquaculture industry. For instance, aquatic animals and fishery products could serve as carriers of drug-resistant microorganisms and resistance genes, which could then be transferred to humans either directly from consumption or indirectly when handling such products. There is evidence that resistance genes detected in the aquaculture sector are identical to the ones in human clinical strains, implying possible intersectoral gene transfer. Moreover, international trade in seafood products

promotes the dissemination of drug-resistant microbes beyond the borders of individual countries. Rising demand for uncooked or lightly processed seafood products increases the risks of contracting food-borne diseases from resistant pathogens (Caputo et al., 2022; Watts et al., 2017).

Economic Consequences of AMR in Aquaculture

AMR represents a severe economic challenge for the aquaculture sector due to reduced productivity, higher mortality rates, and increased costs associated with disease management. The inefficiency of the antibiotics necessitates using larger quantities or other medicines, thus adding costs to operations. Furthermore, the economic consequences of disease breakouts caused by antibiotic-resistant organisms include loss of stocks, which affects smallholders and commercial farms alike. There might be potential consequences at an international level, too, because of the widespread nature of AMR, and importing countries can introduce regulations related to antibiotic contamination and resistance in seafood products.

Environmental Impacts of AMR

The aquatic environment plays a significant role in serving as a source of AMR within the natural ecosystem. The consistent discharge of antibiotics, resistant microorganisms, and their associated genes leads to a shift in the composition of microbial communities and reduced diversity. Resistance genes, such as tet, sul, and bla genes, are known to be abundant in sediments around aquaculture farms and are capable of surviving and spreading through horizontal gene transfer. Notably, the environmental impacts of AMR are long-lasting and not easy to mitigate because they contribute to the global resistome.

Other Methods Used Instead of Antibiotics in Aquaculture

With the emergence of antimicrobial resistance, various methods have been considered as possible alternatives to the use of antibiotics. The most notable is the application of probiotics, prebiotics, and synbiotics. These methods help improve the immune system of fish while ensuring the gut remains healthy; thus, the need for antibiotics is minimized. Another method that has shown success is the use of vaccines in fish. For instance, salmon farming has greatly relied on vaccines, which has led to a significant decrease in the use of antibiotics. Other alternatives include the application of phytobiotics, bacteriophages, and immunostimulants (Watts et al., 2017).

Role of Biosecurity and Best Management Practices

Better farm management and biosecurity practices are fundamental to ensuring fewer cases of diseases and the need for antibiotics. For instance, factors like maintaining high-quality water, maintaining a low stocking density, using high-quality feeds, and quarantining are effective in reducing the prevalence of diseases. Health monitoring and early detection of diseases are also useful in containing their spread. Countries with strong regulatory systems and best management practices such as Norway have managed to cut down antibiotic consumption in aquaculture by introducing vaccination programs and better husbandry practices.

Necessity for Surveillance and Policy Implementation

The efficient management of antimicrobial resistance in aquaculture demands effective surveillance systems and the implementation of policies on both national and international scales. Although there is widespread agreement that AMR is one of the most serious threats today, many countries have yet to develop sufficient surveillance mechanisms for antibiotic consumption and AMR in the aquaculture industry. According to research findings, it is apparent that the majority of national plans for combating AMR fail to cover the aquaculture industry. It is necessary to improve surveillance systems, encourage appropriate antimicrobial usage, and adopt the "One Health" approach (Caputo et al., 2022).

Challenges Associated with the Control of Antimicrobial Resistance in Aquaculture

Although awareness about AMR is growing, control of antimicrobial resistance in aquaculture continues to be quite complicated, owing to several interrelated factors. Lack of strong laws and their implementation in many developing nations where much of the world's aquaculture takes place poses one such challenge. Insufficient availability of diagnostic facilities means that antibiotics are frequently used excessively without knowing what pathogen is involved. Limited information about the use and development of antibiotic resistance makes it even harder to devise effective solutions. Finally, the fact that aquaculture is done in open systems means that resistant microorganisms and genes can move outside the farms into the ecosystem.

Future Perspectives

In the future, any attempt to address antimicrobial resistance should be sustainable and science-driven. Genomic sciences and new diagnostic methods may help in early detection and surveillance of resistant bacteria in aquatic environments. In addition, technologies like whole-

genome sequencing and metagenomics may contribute greatly to the development of an understanding of AMR mechanisms and dissemination. Additionally, more scientific studies into alternatives to antibiotics, such as vaccines, probiotics, and bacteriophage therapy, can also be helpful in addressing antimicrobial resistance. Finally, international collaboration and cooperation are also important in finding an effective response to AMR. More emphasis on precision aquaculture, where disease control will depend on certain circumstances in farms, can be instrumental in minimizing the use of antibiotics (Schar et al., 2021; Watts et al., 2017)

Conclusion

The problem of AMR in aquaculture is an increasing threat on a global level that affects the health and production of fish as well as human and environmental sustainability. The excessive application of antibiotics for treatment and prevention in aquaculture leads to the emergence and spreading of resistant organisms, making the disease management process harder than before. Due to the increasing demand for fish, the necessity of overcoming AMR is vital for sustainable development. The implementation of a holistic approach under the name "One Health," which covers responsible use of antibiotics, better management techniques, other methods of disease control, and effective policy enforcement, will help overcome the problem and ensure the sustainable development of the sector.

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REMOTE SENSING AND GIS APPLICATIONS IN SOIL POLLUTION MAPPING

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Abstract

Soil pollution has become a significant environmental concern in recent decades due to rapid industrialization, urban expansion, intensive agricultural practices, and improper waste disposal. The accumulation of toxic substances such as heavy metals, pesticides, hydrocarbons, and industrial residues in soil systems has led to severe consequences for ecosystem health, agricultural productivity, and human well-being. Conventional soil pollution assessment methods primarily rely on field sampling and laboratory-based analyses, which, although accurate, are time-consuming, expensive, and spatially limited. These limitations restrict their effectiveness in capturing the variability of soil contamination across large geographic areas. In this context, Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as powerful tools for efficient, cost-effective, and large-scale soil pollution mapping.

Remote sensing enables the acquisition of spectral information from the Earth's surface using satellite or airborne sensors, allowing indirect detection of soil properties and contamination indicators. GIS complements this by providing a platform for integrating, analysing, and visualizing spatial data, thereby facilitating the identification of pollution patterns, hotspots, and temporal trends. The integration of RS and GIS, along with advancements in hyperspectral imaging, geostatistics, and machine learning techniques, has significantly improved the accuracy and applicability of soil pollution mapping. This paper presents a comprehensive overview of the principles, methodologies, and applications of remote sensing and GIS in polluted soil mapping, with a particular focus on heavy metal contamination.

It also discusses emerging trends, challenges, and future prospects in this field, emphasizing the need for geospatial technologies in sustainable soil management.

Keywords: Remote Sensing, GIS, Soil Pollution, Heavy Metals, Digital Soil Mapping

1. Introduction

Soil is a vital component of the Earth's ecosystem, serving as the foundation for agricultural production, nutrient cycling, water filtration, and biodiversity support. However, increasing anthropogenic pressures have led to the degradation and contamination of soil resources worldwide. Soil pollution refers to the presence of hazardous substances in soil at concentrations that adversely affect plant growth, soil organisms, human health, and environmental quality. Major contributors to soil pollution include industrial discharges, mining activities, excessive use of agrochemicals, urban waste disposal, and atmospheric deposition of pollutants.

Among various contaminants, heavy metals such as lead, cadmium, arsenic, mercury, and chromium are particularly concerning due to their persistence, toxicity, and ability to bioaccumulate in the food chain. Unlike organic pollutants, heavy metals do not degrade over time and can remain in soils for extended periods, posing long-term risks. These contaminants can enter agricultural systems and accumulate in crops, ultimately affecting human health through food consumption.

Traditional soil pollution assessment techniques involve systematic sampling followed by laboratory analysis. While these methods provide reliable results, they are often constrained by limited spatial coverage, high operational costs, and significant time requirements. Furthermore, soil properties and contamination levels exhibit high spatial variability, making it difficult to accurately represent pollution patterns using conventional approaches alone. Consequently, there is a growing need for advanced technologies that can provide comprehensive, high-resolution, and spatially explicit information on soil pollution.

Remote sensing and GIS have revolutionized environmental monitoring by offering the ability to collect, process, and analyse large volumes of spatial data. Remote sensing provides synoptic and repetitive observations of the Earth's surface, enabling the detection of changes in soil properties and land use patterns over time. GIS facilitates the integration of diverse datasets, allowing for advanced spatial analysis and modelling. Together, these technologies provide a

robust framework for mapping and monitoring soil pollution at various scales, supporting informed decision-making and sustainable land management practices.

2. Soil Pollution: Sources and Impacts

Soil pollution arises from a combination of natural processes and human activities, although anthropogenic sources are the dominant contributors in most cases. Industrial activities play a major role in soil contamination, particularly through the discharge of untreated effluents, improper waste disposal, and emissions from manufacturing processes. These activities introduce a wide range of pollutants, including heavy metals, organic chemicals, and toxic compounds, into the soil environment. Mining and smelting operations are another significant source of contamination, as they release large quantities of metal-rich waste materials that can disperse into surrounding soils.

Agricultural practices also contribute to soil pollution, especially through the excessive use of chemical fertilizers, pesticides, and herbicides. While these inputs are essential for enhancing crop productivity, their overuse can lead to the accumulation of harmful residues in the soil. Urbanization further exacerbates soil pollution through the generation of solid waste, sewage sludge, and construction debris, which often contain hazardous substances. Additionally, atmospheric deposition of pollutants from industrial emissions and vehicular exhaust contributes to the contamination of soils, particularly in urban and peri-urban areas.

The impacts of soil pollution are far-reaching and multifaceted. Contaminated soils pose serious risks to human health, as exposure to toxic substances can lead to various diseases, including cancer, neurological disorders, and organ damage. Soil pollution also affects agricultural productivity by disrupting soil structure, reducing nutrient availability, and inhibiting microbial activity. The uptake of contaminants by plants can result in the accumulation of toxic substances in food crops, compromising food safety. Furthermore, soil pollution negatively impacts biodiversity by altering soil habitats and affecting the survival of soil organisms. These consequences highlight the urgent need for effective monitoring and management strategies to mitigate soil pollution and protect environmental health.

3. Principles of Remote Sensing in Soil Pollution Mapping

Remote sensing is based on the principle of detecting and measuring the interaction between electromagnetic radiation and the Earth's surface. Different soil properties influence the reflectance and absorption of radiation across various wavelengths, creating unique spectral

signatures that can be analysed to infer soil characteristics. Factors such as soil moisture, texture, organic matter content, mineral composition, and surface roughness play a crucial role in determining soil reflectance. The presence of contaminants can alter these properties, thereby affecting the spectral response of soils.

Satellite and airborne sensors capture reflected or emitted radiation in different spectral bands, enabling the analysis of soil characteristics at various spatial and temporal scales. Multispectral sensors, such as those onboard Landsat and Sentinel satellites, provide data in a limited number of broad spectral bands and are widely used for general soil and land use studies. Hyperspectral sensors, on the other hand, capture data in hundreds of narrow spectral bands, offering detailed information that can be used to identify specific soil constituents and contaminants. Thermal sensors measure surface temperature variations, which can be indicative of pollution-related processes, particularly in industrial areas.

The detection of soil pollution using remote sensing is often indirect, relying on the identification of indicators such as changes in vegetation health, soil colour, and surface characteristics. For example, contaminated soils may exhibit reduced vegetation growth, which can be detected using vegetation indices derived from satellite imagery. Similarly, the presence of certain heavy metals can influence soil reflectance patterns, allowing for their estimation using spectral analysis techniques. Advances in sensor technology and data processing methods have significantly enhanced the capability of remote sensing to detect and map soil pollution with greater accuracy.

4. GIS in Soil Pollution Mapping

Geographic Information Systems (GIS) provide a comprehensive platform for managing, analysing, and visualizing spatial data related to soil pollution. GIS enables the integration of data from multiple sources, including remote sensing imagery, field measurements, laboratory analyses, and environmental variables, into a unified framework. This integration facilitates the analysis of spatial relationships and patterns, allowing researchers to identify pollution hotspots and assess the extent of contamination.

One of the key functions of GIS in soil pollution studies is spatial interpolation, which involves predicting pollution levels in unsampled areas based on known data points. Techniques such as Kriging and Inverse Distance Weighting (IDW) are commonly used for this purpose. GIS also supports various spatial analysis methods, including overlay analysis, buffer analysis,

and proximity analysis, which help in understanding the influence of pollution sources and environmental factors on soil contamination.

In addition to mapping pollution distribution, GIS is widely used for risk assessment and decision-making. By integrating data on soil contamination, land use, population density, and ecological sensitivity, GIS-based models can evaluate the potential risks to human health and the environment. The visualization capabilities of GIS allow for the creation of detailed maps and graphical representations, making it easier to communicate findings to policymakers, stakeholders, and the public.

5. Integration of Remote Sensing and GIS

The integration of remote sensing and GIS provides a powerful approach for comprehensive soil pollution mapping. Remote sensing supplies large-scale spatial data, while GIS enables the analysis and interpretation of this data within a spatial context. The typical workflow involves the acquisition of satellite imagery and field data, followed by preprocessing steps such as geometric and radiometric correction. Relevant features and indices are then extracted from the imagery and integrated into a GIS environment along with ancillary data.

This integrated approach allows for the development of predictive models that can estimate soil contamination levels across large areas. By combining spectral information with environmental variables such as topography, climate, and land use, it is possible to generate high-resolution maps of soil pollution. The integration of RS and GIS also facilitates temporal analysis, enabling the monitoring of changes in soil contamination over time.

6. Techniques for Polluted Soil Mapping

Various techniques have been developed to enhance the accuracy of soil pollution mapping using remote sensing and GIS. Spectral indices derived from satellite data, such as the Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI), are commonly used to assess vegetation health and indirectly infer soil contamination. Digital Soil Mapping (DSM) employs statistical and machine learning models to predict soil properties based on environmental covariates.

Geostatistical methods, including Kriging and IDW, are widely used to interpolate pollution data and generate continuous surface maps. Machine learning algorithms, such as Random Forest, Support Vector Machines, and Artificial Neural Networks, have gained popularity due to their ability to model complex relationships between variables and improve

prediction accuracy. These techniques, when integrated with RS and GIS, provide a robust framework for mapping and analysing soil pollution.

7. Applications in Heavy Metal Mapping

Remote sensing and GIS have been extensively applied in the mapping of heavy metal contamination in soils. In industrial areas, these technologies have been used to identify pollution hotspots and assess the spatial distribution of contaminants such as lead, cadmium, and chromium. In mining regions, RS and GIS help in tracking the dispersion of metal-rich waste materials and evaluating their impact on surrounding ecosystems.

In agricultural landscapes, these tools are used to monitor the effects of agrochemical inputs and assess the accumulation of heavy metals in soils. GIS-based risk assessment models enable the evaluation of potential exposure pathways and the identification of areas at high risk of contamination. These applications demonstrate the versatility and effectiveness of RS and GIS in addressing various aspects of soil pollution.

8. Advanced Technologies and Emerging Trends

Recent advancements in remote sensing and GIS technologies have further enhanced their capabilities in soil pollution mapping. Hyperspectral remote sensing provides detailed spectral information that allows for the precise identification of soil contaminants. Unmanned Aerial Vehicles (UAVs), or drones, offer high-resolution data and flexibility for site-specific studies.

The integration of artificial intelligence and big data analytics has improved the efficiency and accuracy of predictive modelling. Cloud computing platforms, such as Google Earth Engine, enable the processing and analysis of large datasets, facilitating large-scale environmental monitoring. These emerging technologies are expected to play a significant role in the future of soil pollution assessment.

9. Challenges and Limitations

Despite the numerous advantages of remote sensing and GIS, several challenges remain in their application to soil pollution mapping. One of the primary limitations is the indirect nature of pollutant detection, as remote sensing relies on proxy indicators rather than direct measurements. Environmental factors such as soil moisture, vegetation cover, and surface roughness can influence spectral signatures, potentially affecting accuracy.

The high cost and limited availability of hyperspectral data, as well as the need for extensive ground truth validation, also pose challenges. Additionally, the complexity of data processing and analysis requires specialized skills and expertise. Addressing these limitations is essential for improving the reliability and applicability of geospatial technologies in soil pollution studies.

10. Conclusion

Remote sensing and GIS have emerged as indispensable tools in the field of soil pollution mapping, offering significant advantages over traditional methods in terms of spatial coverage, efficiency, and analytical capabilities. The integration of these technologies enables the identification of contamination patterns, assessment of pollution sources, and evaluation of environmental risks. Advances in sensor technology, machine learning, and data processing have further enhanced their potential for accurate and large-scale soil pollution assessment.

However, challenges such as data limitations, environmental variability, and the need for standardized methodologies must be addressed to fully exploit these technologies. Future research should focus on integrating multidisciplinary approaches, improving data accessibility, and developing user-friendly tools for practical applications. The adoption of remote sensing and GIS in soil pollution mapping is crucial for sustainable land management, environmental protection, and ensuring food and human health security.

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MICROBIAL ENZYMES AND THEIR APPLICATION IN PULP AND PAPER INDUSTRY

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Abstract

The pulp and paper industry is a vital sector that converts lignocellulosic raw materials such as wood, agriculture residues and waste paper are convert valuable paper products. The process involves in this industry like pulping, bleaching, sheet formation, pressing, and drying. Bleaching is an important stage in the pulp and paper industry aimed at removing residual lignin and enhancing the brightness and purity of pulp. After the pulping process, lignin responsible for the brown colour of pulp remains partially attached to cellulase fibers. In recent times, most of the & pulp industries rely on chemical based process for bleaching of papers. It can be replaced with microbial enzymes, which is eco-friendly and cost-effective. These microbial enzymes from bacteria, fungi & actinomycetes plays a major role in reducing environmental pollution such as xylanase, cellulase, laccase, lipase are widley used in pulping, bleaching, deinking, fiber modification. Their application improves paper quality while supporting sustainable industrial practices.

Keyword: Microbial enzymes, Deinking, Bleaching, Xylanase, Pulping

Introduction

The demand for paper is increasing, which is causing forests to disappear. To solve this problem, recycling paper is considered as alternate solution. Use of microbial enzymes as bio bleaching facilitates residual ink removal by fiber breakage**.** During paper recycling process

conventional methods uses hazardous chemicals namely Na_2SiO_3, NaOH, Na_2CO_3, H_2O_2 which are harmful for the Environment. Use of bio-deinking / Enzymatic deinking is a option. The biological deinking is good for the environment but it is challenging.So using a combination of biological methods can reduce chemical use.

Characteristics of Enzymes:

1) The enzyme should be able to withstand the effects of various additives.

2) The production of enzymes must be cost effective and reproducible.

3) Enzymatic deinking should produce quality recycled paper.

4) The Enzymes should be able to work at stages like pulping, bleaching and deinking.

Enzymes involved in deinking process:

ENZYMES	USES
1. **Cellulase**	• Partially breaksdown cellulose fibre • Loosen ink particles attached to fibres • Improves ink removal efficiency
2. **Hemicellulase (eg: xylanase)**	• Breakdown hemicellulose surrounding fibre • Improves pulp brightness
3. **Lipase**	• Separation of ink from fibres • Reduction in chemical consumption
• **Laccase**	• Oxidize lignin and coloured compound • Helps in ink degraderation and pulp brightening

How Enzymes works?

Cellulase:

The cellulase enzymatic deinking enhance the brightness, strength, cleanliness of fibre. It also reduces fine particles in the pulp by changing the fiber surface and bonds near the ink particles. Another advantage of enzymatic deinking by cellulases is the improvement in the deinking and dewatering ability, which causes the peeling of the individual fibers and bundles with high affinity towards water and ink particles thus improve the paper making ability.

Unlike harsh chemical agents (like sodium hydroxide), enzymes specifically target the bond between the ink and fiber without damaging the core fiber strength, which improves overall paper quality.

Xylanase:

Xylanase enzymes break the bond between lignin and hemicellulose. As a result, xylanase removes xylan. At the next stage of the bleaching process, lignin is easily removed as its links with hemi-cellulose have been broken down. The reduction of xylan concentrations increases the fiber permeability, thus improving its bleachability.

Unbleached Pulp

Bleached Pulp

Lipase:

Lipase enzymes acts on the pitch control. Lipases hydrolyze triglycerides, the major constituents of pitch, into glycerol and free fatty acids. This action prevents the pitch from aggregating and causing "spots" or "holes" in the paper.

Laccase:

Laccase is a pre bleaching which helps in oxidizing the phenols present in lignin with the help of oxygen. This will make the lignin structure weak so that it can be easily washed off.

Deinking in small scale paper industry:

Hydrapulper for waste paper pulping for 20 min

↓

Enzyme addition by individuals or combination

↓

Boiling the pulp for 15-20 min at 121°C)

↓

Water washing for residue removal

↓

Paper production

↓

Quality analysis

Steps involved in paper making:

1.First step in paper making is preparation of raw materials through enzymes such as xylanase. It helps to break tough materials.

2. For bleaching ,enzymes such as laccase are used. It provides colour to wood and breaks down lignin compounds. It also helps to clean up the ink

3. Recycled paper quality get increased by enzymes

4. Overall , with the help of enzymes higher quality and environmental friendly product obtained.

Waste paper

↓ (Xylanase/Cellulase/ Laccase+Lipase)

Pulping

↓ (Cellulase/Xylanase/ Laccase)

Flotation

↓ (Lipase)

Paper Making

Conclusion:

Using enzymes makes the production process cleaner, cheaper and better for the environment. Microbial enzymes such as xylanase, cellulase, lipase and laccase have changed

the pulp and paper industry by offering alternatives to traditional chemical processes. Their ability to improve pulp quality, reduce environmental impact, and enhance process efficiency making them essential in modern paper manufacturing.

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MICROBIAL DYNAMICS OF EM IN SOIL AND THEIR IMPACT ON PLANT DEVELOPMENT

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Abstract

Effective Microorganisms (EM) are a mix of helpful, naturally occurring microbes that are added to soil, plants, and organic waste to improve farming and the environment. Often described as a kind of "probiotic for the soil," EM include bacteria, yeasts, and fungi that work together to break down organic matter, release nutrients and support plant growth. They can improve soil structure, reduce bad odours in compost and help create a healthier balance of microorganisms around plant roots. However, EM work best when combined with organic materials such as compost, manure and their effects can vary depending on soil conditions. While they show promise in improving soil health and productivity, their benefits are not always consistent and are still being studied. Overall, EM offers a natural and eco-friendly approach to supporting sustainable agriculture and waste management when used properly.

Keywords: Effective Microorganism, photosynthetic efficiency, synergy, sustainable agriculture, microbial layer, fermentation.

Introduction

What are Effective Microorganisms?

EM is a carefully combined cultures of naturally occurring microbes that can live together in a stable mixture. These typically include lactic acid bacteria, photosynthetic bacteria, yeasts, actinomycetes and fermenting fungi. The main idea behind EM is simple: by introducing

beneficial microbes into soil or compost, you can influence the existing microbial community support the plant growth, improve nutrient cycling and helps suppress harmful organisms.

Effective Microorganisms (EM) in Agriculture:

Effective Microorganisms (EM) are blends of beneficial microbes used in agriculture as a kind of "environmental probiotic." Farmers apply them to soil, crops or organic waste to improve soil health, boost plant growth and manage waste more efficiently. While some studies show positive effects, others suggest that the benefits often come more from the organic materials mixed with EM than from the microbes themselves.

Main microbial groups and their roles

The key principle behind EM is synergy, microbes help each other:

 Lactic acid bacteria help break down organic matter through fermentation, can reduce harmful microbes and support nutrient availability.

 Photosynthetic bacteria are believed to contribute to plant growth by producing beneficial compounds and supporting nutrient cycling, though their role in soil remains debated. Which use organic compounds and sunlight to produce bioactive substances that support plant growth and microbial activity.

 Yeasts produce vitamins, enzymes, and other bioactive substances that can support plant and microbial activity.

 Actinomycetes and fungi play a major role in conversion of organic material and may help control plant diseases by producing natural antibiotics. Synergistic Relationships (Mutual Support)

Rhizosphere effects of EM

1. Stimulate root growth through microbial metabolites.
2. Enhance nutrient uptake
3. Form protective microbial layers around roots.
4. Induce mild plant defensive responses.

EM application and benefits

Its applications in food waste recycling, enhanced organic composting, enhancing soil structure, increasing soil health and productivity, among other uses, are well documented. Its applications are in the following areas: farming, livestock, environment (polluted waterways, lakes and lagoons) and health care industries, organic production of crops and fruits, as well as flower

cultivation, animal husbandry, fisheries, aquaria and wetlands.

The benefits of EM include its use in the home in daily life for everyone, for the recycling of kitchen waste and turning it into valuable organic material, use in the garden to improve soil structure, increase productivity and suppress both diseases and weeds, solving all kinds of environmental problems such as water, air and soil pollution.

Soil quality and crop yield

Research has shown that applying EM to the soil and plant ecosystem. It will improve soil quality, soil health, growth, yield and quality of crops. EM has been reported to work in the suppression of plant pathogens and diseases, conservation of energy in plants, solubilisation of soil minerals, soil microbial-ecological balance, photosynthetic efficiency and biological nitrogen fixation. EM tends to stimulate the "Rotation Effect". This means that EM can stimulate the regulation of beneficial microorganisms and suppression of harmful ones, which can result from crop rotation. EM prevents putrefaction, decreases pH, suppresses Fusarium propagation, inhibits soil-borne pathogens, fixes and utilises CO_2 and H_2S generated, and promotes active cell and root division. EM produces organic acids that are not usually in the soil, such as lactic acid, acetic acid, amino acids, malic acid and vitamins that could be absorbed by plants. The application of EM compost significantly enhanced organic carbon levels, thereby improving overall soil fertility.

Influence of effective microorganisms (EM-As) on the growth and development of zucchini plants.

Composting

Effective microorganisms accelerate compost decomposition and enhance its quality by enriching the abundance and activity of beneficial macro- and microorganisms. When we pour activated effective microorganisms into environments dominated by putrefactive bacteria, the

microbiomes will be improved, and foul odours will be suppressed.

EM's major effects on crops

TYPE	CROP	EFFECTS
EM-1	Pepper and Chilli	Improved Plant growth and medicinal properties Increased vegetative and root biomass
EM-A	*Aloe arborescens*, *Aloe barbadensis*	Increased Plant growth and quality
EM-A	*Allium cepa*	Increased plant quality and root growth Increased plant growth and fruit production
EM-A	Rose hybrid	Increase vegetative root biomass and biotic resistance
EM-1	Rosemary, sage, mint, thyme	Improved vegetative and roots biomass. Reuse of water for irrigation.

Conclusion

The primary value of effective microorganism lies in their ability to enhance microbial activity, support nutrient cycling, and improved soil structure when applied alongside organic amendments. Positive effects are often associated with processes such as enhanced decomposition, increased availability of plant nutrients, and improved rhizosphere interactions. Their effectiveness is highly context-dependent, varying with soil type, environmental condition and management practices. Evidence suggests that many observed benefits may result from the added organic substrates rather than the microbial inoculants alone. Therefore, consistent and significant improvements in crop productivity and soil health require integration with established agronomic practices, including organic matter management and crop rotation.

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SYNTHETIC MICROBES AND SUSTAINABLE AGRICULTURE

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Abstract

SynComs or Synthetic Microbial Communities, are gaining significant attention in sustainable agriculture as eco friendly alternatives to synthetic or chemical inputs. These designed communities, composed of beneficial microorganisms, work synergistically to enhance soil health, promote plant growth and improve resistance against biotic and abiotic stresses. Their application supports sustainability in crop production, soil health and environmental conservation. This article highlights the potential ability of SynComs in establishing sustainable agriculture for maintaining ecological balance.

Key words: SynComs, Genetic engineering, Sustainable agriculture, r-DNA and Soil health

Introduction:

Currently, agriculture is becoming a major concern because of reducing productivity and degrading lands due to application of chemical fertilizers. The world is realizing that rather increasing sustainable production is more important than increased production by application of inorganic fertilizers. To assist the concept of sustainable agriculture ,organic & biofertilizers are used, but it doesn't have impact as much as inorganic fertilizers. To increase the effectiveness of the biofertilizers, the soil-plant-microbe interactions should be studied. The new concept of "Synthetic Microbes/Synthetic Microbial Communities" helps to develop region/soil/crop specific microbiome which increase the effectiveness of biofertilizers.

This article further discuss more about the concept and its scope in sustainable agriculture.

Synthetic Microbes:

Synthetic microbes are certain microorganisms ”“which are developed through genetic engineering mainly Recombinant DNA(r-DNA) Technology. Synthetic microbes are developed either by addition or deletion of certain genomes in an organism or changing the entire genome sequence or by generating a new genome to perform specific functions.

Synthetic Microbial Communities (SynComs):

Synthetic Microbial Communites or SynComs are group of known species of microorganisms that are assembled together under controlled conditions to understand the interaction of microbial population present in the soil using synthetic biological techniques. SynComs are nothing but microbial consortia consisting of known microbial species that benefit crop health and production. By combining the “Synthetic Microbe Technology” with ‘SynComs’ concept ,we can prepare new beneficial microbial consortia.

Developmental strategies of SynComs:

The Synthetic Microbial Communities or SynComs developed through a series of steps involving are,

1. Understanding the microbial population present in rhizosphere soil of a specific location
2. Identifying the potential beneficial microbiome
3. Screening such microbiomes for the identification of potential beneficial characters
4. Designing SynCom/microbial consortium
5. Analyzing the interaction of microbial consortia with plants
6. Assessment of beneficial effects of microbiome with the plants

Construction of SynComs:

Conventional methods

The conventional methods for the construction of SynComs involves two approaches namely Top-down and Bottom up approaches.Top-down approach involves combining of microbial species for the construction of SynComs.Bottom up approach involves building SynComs community from specific microbial species according to certain desired characters required for the construction of SynComs.

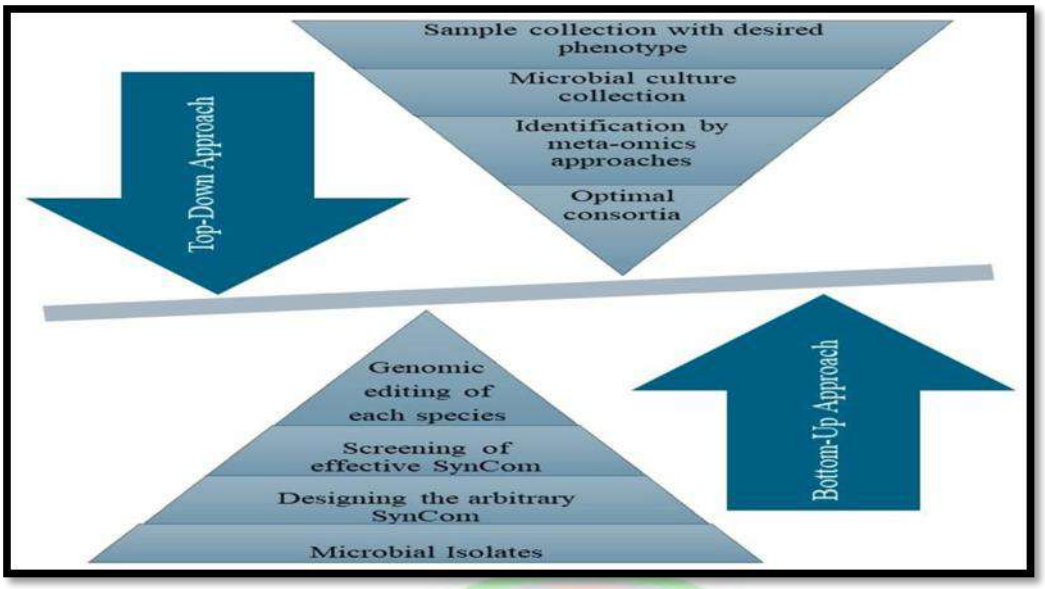

Figure 1. A sketch representing the top-down and bottom-up approach for the construction of SynComs.

Experimental Techniques for the construction of SynComs

The experimental construction of syncoms involves,

1. Sampling
2. Culturing
3. Genomic & Genetic Analysis
4. Functional Analysis
5. Assembling microbes
6. Testing results

Genetic Engineering

The following methodologies in Genetic Engineering are employed for constructing SynComs,

1) Gene selection
2) Addition/deletion of genome
3) Sequencing of entire genome
4) Modification of existing genome.

Computational Models and Genome Sequencing Methodologies:

These models are used to predict the result of the conventional and genomic methods.This model uses Artificial intelligence and Machine learning for prediction.The effectiveness of

microbes are closely related to the genetic markers.Hence,genomic studies are important for analysis of Syncoms.These includes GEM, Bayesian model etc.GEM predicts the characters of Syncoms by analysing the assembled genomes of different microbes.Bayesian model quantifies SynComs using experimental data along with prior knowledge. Apar from this, Geospatial mapping and tracking system using GPS results in monitoring of plant health and development through data collection and analysis(Tariq et al.,2025).

Potential Benefits in Sustainable Agriculture:

There are certain potential benefits of SynComs that help in sustainable agriculture, by improving microbe -microbe interaction and microbe-plant interaction in these ways.

- **Helps in Reduction of synthetic fertilizer Usage**:

  SynComs, including microbes like *Rhizobium & Azospirillum* help in nitrogen fixation thereby enhances the availability of nitrogen in the soil.

- **Enhancement of Plant Growth**:

  PGPR improves nutrient uptake and increases plant biomass thereby enhances plant productivity.

- **Plant Protections**:

  SynComs provide protection against various pests & diseases through antibiosis or competition and provide disease resistant & pest repellant effects.

- **Improves soil health as plant nutrients**:

  SynComs provide wide range of nutrients & enhances the soil structure by helping in organic matter decomposition.

- **Tolerance to environmental stresses**:

  SynComs provide tolerance to salinity, drought, temperature by improvingthe soil structure & enhancing water availability to the plants.

Limiting factors:

- The study of microbiomes of a plant and analyzing the effect of the organisms and isolating takes long time & involves tedious process.
- The development of SynComs has many challenges that all organisms in the community should be compatible without any inhibitory actions.
- SynCom should be stable for a certain period of time in storage & soil/plant ecosystem.
- Synthetic organisms should not have any deleterious/harmful effects on the ecosystem.

- The cost of development of successful SynComs may be high and this limits the availability of syncoms to the farmers.
- The SynComs should not have any residual effect and do not affect the health of the consumers.

Conclusion:

Hence, with the help of Genome Sequencing and Genetic Engineering Technology for the development of region/ soil/ crop tailored Synthetic Microbial Communities (SynComs) with the Synthetic microbes are possible. The emerging concept of 'SynComs' will have an unavoidable effect in the future of Sustainable Agriculture.

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GLOBAL SIGNIFICANCE OF INDIA'S SEAFOOD IMPORT

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Abstract

India's seafood import sector plays an important role in supporting domestic consumption, industrial processing, and international re-export markets. Although India is globally recognized as a major seafood exporter, imports of specific marine products such as salmon, mackerel, tuna, crab, lobster, fish meal, and ornamental fish have increased significantly due to changing consumer preferences, processing requirements, and demand from the hospitality sector. Imported seafood contributes to food diversification, supports value-added seafood industries, and strengthens the supply chain for pharmaceutical and aquaculture sectors. High-value products such as Atlantic salmon and premium shellfish are mainly imported for urban markets, hotels, and restaurants, while fish meal and fish oil imports support aquaculture and poultry industries. Major import partners include Norway, Vietnam, Thailand, China, Japan, and the United States. However, challenges related to quality control, import regulations, disease prevention, and trade balance remain significant. This study examines the commercial value, economic significance, major commodities, trade patterns, challenges, and future prospects of India's seafood import industry.

Keywords: Seafood import, Marine products, Fish trade, Aquaculture inputs, International commerce

Introduction

India is widely known as one of the leading seafood-exporting nations in the world, particularly in frozen shrimp and marine fish products. However, alongside its strong export sector, India also maintains a growing seafood import market that supports domestic

consumption, industrial processing, hospitality services, aquaculture development, and value-added re-export activities. Seafood imports are driven by the need for species that are either not sufficiently available in domestic waters or are demanded by premium consumer markets such as hotels, supermarkets, and urban food chains. The import of high-value marine products such as Atlantic salmon, tuna, crab, lobster, and cod has increased due to rising income levels, expanding international cuisine preferences, and growth in the hospitality sector. Additionally, fish meal, fish oil, and specific aquaculture inputs are imported to support shrimp farming, poultry feed production, and pharmaceutical industries. India also imports ornamental fish and marine biological materials for aquarium trade and research purposes. The seafood import sector contributes to food diversity, industrial productivity, and trade connectivity, although it also raises concerns regarding disease introduction, biosecurity, and foreign exchange expenditure. Effective regulation and quality monitoring are therefore essential for sustainable seafood import management.

Overview of India's Seafood Import System

India's seafood imports system functions through regulated international trade channels involving marine food products, frozen fish, processed seafood, fish meal, fish oil, and ornamental aquatic organisms. The imports are supervised by agencies such as the Food Safety and Standards Authority of India (FSSAI), the Department of Animal Husbandry and Dairying, and customs authorities to ensure compliance with food safety and quarantine standards. Seafood imports mainly enter through major ports such as Chennai, Mumbai, Kochi, Visakhapatnam, Kolkata, and Nhava Sheva. Imported products are distributed to food processing industries, hotels, supermarkets, pharmaceutical units, aquaculture farms, and retail seafood markets. Urban metropolitan cities such as Delhi, Mumbai, Bengaluru, Chennai, and Hyderabad represent major consumption centers for premium imported seafood. In addition to direct consumption, certain imported seafood products are processed and re-exported after value addition, supporting India's seafood trade competitiveness.

Major Imported Seafood Commodities

India imports a variety of seafood products depending on market demand and industrial requirements. Atlantic salmon is one of the most commercially important imported seafood products, particularly for luxury hotels, restaurants, premium supermarkets, and sushi markets.

Since salmon is not naturally abundant in Indian waters, imports mainly come from Norway and Chile to satisfy high-income consumer demand.

Tuna is another important imported product, especially for canning industries and international cuisine markets. High-quality tuna imports support the hotel sector and processed seafood industries. Crab, lobster, scallops, oysters, mussels, and premium shellfish are imported for fine dining establishments and coastal tourism markets. Frozen mackerel and other pelagic fish may also be imported during domestic supply shortages. Fish meal and fish oil represent highly significant industrial imports that support aquaculture feed production, poultry industries, livestock nutrition, and pharmaceutical applications. India also imports ornamental fish species for aquarium trade and breeding industries. These imports expand commercial opportunities across multiple sectors beyond direct seafood consumption.

Import Partner Countries

India imports seafood from several major seafood-producing countries depending on species availability, quality standards, and market pricing. Norway is a major supplier of Atlantic salmon and premium cold-water fish species. Vietnam and Thailand supply processed seafood products, tuna, cephalopods, and value-added frozen marine products. China contributes frozen fish products, shellfish, and aquaculture-related inputs. Japan and the United States are important suppliers of high-quality seafood for hospitality and specialty markets. Indonesia and Malaysia also contribute certain marine products and fish meal exports to India. Chile supplies salmon and cold-water marine products, while European countries support premium shellfish imports. International trade relationships depend on import regulations, sanitary standards, logistics efficiency, and exchange rate conditions. Stable trade partnerships ensure reliable supply chains for both consumption and industrial applications.

Economic Importance of Seafood Import

Seafood imports contribute significantly to India's food diversification and support industries that depend on specialized marine products unavailable in sufficient domestic supply. Premium imported seafood improves the hospitality and tourism sectors by enabling restaurants, hotels, and international food chains to meet global culinary standards. Urban demand for sushi, smoked salmon, lobster dishes, and imported shellfish has created strong commercial opportunities for importers and distributors. Fish meal and fish oil imports are economically important because they support the rapidly expanding aquaculture and poultry industries. Shrimp

farming, fish hatcheries, and animal feed industries depend on imported nutritional inputs for productivity improvement. Pharmaceutical industries also utilize marine oils and bioactive compounds for nutraceutical and medicinal production. Although imports involve foreign exchange expenditure, they contribute indirectly to economic growth through employment generation, industrial development, and high-value market expansion.

Role in Re-Export and Value Addition

Some imported seafood products are not consumed directly but are processed in India for re-export after value addition. Imported tuna, cephalopods, and fish fillets may undergo cleaning, grading, packaging, flavor enhancement, and preservation before being exported to international markets. This strengthens India's seafood processing industry and increases export competitiveness. Processing units benefit from access to imported raw materials when domestic supply is insufficient or when specific international market standards require certain species or product quality. This re-export model improves industrial efficiency and foreign exchange earnings despite initial import costs. Seafood processing hubs in Kerala, Tamil Nadu, Gujarat, and Andhra Pradesh particularly benefit from such integrated trade systems.

Challenges in Seafood Import

India's seafood import sector faces several important challenges related to quality control, disease prevention, market volatility, and regulatory compliance. Imported seafood products may carry microbial contamination, antibiotic residues, heavy metals, or pathogens that threaten public health and aquaculture systems. Strict inspection and quarantine procedures are therefore essential to prevent disease outbreaks and biosecurity risks. Import dependency for fish meal and premium seafood can also create vulnerability to international price fluctuations and supply disruptions. Currency depreciation increases import costs and affects business profitability. Trade restrictions, customs delays, and certification issues can reduce efficiency and raise logistics expenses. Illegal or poorly monitored imports may also threaten domestic producers by creating unfair competition. Balancing import benefits with domestic fisheries protection remains a major policy challenge.

Government Regulations and Policy Support

The Government of India regulates seafood imports through multiple agencies responsible for food safety, animal quarantine, customs clearance, and trade compliance. FSSAI establishes food safety standards for imported seafood products, while the Department of

Fisheries monitors aquatic animal health and disease prevention measures. Import permits, health certificates, residue testing, and cold chain inspections are mandatory for many products. Customs regulations and tariff structures also influence import profitability and domestic market balance. Policies are designed to protect local fisheries while allowing access to necessary industrial and premium food imports. The government encourages domestic fish meal production and sustainable aquaculture development to reduce excessive import dependency. Strengthening traceability systems and digital import monitoring improves transparency and reduces illegal trade risks.

Future Prospects

The future of India's seafood import sector is expected to grow with rising urban incomes, expanding hospitality industries, changing food habits, and increasing demand for premium international cuisine. Imported seafood will continue to support high-value restaurant markets, modern retail chains, and nutraceutical industries. Cold chain expansion and e-commerce seafood delivery platforms will further improve accessibility to imported marine products. At the same time, sustainable import strategies will become more important to ensure food safety, ecological protection, and economic balance. Investment in domestic aquaculture for species substitution may reduce dependence on expensive imports such as salmon alternatives and fish meal replacements. Advanced biotechnology, algae-based feed alternatives, and marine nutraceutical production may transform the future trade structure. Balanced integration of imports with domestic production will be essential for long-term seafood industry resilience.

Conclusion

India's seafood import industry, although smaller than its export sector, holds substantial commercial importance in supporting food diversity, industrial productivity, hospitality growth, and aquaculture development. Imports of premium seafood such as salmon, tuna, crab, lobster, and shellfish satisfy specialized consumer demand, while fish meal and fish oil imports strengthen livestock and aquaculture sectors. The sector also contributes to value-added processing and re-export opportunities that enhance trade efficiency and industrial profitability. However, sustainable growth depends on strong regulatory systems, disease prevention, quality assurance, and balanced trade policies that protect both consumers and domestic producers. Import dependency must be carefully managed to avoid excessive foreign exchange pressure and ecological risks. With effective governance, infrastructure development, and technological

innovation, India's seafood import sector can continue to support economic growth while complementing the country's powerful seafood export industry. It remains an important component of India's broader marine economy and international food trade network.

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INDUSTRIAL EFFLUENT TREATMENT USING MICROBES

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Abstract

Industrial effluents are a major source of environmental pollution, containing a wide range of hazardous substances such as organic pollutants, heavy metals, hydrocarbons, dyes, and emerging contaminants. Conventional treatment methods, though effective to some extent, often suffer from high operational costs and the generation of secondary pollutants. Microbial bioremediation has emerged as a sustainable and eco-friendly alternative that utilizes microorganisms to degrade, detoxify, and transform contaminants into less harmful forms. This article provides a comprehensive overview of industrial effluent characteristics, microbial diversity, treatment technologies, advantages, limitations and future perspective.

Keywords: Microbial bioremediation; Industrial effluent treatment; Microbial consortia; Biofilms; Bacteria; Fungi.

Introduction

The rapid growth of industrialization has significantly increased the discharge of wastewater into natural ecosystems. Industries such as textiles, pharmaceuticals, petrochemicals, food processing and mining generate large volumes of effluents containing toxic and non-biodegradable substances. These pollutants adversely affect aquatic ecosystems, reduce water quality, and pose serious health risks to humans and animals. Traditional wastewater treatment methods, including chemical precipitation, oxidation, and membrane filtration, are widely used

but often involve high energy consumption and operational costs. Additionally, these methods may produce secondary pollutants, creating further environmental challenges.

In contrast, microbial treatment or bioremediation has gained considerable attention as a sustainable approach. Microorganisms possess diverse metabolic pathways that enable them to utilize pollutants as sources of carbon and energy. Through natural biological processes, they convert harmful substances into simpler and less toxic compounds such as carbon dioxide, water, and biomass. This makes microbial treatment a promising solution for managing industrial effluents in an environmentally friendly and cost-effective manner.

NATURE AND COMPOSITION OF INDUSTRIAL EFFLUENTS

Industrial effluents are highly complex and variable in composition, depending on the type of industry and production processes involved. Common characteristics include:

High Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), indicating the presence of large amounts of organic matter.

- Toxic organic compounds, including phenols, dyes, pesticides, and hydrocarbons.
- Heavy metals, such as lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr)
- Oil and grease, particularly in petrochemical and food processing industries.
- Nutrients, including nitrogen and phosphorus, which can lead to eutrophication.

The presence of these contaminants results in oxygen depletion in water bodies, disruption of aquatic ecosystems, and bioaccumulation of toxic substances in the food chain. Therefore, efficient treatment methods are essential to mitigate these impacts.

Microbes in effluent treatment

Microbial treatment can be used instead of traditional wastewater methods because it is cheaper, more efficient and more competent. Bioremediation involves bacteria, fungi, microalgae, yeast etc. these microbes are responsible for degrading or converting contaminants into lesser harmful products. These microbes use biosorption and bioaccumulation to bioremediate. Adsorption occurs when pollutants interact with functional groups on the cell surface. Biosorption can use both live and dead biomass. Bioaccumulation involves intracellular and extracellular processes. Toxins bioaccumulate when they are absorbed from the environment.

Bacteria: The Workhorses of Wastewater Treatment

Bacteria are the most important microorganisms involved in wastewater treatment due to their rapid growth rate and metabolic versatility. They drive the bulk of organic matter degradation and nutrient removal through aerobic, anaerobic, and facultative processes. The treatment of wastewater effluents is based on the capability of bacterial cells to concentrate pollutants (metals). The microbial population and xenobiotic content determine the rate of biodegradation. Plants feed rhizosphere microbes' organic carbon, which helps degrade pollutants. Biofilms in aquatic plants degrade organic compounds like phenols, aldehydes. Methanotrophs use methane to obtain carbon and energy and break down various harmful organic compounds

Bacteria	**Role in bioremediation**
Tolypothrixceytonica and *Anabaena oryzae*	Effective in reducing industrial wastewater.
Aphanocapsu sp. and *Plectonema sp.*	Degrade crude oil.
Desulfovibrio, Desulfotomaculum, Desulfobacter, and *Desulfococcus* genera	Anaerobic sulphate reducing bacteria used in sewage treatment.
Aeromonas hydrophila, Bacillus subtilis, Bacillus cereus, Pseudomonas sp., Pseudomonas luteola, Proteus mirabilis	Degrade azo dyes under in textile effulents.
Pseudomonas aeruginosa	Decolorize various azo dyes and Navitan Fast Blue S5R under aerobic conditions
Mycobacterium, Burkholderia, Gordonia, Brevibacterium, Dietzia, Aeromicrobium, Pseudomonas, Aeromonas, Flavobacteria, Nocardia, Modococci, Chrobacteria, Moraxella, Cyanobacteria, Streptomyces, Bacilli, Arthrobacter	Degrade petroleum products
Acinetobacter sp., Bacillus sp. Pseudomonas aeruginosa, Cellulosimicrobium, Staphylococcus sp.	Degradation of heavy metals.

Fungi: Degraders of complex organic pollutants

Fungi play a crucial role in degrading complex and recalcitrant pollutants that are resistant to bacterial degradation. The two important characteristics of fungi that make them an ideal candidate for wastewater treatment are the secretion of many extracellular enzymes and the

hyphal mesh of fungi that protects the internal organelles from the harmful effects of contaminants.

Cephalosporium aphidicola, Aspergillus parasticia, Verticillum terrestre, candida sp., Acremonium sp., glomus sp, minimedusa sp., talaromyces, hydnobolites, peziza, and other fungal species can be used in wastewater treatment. *Aspergillus flavus, Aspergillus sp., Pleurotus sp., Aspergillus bombycis, Aspergillus niger, Morchellaesculenta, Aspergillus salinarus, Bjerkandera adusta* are used to degrade dyes through biosorption and enzymatic degradation.

Micro algae: Photosynthetic partners

Algae contribute to wastewater treatment by producing oxygen through photosynthesis supporting aerobic microbial activity. These include the use of eukaryotic and cyanobacteria for biological wastewater treatment.

Examples include *Chlorella sp, Scenedesmus sp, Chlorella sp,Picochlorum, Tetraselmis sp,* and other algal and cyanobacterial strains like *Anabaena sp, Oscillator sp., spirulina sp., chroococcus sp., Pseudospongiococcus sp., Scytonema sp., Dolichospermum* are used in wastewater treatment.

Yeast

Yeasts can be used to eliminate pollutants like heavy metals from environment and can also help reduce COD levels and remove mono and polyphenols because it absorbs, accumulate and degrade toxic compounds into nontoxic forms.

Saccharomyces cerevisiae, Candida tropicalis degrade organic compounds and absorb heavy metals. *Saccharomyces cerevisiae, Galactomyces geotrichum, Trichosporon beigelii, candida krusei* can degrade dyes in wastewater.

Microbial Treatment Technologies

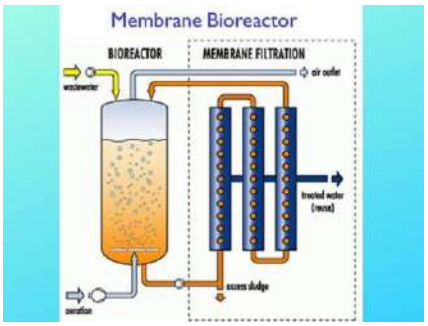
1.Activated Sludge Process: A widely used method in which microorganisms degrade organic matter in aerated tanks. The resulting sludge is recycled to maintain microbial population.

2. Biofilm Reactors: Microorganisms grow on surfaces forming biofilms, which provide stability and enhanced pollutant removal.

3. Anaerobic Digestion: Used for high-strength wastewater, this process converts organic matter into methane and carbon dioxide in the absence of oxygen.

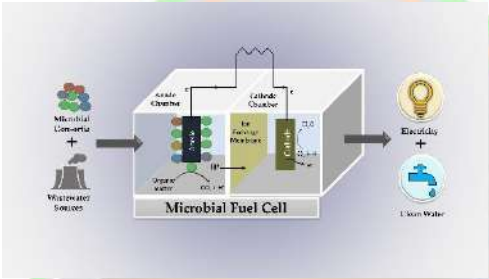
4.Sequencing Batch Reactors (SBR): Operate in cycles and allow efficient removal of organic matter and nutrients.

5.Membrane Bioreactors (MBR): It integrates biological treatment with membrane filtration to produce high quality effluent.



6.Constructed Wetlands: Natural systems that use plants and microorganisms for wastewater treatment.

7.Microbial Fuel Cells: Innovative systems that generate electricity while treating wastewater.



Microbial consortium: emerging technology

Using a single microbe strain to treat wastewater may not give effective results, and efficiency can be compromised. So, the development of consortia is an emerging approach for the wastewater treatment. The fundamental principle in the microbial community is utilizing beneficial relationships which are promoting in pollutant removal from wastewater. In the natural habitat, biofilm is formed by aggregating different groups of microbes attached through exopolymer substances. The whole system is synergistic with microbial partners' contributing toward forming a strong community.

Conclusion:

Microbial treatment of industrial wastewater represents a sustainable and forward-looking solution to the growing global challenge of water pollution. The natural ability of microorganisms such as bacteria, fungi, algae and yeast to degrade complex contaminants offers an eco-friendly and cost-effective alternative to conventional treatment methods. The

development of robust microbial consortia has significantly enhanced more efficient degradation and detoxification pf pollutants. Integrating engineered microbial systems with modern technologies along with interdisciplinary collaboration is essential for improving wastewater efficiency. Therefore, microbial remediation can play a crucial role in achieving environmentally sustainable and commercially viable wastewater management system in future.

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UNDER KEEL CLEARANCE: A CRITICAL FACTOR IN SAFE NAVIGATION

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Abstract

Under Keel Clearance (UKC) remains a fundamental consideration in ensuring safe and efficient maritime operations. It refers to the vertical distance between the lowest point of a vessel's keel and the seabed beneath it. This margin acts as a critical safety buffer, particularly when ships transit through shallow waters such as channels, rivers, estuaries, and port approaches, helping to prevent contact with the seabed. Maintaining adequate UKC is essential for reducing the risk of grounding, preserving the structural integrity of the vessel, and safeguarding onboard machinery. It also plays a significant role in minimizing environmental risks, as hull damage in restricted waters can lead to pollution incidents. Beyond safety, sufficient clearance supports vessel maneuverability, allowing ships to respond effectively to navigational and environmental conditions. These systems provide more accurate and responsive assessments, enabling safer navigation even in constrained waterways. Effective UKC management not only enhances navigational safety but also contributes to operational efficiency. By optimizing clearance margins, ports can accommodate larger vessels, reduce delays, and improve overall throughput. As global shipping continues to grow in scale and complexity, the importance of precise and adaptive UKC management will only become more pronounced.

Introduction

Maritime transport carries a substantial share of global trade and remains a cornerstone of

the world economy. Ships routinely move bulk commodities, petroleum products, agricultural goods, industrial equipment, and consumer items across international borders, enabling supply chains to function efficiently on a global scale. Given the magnitude and value of this activity, ensuring navigational safety is of paramount importance. While open-ocean navigation is generally considered low risk, the level of complexity and hazard increases significantly as vessels approach confined or shallow waters. Areas such as port approaches, coastal channels, inland waterways, canals, and river estuaries demand heightened attention due to restricted depths and limited maneuvering space. In these environments, one of the most critical technical considerations is Under Keel Clearance (UKC). Even when charts indicate sufficient water depth, the actual clearance beneath a vessel is subject to constant variation. Factors such as tidal changes, vessel speed, loading condition, and wave dynamics can quickly reduce the available margin between the keel and the seabed. These fluctuations make precise assessment and continuous monitoring essential.

Any unintended contact between a vessel's keel and the seabed can have serious consequences. Structural damage to the hull, delays in cargo delivery, and expensive repair operations are common outcomes. In more severe cases, such incidents may obstruct navigational routes or result in environmental pollution, particularly if hazardous cargo or fuel is involved. For these reasons, effective management of under keel clearance is not only a matter of operational efficiency but also a critical component of maritime safety and environmental protection. The available under-keel space is influenced by a range of dynamic and static factors. These include the vessel's draft, tidal variations, squat effects caused by movement through water, trim and heel conditions, wave action, seabed characteristics, and water density. Each of these variables can alter the effective clearance and must be carefully assessed during voyage planning and port entry. In recent years, advancements in maritime technology have transformed UKC management. Traditional manual calculations have increasingly been replaced by dynamic systems that integrate real-time environmental data with vessel-specific parameters.

Meaning of Under Keel Clearance

The Under Keel Clearance can be defined as the vertical distance between the deepest part of the ship's keel and the bed of the sea under the ship at any time. In layman's terms, the UKC is the free surface beneath the ship. The reason why the UKC is crucial in maritime operations is because the ship does not stay in one place while sailing. As a result, it heaves up

and down due to wave movements, changes trim when the vessel's cargo load or speed changes, and goes even deeper into the water body due to hydrodynamic effects when sailing through shallow waters. Thus, the UKC is always dynamic for a sailing ship. It should be noted that a positive UKC arises when the depth of water exceeds that of the vessel's draft. When the water depth equals the draft, a grounding risk emerges.

$$\text{UKC} = \text{Available Water Depth} - \text{Ship Draft}$$

This formula represents the basic principle of UKC, although practical navigation requires additional allowances for dynamic conditions.

Historical Development of UKC Practice

For sailors in previous centuries, the existence of sufficient water under their ships could be ascertained by relying on local knowledge, sightseeing, sounding measurements, and experiences of the tides. In those days, nautical charts were not reliable, and surveys could only cover specific regions. Consequently, the ships used large margins of safety or waited until high tides before venturing into shallow waters. Scientific developments and technological advancements have made the calculation of UKC more exact. The application of hydrographic surveys, sounders for measuring depths, tide gauges, computer navigation devices, and even satellite-based positioning systems enables navigators to determine UKC accurately. The management of UKC in today's world is a scientific undertaking based on current and forecasted data.

Importance of Under Keel Clearance

Safety, economics, and environmental protection are some of the factors in which the significance of UKC is found. To start with, UKC is essential in ensuring that grounding does not occur on the vessel. Should the boat come into contact with the sea floor, there will be possibilities for the hull to get torn or dented, while propellers and rudders could become faulty thus leaving the vessel without any way of moving or steering. Such occurrences may put the crew at risk as well as interfere with other traffic around the ship. Sufficient UKC makes manoeuvring safer by reducing risks that arise when the boat moves too close to the seabed. Economically, sufficient UKC is crucial for avoiding delays and effective allocation of berths at ports where even bigger draft ships can easily access. Environmental wise, grounding can lead to fuel leakage, cargo spillage, and damage to the coastal habitat of marine life.

Variables Influencing UKC

There are several factors that affect the amount of UKC available, and these factors can keep on changing at any time during the journey. Draft is one of the most important factors that impact UKC. Whenever cargo, fuel, ballast water, or other supplies are added to the ship, it starts sinking further in the water, and thus its draft becomes larger, resulting in lower UKC. Another important variable that influences UKC is tide. In places where there is a tidal flow, the sea level rises and falls throughout the day. Hence, many ships having large drafts prefer to travel during the time when the tides are high.

Dynamic aspects are also equally significant. Squat is a phenomenon wherein a vessel traversing a shallow area causes water movement around its hull, leading to a reduction in pressure and subsequently causing the ship to sit deeper into the water surface and occasionally trim by either head or tail. Squat is directly proportional to the speed of the vessel and is aggravated when traversing through narrower channels. Movement of waves also contributes to temporary lowering of UKC due to heaving, pitching, and rolling. In case a vessel heels during turning action or because of winds, the side of the hull will touch the sea bottom.

Static and Dynamic UKC

Conventionally, the calculation of UKC was done using static calculations that considered the depth of the navigational route from charts, tides, and draft of the vessel. Static calculations are easy and helpful during planning; however, they do not take into account any factors relating to the movement of the vessel or changes in environmental conditions. The modern-day shipping industry uses dynamic calculations of UKC to allow ships to navigate safely. Dynamic calculations consider the actual height of the tide, squat, wave action, trim, heel, density of water, speed of the vessel, and recent surveying data from the channel being used. They provide accurate information on whether a ship can transit through a certain point at a specific speed..

Example of UKC Assessment

Consider a vessel approaching a harbor where the charted depth is 14 meters. If the tide adds 1 meter, the available water depth becomes 15 meters. If the ship's draft is 13.2 meters, the initial static UKC is:

$$UKC = 15 - 13.2 = 1.8\ m$$

This value may appear sufficient, but if squat at transit speed is estimated at 0.6 meters and wave motion may reduce clearance by another 0.4 meters, the effective UKC becomes only 0.8 meters.

This example demonstrates why navigators must include dynamic allowances rather than relying solely on chart depth and draft.

Images : Under keel clearance

UKC in Different Waterways

UKC plays a role that varies according to the characteristics of each waterway type. For example, where open coastal access is required, the influences of wave action and swell are likely to be important factors, thus necessitating increased safety margins. In dredged channels, issues relating to squat and width limits will assume significance. When rivers or estuaries are involved, the process of sedimentation, flow conditions, and the influence of fresh water will result in rapid variations in depth availability. Within narrow canals, water flow limitations and banking influences will increase hydrodynamic considerations.

Role of Port Authorities and Pilots

The port authorities have a key function in managing the UKCs because they provide guidelines such as proposed restrictions, tides, reporting requirements, and channel information. Most ports use live systems that monitor tide, currents, weather, and traffic information. The harbor master may hold off on moving vessels if there is no safe clearance. Marine pilots are very important as they provide their expertise locally, helping the ship masters to navigate

through the channel. It is very important to know how the channel behaves, the turning points, currents, and even the laws of the port.

Role of Ship Master and Bridge Team

Despite the advice provided by the relevant authorities, it is the master of the vessel who bears full responsibility for ensuring the safety of the ship. It is essential that prior to the passage through shallow waters, there is a clear understanding of the true draft, trim, stability state, depth of the passage, tides, and squat. The passage plan will include such parameters as maximum speed, turning points, anchoring spots, and communication methods. While underway, it is necessary to monitor the depth sounding equipment, electronic chart, radar, and even use the visual aid in case of necessity.

Challenges in UKC Management

However, there are still some difficulties that cannot be avoided. For example, sedimentation might lower the depth of channels between surveys, which would lessen the accuracy of the information provided in the charts, especially if the surveying process is not conducted in time. Moreover, weather conditions might suddenly change, resulting in the occurrence of waves, low water level, or insufficient visibility. One of the most widespread causes of ship accidents is human error, such as inaccurate input of the draft or wrong calculations regarding the tides and squats. The last difficulty relates to the fact that ships are getting bigger.

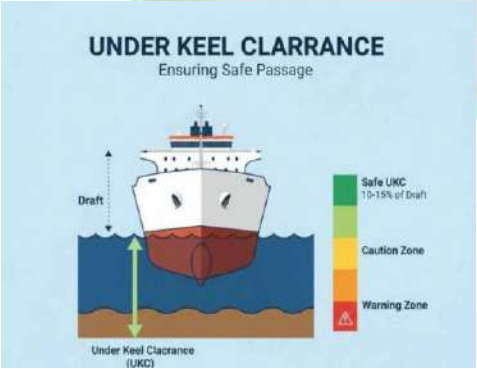

Image : Under keel clearance

Economic and Environmental Significance

Bad UKC management can result in considerable monetary loss. A grounding case will lead to the employment of tug services, salvaging, dry dock, cargo examination, hull repair, and oil spill containment. It may cause port congestion and hinder the supply chain since it blocks access into the port. Insurance companies can claim for insurance coverage in such cases. On the other

hand, the environmental impacts may be great. This includes damage to the environment through oil spills, release of chemicals to the sea, or the bottom of the sea getting disturbed.

Best Practices for Safe UKC Management

Good UKC management starts with good information. The draft must be determined accurately, taking into account any trim or list. Mariners should review the current charts, Notices to Mariners, tidal data, and weather predictions. In the passage plan, speed management, squat, turning circles, and alternative plans should be considered. In the voyage, depth sounding equipment and navigational aids should be watched at all times. Good communication with pilots and harbor masters is important. If there is any doubt, it would be better to slow down, delay, wait for a higher tide, or lighten the ship than to continue with inadequate UKC.

Future Developments

The future of managing UKCs is tied closely with advances in technology. The use of artificial intelligence could be used to help predict safe transits for ships through analyzing tidal information, weather conditions, traffic volume, and ship performance capabilities. Autonomous survey vessels and seabed monitors can keep track of channel depths continually. There could also be satellite technology that can aid in monitoring water levels, as well as digital twin models of ports simulating ship navigation before arrival.

Conclusion

Under Keel Clearance (UKC) is a fundamental parameter in maintaining the safety of vessels operating both at sea and within port limits. Although the concept is straightforward—referring to the vertical distance between a ship's keel and the seabed—its practical application is far more complex and demands careful evaluation. Determining adequate UKC requires consideration of multiple interrelated factors. These include the vessel's draft, tidal variations, and the squat effect that occurs as a ship moves through water. In addition, wave-induced motions, as well as the ship's trim and heel, can significantly influence the effective clearance. External conditions such as channel characteristics and seabed composition further complicate the assessment. Accurate evaluation of these variables is essential to ensure that sufficient clearance is maintained at all times. Proper UKC calculation not only supports safe navigation but also plays a crucial role in preventing grounding incidents, thereby protecting the vessel, its cargo, and the surrounding marine environment. Key factors influencing UKC include the vessel's draft, tidal conditions, squat effect, wave motion, trim and heel, as well as channel characteristics and seabed

conditions. A precise assessment of these elements is essential to maintain adequate clearance and prevent grounding, thereby safeguarding the vessel, its cargo, and the marine environment.

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COMMERCIAL SIGNIFICANCE OF SEAWEEDS

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Abstract

Seaweed has emerged as one of the most valuable marine bioresources with significant commercial importance in food, pharmaceuticals, cosmetics, agriculture, and biotechnology industries. These marine macroalgae, classified as red, brown, and green algae, contain abundant bioactive compounds such as polysaccharides, proteins, vitamins, minerals, antioxidants, and essential fatty acids that support diverse industrial applications. Seaweeds such as *Kappaphycus alvarezii*, *Gracilaria*, *Sargassum*, *Ulva*, and *Laminaria* are extensively cultivated and harvested for the production of agar, carrageenan, and alginates, which serve as stabilizers, thickeners, and gelling agents in food and pharmaceutical products. Their increasing use in biofertilizers, animal feed, nutraceuticals, and renewable biofuel production further strengthens their economic relevance. In addition to industrial applications, seaweed farming contributes to coastal livelihoods, environmental sustainability, and blue economy development. This study explores the commercial value, industrial utilization, economic significance, and future prospects of seaweed in global and regional markets.

Keywords: Seaweed, Marine algae, Commercial value, Bioeconomy, Industrial applications

Introduction

Seaweed refers to large marine algae that grow in coastal and marine ecosystems and play a significant role in both ecological balance and economic development. These multicellular marine macroalgae are broadly classified into red algae (Rhodophyta), brown algae (Phaeophyta), and green algae (Chlorophyta) based on pigmentation, biochemical composition, and habitat characteristics. For centuries, seaweed has been used as food and medicine in Asian

countries such as Japan, China, Korea, and India. In recent decades, scientific advancement and industrial demand have transformed seaweed into a commercially important natural resource with expanding applications in pharmaceuticals, agriculture, cosmetics, biotechnology, and environmental management. Seaweed possesses high nutritional value due to its richness in proteins, dietary fiber, polysaccharides, minerals, vitamins, polyphenols, and omega fatty acids. These characteristics make it a valuable raw material for functional foods and nutraceutical products. Additionally, hydrocolloids extracted from seaweeds such as agar, alginate, and carrageenan are widely used as stabilizers, emulsifiers, and gelling agents in food and pharmaceutical industries. The increasing global demand for sustainable resources and environmentally friendly industrial inputs has significantly enhanced the commercial importance of seaweed. As part of the blue economy, seaweed farming supports employment generation, export growth, and coastal ecosystem conservation.

Classification and Diversity of Commercial Seaweeds

Commercially important seaweeds are mainly grouped into red, brown, and green algae, each possessing unique industrial applications. Red algae such as *Gracilaria*, *Gelidium*, and *Kappaphycus alvarezii* are primarily used for agar and carrageenan extraction. Agar is widely utilized in microbiological culture media, food products, and pharmaceutical formulations, while carrageenan is used in dairy products, cosmetics, and processed foods as a thickening and stabilizing agent.

Brown algae such as *Sargassum*, *Laminaria*, *Turbinaria*, and *Macrocystis* are major sources of alginates, iodine, and fucoidan. Alginates are commercially valuable in textile printing, paper industries, wound dressings, and dental impressions. Brown seaweeds also possess antioxidant and anti-inflammatory compounds that enhance their medicinal importance. Green algae such as *Ulva* and *Enteromorpha* are increasingly used in biofertilizer production, aquaculture feed, and human nutrition due to their high protein and mineral content. This diversity allows seaweed to serve multiple industrial sectors simultaneously, increasing its economic value across global markets.

Seaweed in Food and Nutraceutical Industries

The food industry represents one of the largest sectors utilizing seaweed for direct consumption and food processing. In East Asian countries, edible seaweeds such as *Porphyra* (nori), *Laminaria* (kombu), and *Undaria* (wakame) are staple dietary components valued for

taste and nutritional benefits. These seaweeds are rich in iodine, calcium, magnesium, vitamins A, B, C, and E, and dietary fibers that support digestive health and metabolic regulation.

Seaweed-derived hydrocolloids such as agar and carrageenan are extensively used in confectionery, bakery products, dairy products, beverages, and meat processing. Their gelling and stabilizing properties improve texture, shelf life, and product quality. In nutraceutical industries, seaweed extracts are formulated into capsules, powders, and functional beverages aimed at improving immunity, thyroid function, cardiovascular health, and weight management. The global preference for plant-based diets and natural health products has further increased the commercial demand for seaweed-derived nutraceuticals.

Pharmaceutical and Cosmetic Applications

Seaweed has gained considerable attention in pharmaceutical industries because of its bioactive compounds with antioxidant, antimicrobial, antiviral, anti-inflammatory, antidiabetic, and anticancer properties. Sulfated polysaccharides such as fucoidan, laminarin, and carrageenan exhibit therapeutic potential in immune regulation, wound healing, and cancer prevention. Seaweed-derived compounds are increasingly investigated for drug discovery and biomedical applications.

In the cosmetic industry, seaweed extracts are used in skincare products, anti-aging creams, shampoos, facial masks, and body lotions due to their moisturizing, anti-inflammatory, and skin-rejuvenating properties. Minerals, vitamins, and antioxidants present in seaweed improve skin elasticity and protect against oxidative stress. Marine cosmetics are becoming highly popular because consumers increasingly prefer natural and sustainable beauty products. This has created strong commercial demand for seaweed-based cosmetic ingredients worldwide.

Agricultural Importance and Biofertilizer Production

Seaweed is widely used in agriculture as biofertilizers and plant growth stimulants because of its high content of micronutrients, amino acids, plant hormones, and organic matter. Liquid seaweed extracts improve seed germination, root development, flowering, fruiting, and crop yield while reducing dependence on chemical fertilizers. Seaweed biofertilizers enhance soil microbial activity and improve resistance against pests and environmental stress.

Species such as *Sargassum*, *Ascophyllum nodosum*, and *Ulva* are commonly processed into foliar sprays and soil conditioners for sustainable agriculture. Organic farming systems particularly benefit from seaweed-based products due to their eco-friendly nature and long-term

soil health benefits. The growing emphasis on sustainable agriculture and reduced chemical input has significantly expanded the commercial market for seaweed fertilizers and agricultural biostimulants.

Seaweed in Animal Feed and Aquaculture

Seaweed has become an important component in livestock feed and aquaculture because of its nutritional richness and health-promoting properties. It provides proteins, essential amino acids, minerals, vitamins, and bioactive compounds that improve animal growth, immunity, and reproductive performance. Seaweed supplements in poultry and cattle feed enhance digestion, milk production, and disease resistance.

In aquaculture, seaweed serves both as feed and as an environmental management tool in integrated multi-trophic aquaculture systems. Fish, shrimp, and shellfish farming increasingly incorporate seaweed to improve water quality by absorbing excess nutrients and reducing pollution. Additionally, recent studies show that specific seaweed additives can reduce methane emissions from cattle, increasing their relevance in climate-smart agriculture. This multifunctional role strengthens the economic value of seaweed in livestock and fisheries sectors.

Seaweed Farming and Coastal Economy

Seaweed farming has become a major source of livelihood for coastal communities, especially in India, Indonesia, the Philippines, China, and Tanzania. Cultivation methods such as raft culture, long-line systems, and off-bottom farming allow large-scale production with relatively low investment. Species like *Kappaphycus alvarezii* and *Gracilaria* are extensively cultivated due to their high market demand and rapid growth rates.

In India, coastal states such as Tamil Nadu and Gujarat have significant potential for seaweed farming, contributing to rural employment and women's self-help group income generation. Seaweed farming supports the blue economy by combining economic productivity with marine ecosystem sustainability. Export of processed seaweed products generates foreign exchange earnings and strengthens marine resource-based industries. Government support and scientific interventions have further improved production efficiency and commercial viability.

Biofuel and Environmental Applications

Seaweed is increasingly recognized as a promising raw material for renewable biofuel production due to its fast growth, high carbohydrate content, and absence of lignin. Unlike

terrestrial biofuel crops, seaweed cultivation does not require freshwater, arable land, or chemical fertilizers, making it environmentally sustainable. It can be converted into bioethanol, biogas, biodiesel, and biohydrogen, supporting clean energy development.

Environmental applications of seaweed also include carbon sequestration, wastewater treatment, and heavy metal removal. Seaweed absorbs excess nutrients such as nitrogen and phosphorus, helping control eutrophication and marine pollution. Its role in climate change mitigation and ecosystem restoration increases its non-market commercial value by supporting sustainable environmental management. This dual benefit of economic production and ecological protection makes seaweed a strategic resource for future industries.

Challenges and Future Prospects

Despite its vast commercial potential, the seaweed industry faces several challenges including inconsistent supply, post-harvest losses, lack of processing infrastructure, market fluctuations, and limited awareness among coastal farmers. Climate change, ocean warming, and disease outbreaks also threaten seaweed cultivation systems. In many developing countries, insufficient policy support and weak value chain management reduce profitability.

Future development requires improved cultivation technologies, genetic improvement of high-yielding strains, efficient drying and storage systems, and stronger industrial linkages. Research on high-value bioactive compounds, pharmaceutical applications, and advanced biotechnology can significantly increase market value. Government initiatives promoting blue economy strategies, startup support, and marine entrepreneurship can further accelerate seaweed commercialization. Sustainable farming practices and international trade expansion will determine the future success of the seaweed industry.

Conclusion

Seaweed represents one of the most promising marine resources with exceptional commercial value across food, pharmaceutical, agricultural, cosmetic, and bioenergy sectors. Its diverse biochemical composition supports multiple industrial applications, while its cultivation contributes significantly to coastal livelihoods and sustainable economic development. The extraction of agar, alginates, and carrageenan alone has established seaweed as a critical raw material in global industries, while emerging uses in nutraceuticals, biofertilizers, and renewable energy continue to expand its market potential.

Beyond economics, seaweed offers substantial environmental benefits through carbon capture, water purification, and ecosystem restoration, strengthening its importance in climate-resilient development. However, maximizing its commercial potential requires scientific innovation, policy support, infrastructure development, and sustainable management practices. Seaweed should be viewed not only as a marine crop but also as a strategic bioresource capable of transforming the future of blue economy systems. Its integration into modern industries presents significant opportunities for both economic growth and environmental sustainability.

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DYNAMIC EPIGENETIC REGULATION OF IMPRINTED GENES: MECHANISMS, PHENOTYPIC IMPACT AND FUTURE APPLICATIONS

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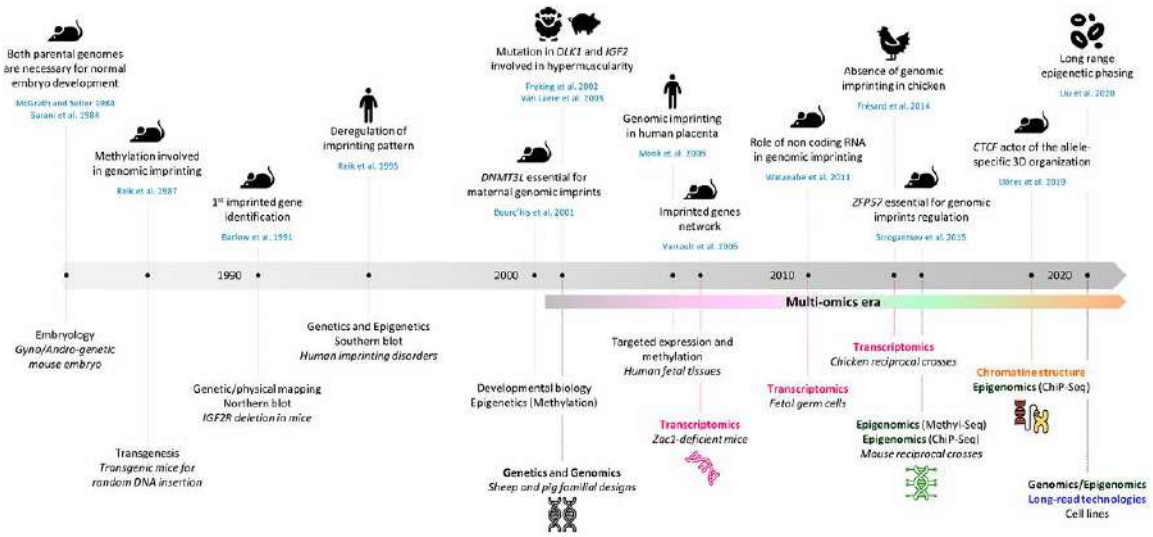
Abstract

Genomic imprinting is not a static phenomenon; rather, it exhibits dynamic regulation across developmental stages, tissues and environmental conditions. Imprinted genes demonstrate flexibility in expression, allowing organisms to adapt gene dosage according to physiological needs. A notable example is the *Dlk1* gene, which is strictly expressed from the paternal allele during embryonic development. However, after birth, this imprinting is selectively relaxed in neurogenic niches, resulting in increased gene dosage that supports neural stem cell maintenance and lifelong neurogenesis (Ferron et al., 2011). This dynamic gain or loss of imprinting highlights an essential principle: epigenetic regulation can fine-tune gene expression without altering DNA sequence, enabling context-dependent biological responses. Such plasticity is critical for maintaining tissue homeostasis and developmental flexibility.

Role of Imprinted Genes in Placental Function and Nutrient Allocation

Imprinted genes play a central role in placental development and fetal growth regulation, particularly in balancing nutrient allocation between mother and fetus. The *Igf2–H19* locus serves as a key regulatory hub, functioning as a nutritional and developmental sensor that integrates environmental signals such as maternal diet and energy availability (Fowden et al., 2010). This locus exemplifies the evolutionary “parental conflict” theory, where paternally expressed genes promote fetal growth, while maternally expressed genes restrict excessive resource utilization. Proper functioning of this system ensures optimal fetal development while preserving maternal health.

Disruption of this balance can lead to abnormal growth patterns and long-term metabolic disorders.



Different timeline of important discoveries in genomic imprinting and novel high-throughput sequencing technologies. The references cited in the figure are also present in the text unless they are mentioned hereafter (Surani et al., 1984; Watanabe et al., 2011; Strogantsev et al., 2015)

Epigenetic Regulation and Functional Complexity of the H19–IGF2 Axis

The *H19* gene, initially identified as a fetal-specific transcript, plays a complex regulatory role in development and disease. Although often described as a tumor suppressor, its primary function appears to be linked to embryonic differentiation and developmental regulation (Pachnis et al., 1988; Hao et al., 1993). *H19* influences the expression of *IGF2* through trans-regulatory mechanisms, affecting translation efficiency and protein levels (Li et al., 1998). During early embryonic development in sheep, *H19* expression coincides with trophoblast attachment and increased *IGF2* activity, suggesting coordinated regulation of placental growth and implantation (Lee et al., 2002).

Importantly, reduced maternal expression of *H19* can activate the normally silent maternal *IGF2* allele, leading to increased fetal growth and birth weight, demonstrating how epigenetic alterations directly influence phenotype. Furthermore, studies have shown that imprinting of *H19* is independent of genomic integration sites and remains stable even when its transcriptional unit is modified, emphasizing the robustness of epigenetic control mechanisms (Pfeifer et al., 1996).

DNA Methylation and Allele-Specific Regulation: IGF2R as a Model

The *IGF2R* gene provides a clear example of allele-specific DNA methylation controlling gene expression. In humans, differential methylation occurs at specific CpG islands, with one region being hypermethylated on the maternal allele while another remains unmethylated (Riesewijk et al., 1996). These methylation patterns regulate transcriptional activity by influencing chromatin structure and accessibility. Interestingly, differences in methylation patterns between species (e.g., humans and mice) indicate that DNA conformation and genomic context play significant roles in imprinting regulation. Such mechanisms demonstrate how subtle epigenetic modifications can produce significant functional differences in gene expression, ultimately affecting growth, metabolism and disease susceptibility.

Epigenetic Mechanisms Underlying Imprinting

The regulation of imprinted genes is mediated by a network of epigenetic mechanisms, including:

- DNA methylation at differentially methylated regions (DMRs)
- Histone modifications (acetylation, methylation, phosphorylation)
- Chromatin remodeling and nucleosome positioning
- Non-coding RNAs (lncRNAs and miRNAs)

DNA methylation acts as a primary imprinting mark, silencing one parental allele. Histone modifications alter chromatin compaction, thereby regulating gene accessibility. Non-coding RNAs further modulate gene expression by interacting with chromatin and transcriptional machinery. Together, these mechanisms form a multi-layered regulatory system that ensures precise temporal and spatial control of gene expression.

Epigenetic Manipulation of Phenotype: From Mechanism to Observable Traits

Epigenetic regulation of imprinted genes has a direct and measurable impact on phenotype. Changes in imprinting status can lead to:

- Altered fetal growth rates
- Variations in birth weight and body composition
- Differences in metabolic efficiency and disease susceptibility

For example, activation of the maternal *IGF2* allele due to reduced *H19* expression can increase fetal growth, while improper imprinting in cloned animals has been associated with developmental abnormalities and high mortality rates (Young et al., 2003). These examples

illustrate that epigenetic modifications act as a bridge between genotype and phenotype, translating environmental and developmental signals into observable biological outcomes.

Practical Importance in Livestock and Farming Systems

In livestock production, imprinting has profound implications for:

- Growth performance and feed efficiency
- Reproductive success and embryo viability
- Milk production and carcass quality

Understanding imprinting mechanisms allows for precision breeding strategies, where parental origin of alleles is considered alongside genetic merit. For farmers, this means:

- Selecting breeding pairs that optimize growth-promoting paternal genes
- Managing maternal nutrition to influence epigenetic programming of offspring
- Reducing losses associated with embryonic mortality and developmental defects

Thus, imprinting knowledge can directly enhance productivity, profitability and sustainability in farming systems.

Future Perspectives: Integrative Omics and Precision Livestock Genomics

The future of imprinting research lies in integrative omics approaches, combining:

- Genomics (DNA variation)
- Epigenomics (methylation, histone marks)
- Transcriptomics (gene expression profiles)
- Proteomics and metabolomics

By integrating transcriptomic data with epigenetic profiles, researchers can identify allele-specific expression patterns and regulatory networks governing complex traits. This systems-level understanding will enable:

- Development of epigenetic biomarkers for selection
- Early prediction of growth and disease traits
- Design of precision nutrition programs tailored to genetic background

For farmers, this translates into data-driven decision-making, where breeding, feeding and management strategies are optimized based on molecular insights. In the long term, advances in gene editing and epigenome modulation may allow controlled manipulation of imprinting patterns, opening new avenues for improving livestock productivity while maintaining animal welfare.

Conclusion

The dynamic nature of genomic imprinting highlights its role as a key regulatory interface between genetics, environment and phenotype. Through mechanisms such as DNA methylation, histone modification and non-coding RNA regulation, imprinted genes orchestrate critical processes in development and growth. Their ability to respond to environmental cues and influence economically important traits makes them highly relevant in modern livestock production and biomedical research. With the integration of multi-omics technologies, genomic imprinting is poised to become a cornerstone of precision agriculture and future breeding strategies, ultimately benefiting both scientific advancement and practical farming applications.

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BANANA BURROWING NEMATODE (*RADOPHOLUS SIMILIS* THORNE, 1949) – A SILENT THREAT TO SOUTH INDIAN PLANTATIONS

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Introduction

Banana (*Musa* sp.) is the most important fruit crop in India grown both in tropical and subtropical region contributing about 37% of the total fruit production. Banana is a rich source of carbohydrate and is rich in vitamins particularly vitamin B. It is also a good source of potassium, phosphorus, calcium and magnesium.

Plant parasitic nematodes and microbivorus nematodes are the most common, abundant and dominant groups in the community of nematodes in Banana plantations[1]. Phytoparasitic nematodes are one of the major factors negatively affecting the banana production throughout the world. More than 151 nematode species of 51 genera have been documented worldwide. Nematode infestations, notably *M. incognita* and *R. similis*, can result in substantial reductions of 20–30% yield[2]. Other nematode species viz., lesion nematode, *Pratylenchus coffeae* (Zimmermann.), spiral nematode, *Helicotylenchus multicinctus* (Cobb.) co-habit with *R. similis* resulting substantial yield loss. The first report of occurrence of *R. similis* on banana from India was made from Kerala where the entire crop was damaged and lost due to its attack[3]. *R. similis* is considered the fourth most destructive nematode that attacks different crops and the most damaging to banana cultivation. *R. similis* is a migratory endo-parasitic nematode that feeds on the root cortical tissue of bananas forming dark red lesions, which result in reduced bunch weights, increased vegetative cycling periods and result in toppling at harvesting stage.

Nematode - Fungal complex

Besides direct damage, they serve as predisposing agents in development of disease complexes with fungi and bacteria. Wilt complex disease caused by *Fusarium oxysporum* f. sp. *cubense* and *Radopholus similis* is considered as a serious threat Banana cultivation. *Fusarium*

oxysporum f. sp. *cubense* is a soil necrotrophic pathogen that produces chlamydospores, survival spores that remain viable allowing the disease to persist.

Symptoms of damage

Below ground symptom

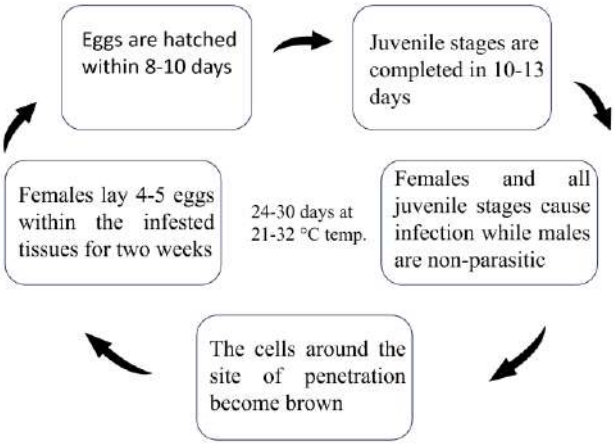
Symptoms of infection are characteristic reddish-brown lesions on the infected roots and corm; plants are poorly anchored and may be uprooted during wet and windy weather at bunch maturation stage.

Above ground symptom

The above ground symptoms are characterised by leaf chlorosis, dwarfing, reduction in pseudostem girth, yellowing and drying of leaves with small bunches[4]. Toppling of banana is the typical symptom for the disease (Fig. 1). Blackhead disease results from the eventual migration of burrowing nematodes from roots into the rhizome, which results in black, round lesions.

Fig. 1. Toppling of banana infected by burrowing nematode

Lifecycle of Radopholus similis



Epidemiology

R. similis reproduces best in warm soil, with an optimal temperature range of 24°C to 32°C. Reproduction is highest at around 30°C and ceases below 16–17°C or above 33°C. High soil moisture levels, ranging from field capacity to water saturation, are highly favourable, as the nematodes move through the film of water in the soil. Females can reproduce sexually or via self-fertilization, allowing populations to expand rapidly even if low numbers are introduced, often spreading through infested planting materials. Burrowing nematode is severe in South India, particularly Kerala, Tamil Nadu and Karnataka due to the region's hot, humid tropical climate and sandy loam soils, which are ideal for rapid, year-round nematode reproduction.

Management strategies for burrowing nematode in Banana

Selection of planting material

Selecting high-quality, nematode-free planting material is the most critical cultural method for managing the banana burrowing nematode. Selecting nematode-free banana suckers for burrowing nematode management involves choosing 3–4 months old sword suckers (1.5–2 kg), trimming all roots and discoloured corm tissues (paring), followed by sanitation treatments such as hot water treatment (55°C for 10 min) or chemical dipping (Carbofuran 3G).

Growing of resistant variety

Host plant resistance offers an effective and economical way to escape from yield loss due to plant parasitic nematodes. The conferred resistance to *R. similis* has been reported in Yangambi Km5(YKM-5) and Pisang Jari Buaya which have been widely used by banana breed-ers to develop *R. similis* -resistant hybrids. Key resistant or tolerant varieties include the banana hybrids H 912, H 914, H 916, H 926, and H 943, which show high resistance to root and corm lesions.

Growing of tissue culture plantlets

The use of Tissue culture banana plants has numerous benefits, such as providing clean, healthy planting material that is free of pests and diseases. Ideal plantlets should be 30 cm high, have 5–6 healthy green leaves, and 25–30 active roots. Although TC plants are sterile, they are susceptible to contamination during hardening. Ensure potting media (sand, soil, FYM) used for hardening is fumigated or sterilized.

Hot water treatment

Hot water treatment at 50 °C for 20-25 min has proved successful in reducing nematode

infestation in the planted crop and successive cycles (ratoons), and in increasing plant establishment, sucker survival and yields for plantain. Treatment of suckers with boiling water for 20-30s will inevitably improve plant quality and productivity[5].

Application of organic amendments

The application of composts and other organic amendments improve soil physical (water holding capacity, porosity and bulk density), chemical (pH, electrical conductivity and nutrient content) and biological properties such as soil microbial populations and plant growth. It is also possible that these amendments stimulated bacteria and fungi, which were antagonistic to nematodes preventing them from penetrating the roots or reducing their multiplication once they had penetrated banana roots. Bio-rationale treatments viz., application of neem cake, vermicompost and press mud, coriander intercrop and marigold intercrop in banana resulted in a general reduction in the population of plant parasitic nematodes.

Biological management

Among biological treatments, neem cake and marigold treatments are superior on nematode control than *P. fluorescens, G. mosseae* and coriander treatments. Neem cake application @ 500 g/plant at planting and growing Marigold (*Tagetes errecta*) around the basin and incorporation of their bio mass 60 days after sowing was proved to be the most effective treatments against *R. similis* and *H. multicinctus* in first cycle banana crop[6]. Application of *Pseudomonas fluorescens* @ 20g/plant is found effective which increases the fruit yield and decreases the nematode population by more than 50%. Beneficial fungal endophytes colonise host plants without inducing any penalty to the host or pathogenic symptoms, existing in a harmonious association with their plant hosts.

Effective botanicals

The application of phytochemicals (azadirachtin and allicin) as alternatives to synthetic nematicides is effective and comparable to ethoprophos at preventing plant growth and yield losses. This will be beneficial to banana producers by decreasing the time for fruiting and increasing the productive life of the fields. Plants treated with azadirachtin also had a low root necrosis index which may result in fewer plants toppling and uprooting[7].

Chemical control

Chemical nematicides such as carbofuran and methyl bromide have been used for the management of banana nematodes. Soil application of granular Carbofuran gives only a short-

term solution for nematode control. Repeated application at higher dosage becomes costly and hazardous. The soil application of cartap hydrochloride, a natural derivative of nereistoxin from marine *Lumrineris* spp. was found to reduce nematode population density in certain crops[8].

Integrated Nematode Management in Banana

The integration of neem cake (neem extracts), Carbofuran, *P. penetrans*, and *Glomus fasciculatum* is the most effective management in enhancing banana plant growth and yield. Incorporating 250 g neem cake, 20 g *T. viride*, and Carbofuran 3G at 10 g/sucker resulted in a reduction of *R. similis* population in soil and banana roots. Paring + hot water treatment of suckers at 55 °C for 10 minutes + carbofuran 3G @ 0.5gm / plant + neem cake@ 1 kg/plant (at the time of planting) yields the greatest result[9].

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SEED BALL TECHNOLOGY FOR FOREST RESTORATION: A CASE STUDY OF FIELD RESEARCH IN TAMIL NADU FORESTS

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Abstract

Forests are increasingly degraded by deforestation, grazing, soil erosion, and climate change impacts, necessitating cost-effective, scalable restoration approaches. Seed ball technology, which involves preparing small balls comprising of soil, organic matter, and seeds, is designed to protect seeds until favourable conditions support germination. However, its effectiveness under natural forest conditions remains insufficiently understood. Hence, this study was undertaken to evaluate the establishment potential of seed balls in forest ecosystems of Tamil Nadu. Laboratory experiments assessed germination of selected tree and grass species using different methods. Based on these results, seed balls were prepared using an optimized mixture of red soil and vermicompost (2:1), which exhibited desirable physical properties, including appropriate size, strength, and disintegration capacity. Field trials were conducted in Athikadavu and Pethikuttai during the South-West and North-East monsoon seasons. Seven species were evaluated under natural conditions. In laboratory conditions, grass species performed better, with *Apluda mutica* (Moongil pul) (80%) and *Eriocoma hymenoides* (Arisippul) (85%) showing high germination, while *Albizia amara* (Usil) recorded lower germination (25%). Under field conditions, performance declined significantly, with germination ranging from 2–7% during the South-West

monsoon and improving slightly to 8–9% during the North-East monsoon. Grass species established better than trees, with *Albizia amara* (Usil) and *Acacia chundra* (Senkarungali) showing very limited survival. This study concludes that seed ball technology in the current form is highly influenced by rainfall, fungal infections, pests, and environmental stress. Overall, seed balls are not a standalone solution but can support restoration when integrated with scientific planning and management.

Keywords: Seedballs; Establishment Potential; Restoration; Germination; Monsoon; Species

Introduction

Forests play a vital role in supporting biodiversity, regulating climate, conserving soil and water, and providing livelihoods. Yet, forests around the world are being degraded by deforestation, overgrazing, land-use changes, soil erosion, and climate change (Griffiths *et al*., 2025). In India, especially in Tamil Nadu, dry and moist deciduous forests are particularly at risk, resulting in reduced natural regeneration and lower productivity. This ongoing damage affects the ecological balance and threatens the long-term sustainability of forest resources.

Restoring degraded forests is now a global priority. Traditional methods like planting nursery-grown seedlings work well but are expensive, labour-intensive, and hard to scale up. Direct seeding has become popular because it is simpler and easier to implement at scale. However, it often has low field success rates due to factors such as seed predation, insufficient moisture, poor soil, and seed dormancy (de Souza & Engel, 2023; Lázaro-González *et al*., 2023). Research shows that direct seeding in tropical forests typically results in fewer than 20% of seeds establishing, underscoring the need for better methods (Naruangsri *et al*., 2024).

Around the world, new methods have been tried to make forest restoration more effective. These include seed pelleting, adding nutrients to seeds, and using bio-enhanced seed balls to help seeds germinate and grow in tough conditions (Nwankwo *et al*., 2018; Teichroew & Rew, 2025). Seed ball technology, popularized by Masanobu Fukuoka, is seen as a low-cost, nature-based way to restore degraded land. Seed balls are small pellets of soil, organic matter, and seeds that protect seeds from stress, retain moisture, and create a favourable environment for germination (Rawat *et al*., 2024). Research shows that these methods can help more seedlings grow in dry, degraded areas (Sudrajat & Rustam, 2020; Zubaidah *et al*., 2022).

In India, seed ball technology has become popular through environmental campaigns, education, and tree planting projects. It is often promoted as an easy and scalable way to restore

degraded land. However, most uses are not closely monitored, and there is little scientific data on how well seed balls work in the field (Johnstone *et al*., 2026). Most research has focused on lab or controlled settings, where seeds tend to germinate more easily. In real field conditions, factors such as uneven rainfall, fungal infections, pests, and changing soil conditions make it much harder for seeds to germinate (Vieira *et al*., 2021; Grossnickle & Ivetić, 2017).

In addition, species-specific characteristics play a crucial role in determining establishment success. Native tree and grass species in Tamil Nadu forests, such as *Albizia amara*, *Acacia chundra*, *Apluda mutica*, and *Eriocoma hymenoides*, are adapted to local climatic conditions, yet their regeneration through direct seeding remains inconsistent due to environmental stress and competition (Khurana & Singh, 2001). Seasonal variation, particularly between the South-West and North-East monsoons, further influences soil moisture availability and germination success, underscoring the need to evaluate restoration technologies across different climatic conditions.

Despite the increasing adoption of seed ball technology, there is a clear research gap regarding its real-world effectiveness in forest ecosystems, particularly in the Indian context. Most studies lack field validation across seasons, species, and environmental conditions. Addressing this gap is crucial to determining whether seed balls can serve as a reliable restoration tool or merely a supplementary method. Therefore, the present study was undertaken to evaluate the establishment potential of seed balls in forest ecosystems of Tamil Nadu, with specific emphasis on species performance, seasonal influence, and field-level constraints affecting germination and survival.

METHODOLOGY

Study Area and Experimental Design

This study took place in two forest areas: Athikadavu in the Karamadai range and Pethikuttai in the Sirumugai range, both in the Coimbatore Forest Division, Tamil Nadu. These sites are examples of dry and moist deciduous forests that often face degradation and struggle to regenerate naturally. Experiments were conducted during both the South-West monsoon (August–September) and the North-East monsoon (November–December) to examine how seasonal changes affect seed germination and plant growth under natural conditions. Differences in rainfall and soil moisture between seasons are known to significantly impact seedling growth (Mwendwa *et al*., 2020). The experimental plots are shown in Figure 1.

a

b

Figure 1. GPS mapping of experimental plots (a) Athikadavu & (b) Pethikuttai forest

Selection of Species

Seven native species were selected following field surveys and consultations with forest officials. The selected species included five tree species, namely *Albizia amara* (Usil), *Acacia chundra* (Senkarungali), *Sapindus emarginatus* (Soapnut), *Zizyphus jujuba* (Elanthai), and *Chloroxylon swietenia* (Porasu)and two grass species, namely*Apluda mutica* (moongil pul) and *Eriocoma hymenoides* (Arisippul). While these species are adapted to the local environment, their ability to grow from direct seeding is often limited by environmental stress and their own traits (Khurana & Singh, 2001).

Preparation of Seed Balls

Seed balls were made with a 2:1 mix of red soil and vermicompost, which proved to be the best combination in early tests. This mix gave the seed balls the right size, strength, and ability to break down, all of which help protect seeds and support germination (Lord *et al*.,

2025). Adding vermicompost helps the balls retain moisture and provide nutrients, supporting early seedling growth (Rawat *et al*., 2024; Zubaidah *et al*., 2022). Seeds were placed in the mix, shaped into small balls, and air-dried before use in the field.

Laboratory Evaluation

Prior to field application, laboratory experiments were conducted to assess the inherent germination potential of the selected species. Standard methods such as sand tray, roll towel, and pot culture techniques were employed under controlled conditions. These methods help evaluate seed viability and germination behaviour in the absence of environmental stress, allowing comparison between laboratory and field performance (Milano *et al*., 2024).

Field Experiment and Observation

Field trials were conducted at both study sites, with seed balls placed in designated plots for each species. During the South-West monsoon, seed balls were randomly spread to mimic natural dispersal. After observing this phase, changes were made for the North-East monsoon trial, including placing seed balls in a more organized manner for better monitoring and treating seeds with *Trichoderma viride* to reduce fungal infections. Using biological treatments like this can help seeds survive by reducing losses from pathogens in the field (Nwankwo *et al*., 2018).

Germination and seedling establishment were monitored at regular intervals. Observations were recorded to evaluate species performance, seasonal variation, and the effectiveness of seed ball technology under natural forest conditions. Field-level constraints such as moisture stress, pest incidence, and soil conditions were also considered, as these factors significantly influence seedling establishment (Vieira *et al*., 2021; Grossnickle & Ivetić, 2017).

RESULTS AND DISCUSSION

Laboratory Performance of Selected Species

Under laboratory conditions, clear differences were observed among the selected species in terms of germination. Grass species performed consistently better than tree species, with germination levels reaching around 80–85%, whereas most tree species showed comparatively lower germination, generally ranging between 25–60%. This variation highlights the inherent differences in seed characteristics, dormancy behaviour, and adaptability among species.

The superior performance of grass species under controlled conditions can be attributed to their faster germination rates and lower dormancy than those of tree species. Earlier studies have also reported that seed size, dormancy level, and physiological traits significantly influence

germination behaviour under favourable conditions (Cevallos *et al*., 2022; Milano *et al*., 2024). These findings confirm that laboratory conditions provide an ideal environment for seed germination, but may not reflect real field conditions.

Field Performance under Forest Conditions

A sharp decline in germination was observed when seed balls were tested under natural forest conditions. During the South-West monsoon, germination remained very low, generally around 2–7%, even after rainfall events. Although grass species performed relatively better than tree species, overall establishment remained limited. During the North-East monsoon, germination improved slightly to around 8–9%, which may be attributed to better soil moisture conditions and improved experimental practices, such as systematic placement and biological treatment. However, overall establishment remained low, indicating that favourable rainfall alone is insufficient for successful seedling establishment.

These findings were consistent with earlier studies, which have shown that direct seeding methods often exhibit high germination under controlled conditions but significantly lower establishment under field conditions due to environmental stress and biotic factors (Grossnickle & Ivetić, 2017; Vieira *et al*., 2021).

Species-wise Establishment Trends

Species-wise evaluation revealed that grass species such as *Apluda mutica* and *Eriocoma hymenoides* consistently showed better establishment in both seasons than tree species. Among the tree species, *Albizia amara* and *Acacia chundra* showed limited survival, while the other species failed to establish under field conditions.

This pattern indicates that species adaptability plays a crucial role in restoration success. Native grasses are generally more resilient to environmental stress and can establish quickly, whereas tree species often require favourable microsite conditions and protection during early growth stages. Similar observations have been reported in restoration studies, where species-specific traits strongly influence seedling establishment and survival (Piotrowski *et al*., 2023; Khurana & Singh, 2001).

Influence of Environmental and Soil Factors

Field observations clearly indicated that environmental conditions had a major influence on seed ball performance. Factors such as irregular rainfall, soil moisture stress, fungal infections, pest attacks, and competition from existing vegetation significantly reduced

germination and seedling survival.Moisture availability is one of the most critical factors influencing seed germination under field conditions. In seasonal forest ecosystems, uneven rainfall distribution can lead to rapid drying of the soil surface, thereby affecting seed hydration and germination (Mwendwa *et al*., 2020). In addition, fungal infections and pest incidence can further reduce seed viability and seedling survival, particularly in untreated seeds.

Soil characteristics also play an important role in determining establishment success. Variations in soil properties such as organic carbon content, porosity, and nutrient availability influence water retention, aeration, and root development. Previous studies have shown that soil physical properties and microsite conditions are key determinants of seedling emergence and establishment in forest restoration (Heydari *et al*., 2017; Stapleton *et al*., 2023).Furthermore, competition from weeds and existing vegetation, along with seed predation, can significantly reduce seedling establishment in direct seeding approaches (Lázaro-González *et al*., 2023).Similar studies have reported that seed balls enhance initial germination but do not always ensure long-term establishment under field conditions (Johnstone *et al*., 2026). These combined factors highlight the complexity of field conditions compared to controlled environments.

Gap between Laboratory and Field Performance

One of the most significant findings of this study is the clear gap between laboratory and field performance. While laboratory experiments showed high germination potential across species, field trials recorded establishment rates of around 8–10%.This gap can be attributed to the absence of environmental stress in laboratory conditions, where factors such as temperature, moisture, and pest protection are controlled. In contrast, field conditions expose seeds to multiple stresses simultaneously, including moisture fluctuations, soil variability, microbial attack, and predation.Similar discrepancies between laboratory and field performance have been widely reported in restoration studies.

Direct seeding approaches often show promising results under controlled conditions but fail to achieve comparable success under natural conditions due to environmental constraints (de Souza & Engel, 2023; Lázaro-González *et al*., 2023).The transition from seed germination to successful seedling establishment is often limited under field conditions, particularly in degraded ecosystems (Araujo & Pérez, 2022). These findings emphasize the importance of field validation before large-scale application of restoration technologies.

Implications for Forest Restoration

The findings of this study provide important insights into the practical application of seed ball technology for forest restoration. Although seed balls offer advantages such as low cost, ease of preparation, and suitability for large-scale application, their effectiveness under natural forest conditions is limited. Seed ball technology should therefore not be considered a standalone solution for forest restoration. Instead, it should be integrated with scientific planning, including proper species selection, appropriate sowing time, and post-establishment management practices(Jawahar & Umarani, 2020). Incorporation of biological treatments, soil preparation techniques, and moisture conservation measures can further improve establishment success.

Previous studies have also highlighted the need for integrated approaches in ecological restoration, combining seed-based techniques with site-specific management strategies to improve success rates (Sudrajat & Rustam, 2020; Nwankwo *et al*., 2018). Though, seed ball technology has a potential to support in forest restoration, its success depends largely depends on environmental conditions and management practices. Therefore, further researches to redesign seed ball technology with multi field-level trials are essential to improve its effectiveness for large-scale forest restoration.

Conclusion

This study assessed the effectiveness of seed ball technology for forest restoration in Tamil Nadu. While laboratory results showed high germination rates, especially for grass species, the actual field performance in the real forests was significantly lower. Germination in forest conditions remained limited, with a small percentage of seeds successfully establishing, even under favourable seasonal conditions. These results clearly indicate that environmental factors such as rainfall variability, soil conditions, pests, and fungal infections strongly influence seed germination and survival. Grass species showed relatively better establishment compared to tree species, highlighting the importance of species selection in restoration efforts. Overall, the study demonstrates that seed ball technology alone is not sufficient for successful forest restoration. However, it can still be useful as a supportive method when combined with proper planning, suitable species selection, and field management practices. Improving the timing of sowing, seed treatment methods, and overall implementation strategies can enhance its effectiveness. Though seed balls offer a low-cost and scalable approach, their success depends on how well they are integrated with scientific and site-specific restoration practices.

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PESTICIDE DEPENDENCY AND ITS SOCIAL CONSEQUENCES FOR FARMING COMMUNITIES: A REVIEW

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Abstract

The accelerated dependence on chemical pesticides in modern agriculture has brought both productivity gains and severe social consequences. While pesticides have historically been essential to pest management and yield stabilization, over-reliance has created a "pesticide trademill" that undermines both environmental and human health. This review synthesizes interdisciplinary research on pesticide dependency and its social consequences, focusing on smallholder farming communities in India. Key dimensions include economic burdens, health hazards, gender disparities, erosion of local knowledge, and declining community resilience. The review concludes with pathways for policy reform and sustainable alternatives that can promote social well-being and ecological balance.

Keywords: pesticide dependency, farming communities, social impact, integrated pest management, India, agricultural sustainability

1. Introduction

Pesticides have become integral to modern agriculture, supporting food production and pest control. However, their persistent and excessive use has resulted in dependency among farmers, especially in developing economies like India. "Pesticide dependency" refers to a structural reliance where agricultural systems and farmers cannot maintain yields without routine or escalating chemical interventions (Hu, 2020).

In India, the Green Revolution (1960s–1980s) marked a dramatic shift toward high-yielding varieties and chemical-intensive agriculture. While it boosted productivity, it also entrenched a system reliant on fertilizers and pesticides (Shiva, 2016). This chemical dependence

now threatens both the ecological and social sustainability of rural livelihoods. Farmers face economic strain, health issues, and the erosion of traditional pest management knowledge (Narasimha *et al*., 2019).

This review aims to explore pesticide dependency from a social science perspective—highlighting the socio-economic, cultural, and institutional dimensions that perpetuate chemical reliance in Indian agriculture.

2. Conceptual Framework of Pesticide Dependency

Definition and Characteristics

Pesticide dependency is characterized by -

i. increased application rates
ii. declining efficacy due to pest resistance,
iii. habitual chemical use despite alternatives
iv. systemic reliance on agrochemical markets (Pimentel, 2005). Farmers trapped in this cycle face diminishing returns and greater vulnerability to input costs.

Drivers of Dependency

According to Hu (2020), pesticide dependence arises from a complex interaction of agronomic, economic, and social factors:

- **Economic incentives:** Input suppliers and credit systems promote chemical solutions for quick pest control.
- **Institutional structures:** Agricultural policies often subsidize or encourage pesticide use while providing limited support for ecological alternatives.
- **Knowledge and extension gaps:** Limited farmer awareness about IPM and ecological pest management perpetuates reliance.
- **Social norms:** Peer influence, perceived risk, and community spraying practices reinforce habitual pesticide use (Jors *et al.*, 2021).

These drivers illustrate that dependency is not merely an individual choice but a socially and institutionally embedded phenomenon.

3. Social Consequences of Pesticide Dependency

Economic Burden and Indebtedness

Pesticides constitute a major production cost, particularly for crops like cotton, chili, and paddy. As pests develop resistance, farmers increase spray frequency, leading to high input

expenditure and financial strain (Pimentel, 2005). In regions such as Telangana and Vidarbha, this economic burden contributes to chronic indebtedness and farmer suicides (Narasimha *et al.*, 2019).

Health and Well-being

Occupational exposure to pesticides causes both acute and chronic health problems, including respiratory illness, neurological disorders, and reproductive harm (Jørs et al., 2021). In India, poor literacy and lack of protective equipment exacerbate exposure risks. Long-term exposure has been linked to psychological stress and mental health issues (Narasimha *et al*., 2019).

A BMC Public Health study found that more than 60% of rural farm workers in Karnataka and Andhra Pradesh experienced at least one symptom of pesticide exposure annually (Jørs *et al.*, 2021).

Gendered Impacts

Women in farm households frequently handle pesticide mixing and cleaning tasks but have limited decision-making authority regarding pesticide use (Hu, 2020). As a result, they face disproportionate health risks. Moreover, when male farmers suffer from illness or financial distress, women shoulder additional economic and domestic burdens, intensifying gender inequities.

Labour, Knowledge, and Social Structure

The increasing dependence on chemical pest control has caused "deskilling" among farmers—the gradual erosion of traditional ecological knowledge of pest cycles and natural control methods (Shiva, 2016). Input dealers now act as key advisors, replacing local knowledge networks. This shift weakens community autonomy and reinforces commercial dependency.

Community and Environmental Resilience

Ecologically, pesticide overuse degrades soil, water, and biodiversity, reducing the resilience of agroecosystems (Pimentel, 2005). Socially, this environmental degradation leads to livelihood instability, migration, and declining community trust (Narasimha *et al*., 2019). Once communities become dependent on chemical inputs, their capacity to adapt to environmental or market shocks diminishes.

Social Justice and Equity

Pesticide dependency deepens social inequalities. Marginal farmers and agricultural

laborers often experience the greatest exposure but the fewest economic benefits. Wealthier farmers can afford protective equipment and quality chemicals, while smallholders rely on cheaper, more hazardous formulations (Jørs *et al*., 2021). This disparity reflects structural injustice in agricultural systems.

4. Case Studies from India

Telangana Cotton Belt

In Telangana, cotton farmers apply pesticides up to 30–40 times per season, often mixing multiple chemicals. This has led to pesticide-related illnesses and economic debt. Narasimha *et al*. (2019) describe these as "toxic landscapes," where chemical exposure and financial vulnerability coexist.

Karnataka Horticultural Systems

Studies in Karnataka show persistent pesticide misuse despite awareness campaigns. Farmers often over-apply due to fear of crop loss and lack of affordable alternatives (Jørs *et al*., 2021). The socio-economic cost manifests as health expenditure and reduced farm profits.

Punjab and Maharashtra

Long-term pesticide exposure has resulted in "cancer belts" in parts of Punjab and Maharashtra (Pimentel, 2005). Contaminated groundwater and chronic diseases have caused rural distress and migration, further fracturing community structures.

5. Pathways to Reduce Dependency

Integrated Pest Management (IPM)

IPM combines biological, mechanical, and cultural methods to minimize chemical use. Research shows that IPM can reduce pesticide applications by 40–60% without yield loss (Hu, 2020). Farmer Field Schools and participatory IPM programs are critical for adoption.

Agroecology and Organic Practices

Agroecological systems promote biodiversity and natural pest control.

However, adoption requires supportive policy environments, extension training, and market incentives for low-residue produce (Shiva, 2016).

Strengthening Farmer Knowledge and Agency

Farmer empowerment through training, local experiments, and community-based networks enhances autonomy and ecological literacy (Narasimha *et al*., 2019). Reducing dependency requires restoring farmer decision-making capacity and ecological understanding.

Policy and Institutional Reforms

Policies should:

- Phase out highly hazardous pesticides;
- Encourage IPM through subsidies and extension programs;
- Regulate pesticide marketing and labeling; and
- Strengthen monitoring of pesticide residues and farmer health (Hu, 2020; Jørs *et al.*, 2021).

Social Protection and Health Monitoring

Rural health programs must include pesticide exposure tracking and medical support for affected communities. Social protection mechanisms can reduce the vulnerability of indebted farmers during the transition to sustainable practices.

6. Conclusion

Pesticide dependency is not merely an agronomic issue—it is a social, economic, and moral challenge. Its persistence stems from institutional inertia, market pressures, and insufficient support for alternatives. The resulting economic, health, and social costs are disproportionately borne by small and marginal farmers. A transition toward socially sustainable agriculture requires integrated approaches combining ecological science, policy reform, and participatory extension. Agricultural universities and research institutions must lead this shift to ensure that farming remains both productive and socially just.

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POLLINATOR DECLINE AND ITS SOCIO-ECONOMIC IMPLICATIONS FOR FARMERS

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Abstract

Pollinators provide a critical ecosystem service that underpins the production and quality of many food, feed and fibre crops. Global and regional evidence indicates declines in abundance and diversity among key pollinator groups, driven by habitat loss, pesticide exposure, pathogens, invasive species, and climate change. For farmers, particularly smallholders in India, reductions in pollination services translate into measurable yield and quality losses, increased production costs, reduced incomes and heightened vulnerability. This review synthesises current knowledge on the causes and extent of pollinator decline with emphasis on India, quantifies socio-economic impacts on farming households, examines policy and management options, and identifies priority research and development actions. We draw on ecological, agronomic and economic literature to provide an integrative perspective suitable for researchers, extension specialists and policymakers.

Keywords: pollinators; ecosystem services; agriculture; socio-economic impact; farmers; India

1. Introduction

Animal pollinators — including bees (social and solitary), butterflies, moths, flies, beetles, bats and birds — are essential for the reproduction of a large share of the world's flowering plants and a substantial fraction of agricultural crops. Seminal global assessments estimate that between 75% and 87% of leading food crops receive benefits from animal pollination, with varying degrees of dependence (Klein *et al*., 2007; IPBES, 2016). Pollination contributes not only to yield quantity but also to quality attributes such as fruit size, seed set and marketability (Garibaldi *et al*., 2013).

In India, a diverse mosaic of agro-ecological zones supports numerous pollinator species and a wide range of pollinator-dependent crops, including fruits (mango, guava), vegetables (brinjal, cucurbits), oilseeds (mustard), spices and coffee. Given the predominance of smallholder production systems and the nutritional importance of many pollinator-dependent crops, pollinator decline represents a direct threat to farmer incomes, household nutrition and broader rural economies.

2. Importance of Pollinators in Agriculture

Pollinators enhance reproductive success in entomophilous crops through pollen transfer that increases fruit set, uniformity and quality. Economically, pollination services have been valued at hundreds of billions of US dollars annually at the global scale, though estimates vary with method and scope (Potts *et al*., 2016; Hanley *et al*., 2015). Wild pollinators often contribute equal or greater pollination benefits compared with managed honey bees, particularly in diversified and smallholder systems (Garibaldi *et al*., 2013).

Table 1. Representative pollinator-dependent crops in India and relative dependence

Crop	**Relative dependence**	**Key pollinators**
Mustard (Brassica spp.)	High	Apis spp., solitary bees
Mango (Mangifera indica)	Medium	Bees, flies, beetles
Cucurbits (e.g., cucumber, melon)	High	Bees, syrphid flies
Sunflower (Helianthus annuus)	High	Bees, beetles
Coffee (Coffea spp.)	Moderate	Bees, stingless bees
Brinjal (Solanum melongena)	Moderate	Bees, flies

3. Extent and Drivers of Pollinator Decline

Multiple interacting drivers underlie observed declines in pollinator abundance and diversity across regions. Major drivers include habitat loss and fragmentation, agricultural intensification and monoculture, pesticide exposure (notably neonicotinoids), emerging pathogens and parasites (e.g., *Varroa destructor* in honey bees), invasive species, and climate change that alters phenology and suitable ranges (Goulson *et al*., 2015; IPBES, 2016).

Habitat loss reduces the availability of floral resources and nesting sites. Agricultural landscapes dominated by large monocultures provide brief pulses of floral resources during crop bloom but little year-round forage for pollinators (Baude *et al*., 2016). Pesticide exposure, both acute and sublethal, can impair navigation, foraging efficiency and immune function (Goulson *et al*., 2015). Climate warming and increased frequency of extreme events threaten temperature-sensitive pollinators such as bumblebees (Kevan *et al*., 2024).

4. Evidence of Pollinator Losses: Global and Indian Perspectives

Global syntheses and regional monitoring indicate declines for many pollinator taxa. The IPBES (2016) assessment reported worrying trends in both wild and managed pollinators, identifying land-use change and agricultural practices as major contributors. Longitudinal surveys in Europe and North America show declines in bee species richness and abundance for several taxa (Potts *et al*., 2016; Goulson *et al*., 2015).

In India, systematic long-term monitoring is limited, but recent reviews highlight fragmented evidence of declines in pollinator diversity in multiple states, linked to habitat alteration and pesticide misuse (Adit *et al*., 2024). Case studies document local declines in honey bee foragers, reduced wild bee diversity in intensively farmed landscapes, and reported pesticide-related mortalities (Chauhan *et al*., 2020; Hem Raj, 2021).

5. Socio-Economic Implications for Farmers

Pollinator declines translate into several socio-economic impacts for farming households. These include direct reductions in crop yield and quality, increased costs where farmers substitute services (e.g., renting hives or manual pollination), changes in crop choice and income diversification, implications for local labour and downstream agribusinesses, and broader nutritional impacts for consumers reliant on fruits and vegetables (Chaplin-Kramer *et al*., 2022; Hanley *et al*., 2015).

Quantifying these impacts requires linking ecological measures of pollination to agronomic outcomes and then to household economics. Several modelling exercises have estimated substantial economic losses from pollination deficits at national and global scales; Chaplin-Kramer *et al*. (2022) modelled substantial health impacts driven by reduced availability of nutritious foods when pollination is insufficient. Regionally, economic valuation studies show that insect pollination supports large shares of horticultural value chains.

Table 2. Economic impacts of pollination deficits on selected Indian crops.

Crop	Estimated yield loss (%)	Estimated income loss (INR/ha)	Source (illustrative)
Apple	15–25	₹30,000–₹60,000	Hem Raj, 2021; Garibaldi *et al*., 2013
Mustard	10–20	₹8,000–₹20,000	Klein *et al*., 2007; local studies
Cucurbits	20–30	₹15,000–₹40,000	Garibaldi *et al*., 2013; Chaplin-Kramer *et al*., 2022
Sunflower	12–20	₹10,000–₹25,000	Blitzer *et al*., 2016

6. Adaptation, Management and Policy Responses

Farm-level practices to support pollinators include creating floral resources through hedgerows, wildflower strips and cover crops, retaining non-crop habitat, reducing pesticide use via integrated pest management (IPM), and providing nesting substrates for cavity-nesting and ground-nesting bees (Blaauw & Isaacs, 2014).

Policy interventions can align agricultural incentives with biodiversity goals — for example, including pollinator habitat in agri-environment schemes, supporting organic and low-input systems, and funding extension programmes to educate farmers on pollinator-friendly practices (Breeze *et al*., 2014). In India, mainstreaming pollinator conservation into the National Biodiversity Action Plan and state agricultural policies is a priority (MoEFCC, 2023).

7. Selected Indian Case Studies

Himachal Pradesh (apple production): Farmers report declining bee activity and reduced fruit set in some orchards; integrated management including avoidance of insecticide spraying during bloom and planting of nectar corridors improved bee visitation in demonstration plots (Hem Raj, 2021).

Punjab and Haryana (beekeeping integration): Managed honey bee pollination and promotion of apiary services have been used to improve oilseed and fruit yields; however,

overreliance on managed *Apis mellifera* can risk disease spillover to wild pollinators and reduce pollinator diversity (Delaplane *et al*., 2013).

Western Uttar Pradesh (mustard and cucurbits): Studies indicate lower wild pollinator diversity in intensively farmed areas compared with nearby semi-natural habitats; farmers adopting habitat retention and reduced pesticide regimes observed yield improvements over 2–3 seasons (Adit *et al*., 2024).

8. Research Gaps and Future Directions

Key research priorities include (i) establishing long-term, spatially representative pollinator monitoring networks across India; (ii) conducting crop-specific pollinator dependency and pollination deficit studies in diverse agro-ecologies; (iii) economic valuation studies linking pollination service changes to household welfare; (iv) evaluating effectiveness and adoption constraints for farm-level interventions; and (v) integrating climate vulnerability assessments for pollinators into adaptation planning (Adit *et al*., 2024; Hanley *et al*., 2015).

Conclusion

Pollinator decline poses a tangible risk to agricultural productivity, rural incomes and nutritional security in India. Addressing this challenge requires integrated action spanning research, policy, extension and on-farm management. By recognising pollinators as essential agricultural inputs and aligning incentives to conserve pollinator habitat, India can safeguard both biodiversity and farmer livelihoods.

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SOCIO-ECONOMIC IMPACTS OF INSECT PEST OUTBREAKS ON SMALLHOLDER FARMERS IN INDIA: A REVIEW

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Abstract

Insect pest outbreaks remain one of the most serious threats to Indian agriculture, particularly for smallholder farmers who operate under constrained resources and limited risk-coping capacity. This review synthesizes evidence on the socio-economic impacts of insect pest outbreaks on smallholders in India, outlining yield losses, increased production costs, livelihood disruptions, and broader implications for rural poverty and food security. Evidence indicates that pest infestations can reduce yields by 15–30 % in major crops, escalate pesticide expenditure by up to 50 %, and induce significant credit dependency. The discussion highlights causal pathways and identifies key gaps in knowledge. Integrated Pest Management (IPM), institutional extension, and risk-sharing mechanisms are reviewed as mitigation measures. The paper concludes that strengthening farmer awareness, pest surveillance systems, and affordable IPM adoption are vital to reducing vulnerability and sustaining smallholder livelihoods.

Keywords: Insect pests; Smallholder farmers; Socio-economic impact; India; IPM; Yield loss; Livelihoods

1. Introduction

India's agricultural sector supports the livelihoods of nearly 55 % of the population, with over 86 % of farmers classified as small and marginal holders owning less than 2 ha of land (Government of India, 2023). These farmers face persistent challenges from biotic and abiotic stresses, among which insect pests remain a major constraint to productivity and income stability.

Insect pest outbreaks—such as those of *Helicoverpa armigera* in cotton, *Spodoptera frugiperda* in maize, and mustard aphid (*Lipaphis erysimi*) in oilseeds—have repeatedly caused large-scale yield losses and socio-economic distress (Kranthi *et al*., 2020; Shylesha *et al*., 2018). The socio-economic consequences go beyond crop damage, affecting household food security, farm profitability, and rural employment (FAO, 2021). This review collates existing literature to analyze these impacts and discuss policy and management options for smallholder resilience.

2. Extent of Insect Pest Damage in Indian Agriculture

2.1 Magnitude of Losses

Estimates suggest that insect pests cause an average annual crop loss of 15–25 % in India, valued at approximately USD 36 billion (Dhaliwal *et al*., 2015). Crop-wise losses have been reported as: cotton (up to 50 %), rapeseed-mustard (35 %), pulses (30 %), rice (25 %), sugarcane (20 %), and wheat (5 %) (Dhaliwal & Arora, 2019).

Field studies in Punjab found yield losses due to mustard aphid and cabbage caterpillar ranging from 6.5 % – 26.4 % over six years (Kaur *et al*., 2017). Similarly, fall armyworm outbreaks since 2018 have caused maize yield losses of 20–45 %, severely affecting rainfed smallholders in Karnataka, Maharashtra, and Madhya Pradesh (Deshmukh *et al*., 2020).

2.2 Climate and Ecological Drivers

Rising temperatures and shifting rainfall patterns are altering pest population dynamics and increasing outbreak frequency (Saseendran *et al*., 2024). Warmer winters favor survival of insects such as aphids and whiteflies, while monocropping systems provide continuous host availability (Prasad *et al*., 2021). Invasive alien species—such as the fall armyworm (*S. frugiperda*)—have expanded due to globalization and weak biosecurity, posing new challenges (CABI, 2022).

3. Socio-Economic Impacts on Smallholder Farmers

3.1 Yield and Income Losses

Yield losses translate directly to reduced farm income and food availability. Smallholders typically depend on 1–2 ha of land for both subsistence and market sales; hence, a 20 % loss can compromise household nutrition and debt repayment (Birthal *et al*., 2015). In cotton belts of Vidarbha, pest-related crop failure has historically been linked to indebtedness and farmer distress (Nagaraj *et al*., 2018).

Economic modeling in Andhra Pradesh revealed that pest outbreaks reduced net farm returns by INR 6,000–10,000 per ha in cotton and pigeon pea systems (Reddy *et al*., 2019). Similarly, mustard growers in Rajasthan reported income reductions of 28–40 % due to aphid infestations (Kumar & Yadav, 2020).

3.2 Escalation in Production Costs

Pest outbreaks often trigger higher chemical input use. In India, insecticides account for 60 % of the total pesticide market value (Dhaliwal & Arora, 2019). Smallholders increase spray frequency—sometimes from 3 to 10 times per season—raising input costs and health risks (Gupta *et al.*, 2020). The incremental cost burden reduces profit margins and can lead to credit dependency.

3.3 Market and Price Effects

Severe pest outbreaks influence market supply and prices. Reduced crop quality (e.g., bollworm-damaged cotton or discolored pulses) fetches lower prices, while oversupply in unaffected regions causes volatility (ICAR-NIAP, 2022). Smallholders, being price takers, often fail to recover costs, compounding economic stress.

3.4 Food Security and Livelihood Vulnerability

Pest-induced yield shocks affect both food and nutrition security. Households report reduced consumption diversity and increased borrowing during outbreak years (Rao *et al*., 2021). Labourers depending on seasonal farm work also face employment loss. The socio-economic ripple extends beyond farms—affecting rural credit systems, input dealers, and local markets.

3.5 Health and Environmental Externalities

Frequent and improper pesticide use leads to health hazards and environmental contamination. Incidence of pesticide poisoning among farmers and sprayers is high in cotton and vegetable belts (Pradhan *et al*., 2019). Such costs are often externalized and under-recognized in economic assessments.

4. Management and Mitigation Strategies

4.1 Integrated Pest Management (IPM)

IPM integrates biological control, cultural practices, monitoring, and selective chemical use. Studies show significant economic benefits. In Karnataka, maize fields using a four-component IPM approach against fall armyworm recorded yield gains of 17–25 % and higher benefit-cost

ratios (2.3–2.7) compared to conventional farmers (Prasanna *et al*., 2023). Cotton IPM programs reduced pesticide expenditure by 28 % and improved net returns (Kranthi *et al*., 2020).

However, adoption remains limited among smallholders due to low awareness, limited extension contact, and lack of affordable inputs (Tripathi & Singh, 2022).

4.2 Institutional and Policy Measures

The Government of India's **National Integrated Pest Management Programme (NIPMP)** and **Plant Health Clinics** aim to enhance farmer capacity and surveillance. Yet coverage is patchy. Pest risk insurance is not mainstreamed—most crop insurance under PM-FBY focuses on weather risk (GoI, 2023). Introducing pest-specific clauses could strengthen resilience.

4.3 Farmer Knowledge and Extension Support

Socio-economic studies reveal that knowledge level strongly correlates with adoption of pest control measures. In Kabirdham district (Chhattisgarh), 73 % of chickpea growers had annual income below ₹1.4 lakhs, and adoption of pest management practices was moderate—50 % cultural and 34 % chemical (Dewangan et al., 2022). Strengthening farmer field schools, ICT-based advisories, and community pest monitoring can enhance adaptive capacity.

4.4 Biological Control and Eco-Friendly Alternatives

Increasing availability of bio-agents (*Trichogramma*, *Chrysoperla*, *Metarhizium anisopliae*) and botanical pesticides (neem-based formulations) offers safer, cost-effective options. Studies have shown that these can reduce pest populations by > 60 % in vegetable and pulse systems while cutting chemical costs (Reddy & Krishna, 2021).

5. Socio-Economic Research Gaps

1. **Lack of disaggregated data:** Few studies quantify pest impacts by region, crop type, or farm size.
2. **Limited household-level analysis:** Most work measures agronomic loss, not welfare outcomes.
3. **Inadequate valuation of externalities:** Health, environment, and ecosystem services rarely included.
4. **Low integration of climate and pest modeling:** Future projections under climate change are sparse.
5. **Gender dimensions:** Women farmers' roles in pest management and coping remain under-studied.

6. Policy Implications

- **Strengthen Pest Surveillance:** Build real-time regional pest monitoring using digital tools and farmer networks.
- **Promote IPM at scale:** Subsidize bio-inputs, pheromone traps, and training for smallholders.
- **Integrate Risk Insurance:** Expand PM-FBY to cover pest-related yield shocks explicitly.
- **Support Farmer Education:** Use mobile-based advisories and farmer field schools.
- **Encourage Diversification:** Crop rotation and intercropping can reduce pest pressure and income risk.
- **Enhance Institutional Coordination:** Link research institutes (ICAR, SAUs) with extension and farmer producer organizations (FPOs).

7. Conclusion

Insect pest outbreaks exert multifaceted socio-economic impacts on India's smallholder farmers through yield losses, increased input costs, and livelihood insecurity. Despite advances in pest control technology, limited adoption and weak institutional support exacerbate vulnerability. Building resilience requires an integrated approach combining IPM, pest surveillance, credit protection, and farmer education. Strengthened research on socio-economic dimensions and localized interventions is crucial to safeguarding India's smallholder farming systems against future pest threats.

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PRECISION DIAGNOSTICS FOR SUBCLINICAL MASTITIS TO MITIGATE ANNUAL DAIRY LOSSES

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Introduction

Bovine mastitis ranks among the most economically devastating diseases in the global dairy industry, with annual losses exceeding ₹71,655 crores (approximately US$2 billion equivalent at historical rates) across India due to reduced milk yield, discarded contaminated milk, veterinary treatments, increased labor, and premature culling of affected animals. In the Indian context, where dairy supports millions of smallholder farmers, studies by Bansal and Gupta (2009) estimate nationwide losses at around ₹7,165 crores annually, predominantly from subclinical cases that silently erode 10-20% of milk production per infected quarter without visible symptoms. Early detection remains crucial to limit progression from subclinical to clinical stages, curbing per-lactation losses estimated at ₹1,390 per animal (including 49% from milk yield drops and 37% from treatment costs) and preventing broader herd impacts in resource-constrained tropical farms.

Challenges in Detecting Subclinical Mastitis

Subclinical mastitis, an initial infection stage lacking overt clinical signs such as udder swelling or milk abnormalities, evades routine visual inspection. It prevails in 15-40% of dairy herds worldwide, silently elevating somatic cell counts (SCC >200,000 cells/mL) and fostering pathogen persistence (Bradley, 2002). Confirmation relies on gold-standard methods like SCC via automated flow cytometry and microbial culture, which identify causative agents such as *Staphylococcus aureus* or *Streptococcus uberis.* However, these techniques demand laboratory infrastructure, delaying intervention.

Limitations of the California Mastitis Test (CMT)

The California Mastitis Test (CMT) remains a staple on-farm diagnostic tool owing to its simplicity, affordability (<$1 per test), and speed (<5 minutes). It mixes milk with a detergent reagent to assess SCC via gel formation viscosity. Nonetheless, its dependence on subjective human interpretation introduces inter-observer variability (up to 20% discordance) and limits sensitivity for low-SCC cases, undermining reproducibility (Sargeant et al., 2001). ncorporating artificial intelligence (AI), particularly deep learning, has significantly enhanced the diagnostic precision of infrared thermal (IRT) imaging for monitoring dairy cattle udder health. Traditional analysis relied on manual interpretation of thermograms or basic threshold-based thermometry, both prone to high inter-observer variability and unable to detect subtle thermal patterns indicative of early mastitis.

Artificial intelligence in mastitis detection:

In contrast, AI-driven models such as convolutional neural networks (CNNs) and YOLOv5 object detection algorithms autonomously learn complex thermal signatures and vascular irregularities from udder images, minimizing subjectivity and boosting accuracy. These systems achieve superior performance metrics, including overall accuracy up to 88%, sensitivity around 96% (for true positive mastitis detection), and specificity near 85%, outperforming visual assessments and rivaling laboratory tests like somatic cell counts.

Beyond classification, AI enables real-time processing, allowing thermal cameras in milking parlors or barns to instantly evaluate udder quarters, flag anomalies, and trigger alerts for farmers. Edge computing further empowers on-device analysis alongside cloud integration, ensuring low-latency decisions that prevent subclinical cases from progressing to costly clinical stages and supporting scalable precision dairy farming.

Infrared Thermography as an Emerging Solution

Infrared thermography offers a promising non-invasive alternative for subclinical mastitis detection. This technique employs thermal imaging cameras to quantify udder surface temperature elevations (typically 0.5-1.5°C above baseline) attributable to inflammation-induced hyperemia and immune response (e.g., prostaglandin release). Infrared thermal imaging (IRT) operates on the principle of thermal radiation, a fundamental physical process where every object with a temperature above absolute zero (-273.15°C) emits infrared energy proportional to its surface temperature, as described by the Stefan-Boltzmann law. This emitted radiation, invisible

to the human eye, carries precise information about the object's thermal state. IRT systems capture this energy using specialized sensors that convert it into visible infrathermograms color coded thermal maps displaying temperature variations across the object's surface with high spatial resolution, often down to 0.1°C accuracy. Unlike conventional visible-light imaging or invasive diagnostic tools, IRT enables completely non-contact, real-time thermal profiling from a safe distance, making it ideal for monitoring live animals without stress or risk of disease transmission.

In veterinary applications, such as detecting mastitis an inflammatory udder infection common in dairy cows IRT is an early diagnostic tool. Mastitis triggers hyperemia, an abnormal surge in blood flow to the affected tissue, which elevates local temperatures due to increased metabolic activity and vasodilation. This heat signature radiates from the cow's udder skin surface, even before visible or palpable symptoms emerge. The cow's udder is divided into four independent compartments known as quarters, and inflammation typically affects one or more selectively. IRT reveals these quarter-specific temperature asymmetries often 1–2°C hotter in infected areas—allowing veterinarians to pinpoint subclinical cases (infections without overt signs like swelling, hardness, or milk abnormalities) days or weeks earlier than traditional methods like somatic cell counts or California Mastitis Tests. By enabling prompt intervention, such as targeted antibiotic treatment or quarter isolation, IRT reduces economic losses from reduced milk yield, culling, and treatment costs, while promoting animal welfare in large scale dairy operations.

Advantages and Validation

Thermography integrates seamlessly with precision dairy farming, enabling real-time monitoring via handheld or automated drone-mounted systems. Validation across breeds (e.g., Holstein-Friesian) confirms robustness against environmental confounders like ambient temperature through algorithmic normalization (e.g., thermal gradients). A meta-analysis of 12 trials (n=1,500 quarters) yielded a pooled diagnostic odds ratio of 12.4, positioning it as a viable adjunct to SCC (Relova et al., 2021).

Integration with Nanotechnology for Enhanced Diagnostics

Recent advances fuse thermography with nanotechnology, such as nanoparticle-enhanced contrast agents (e.g., gold nanorods) that amplify thermal signatures via photothermal effects under near-infrared excitation. Preliminary bovine trials demonstrate 15-20% improved

sensitivity for biofilm-associated pathogens, aligning with Technology Readiness Level 4 (lab-validated) and promising translational socio-economic benefits through reduced antibiotic use (by 30%) and herd-level productivity gains (Kumar et al., 2024).

Future Directions

Prospective integration with AI-driven image analysis and multiplex biosensors could elevate thermography to a frontline tool, addressing subclinical mastitis's hidden burden while supporting sustainable dairy practices.

Limitations and Environmental Constraints

Despite its promising potential for early mastitis detection, infrared thermal imaging (IRT) encounters significant hurdles when deployed in real-world farm environments, where controlled lab conditions rarely apply. Environmental factors introduce substantial variability that can distort surface temperature readings and compromise diagnostic reliability. Fluctuations in ambient temperature, high humidity, wind speed, and direct sunlight exposure create thermal gradients across the cow's udder, often leading to false positives (overestimating inflammation) or false negatives (missing subtle heat signals). For instance, in tropical regions like southern India, where daytime temperatures exceed 35°C and humidity tops 80%, baseline udder skin temperatures naturally elevate due to solar radiation and heat stress, potentially masking the 1–2°C hyperemic rise from subclinical mastitis. Conversely, in temperate or winter conditions, evaporative cooling from wind or moisture can artificially lower readings, underestimating internal inflammation.

Technical limitations of IRT systems further compound these issues. Inaccurate device calibration, insufficient camera resolution (e.g., below 320x240 pixels), or suboptimal imaging distance (ideally 1–2 meters for udder focus) reduce spatial precision and temperature sensitivity. Animal-specific factors exacerbate the problem: restless cow movement during scanning causes motion blur in images; thick hair coats, accumulated dirt, manure, or wet udders impede infrared emission, as these act as insulators or emissivity modifiers (reducing the udder's effective emissivity from ~0.98 for clean skin to as low as 0.90). Moreover, IRT captures only superficial skin temperatures, which may not fully reflect deeper mammary gland inflammation, especially in chronic cases where heat dissipates before reaching the surface.

These constraints explain why IRT excels in standardized research settings but struggles as a standalone tool on commercial dairy farms, where diagnostic accuracy can drop below 80%

without corrections. To enable large-scale adoption, particularly in resource-limited tropical farms, IRT must integrate with advanced compensatory measures. Data correction algorithms can normalize readings for ambient conditions using real-time meteorology sensors. Multi-sensor fusion combining IRT with milk conductivity meters, wearable activity trackers, or rumen bolus data—boosts specificity by cross-validating thermal anomalies. Automated protocols, such as robotic milking parlor integrations with fixed-angle cameras and image standardization (e.g., via edge detection for quarter segmentation), minimize human error. Emerging hybrid systems leveraging artificial intelligence (AI) and Internet of Things (IoT) platforms analyze vast datasets in real-time, employing machine learning models to filter environmental noise, predict inflammation thresholds, and achieve sensitivities above 90%. These innovations position IRT as a viable component of precision dairy farming, transforming it from a lab curiosity to a practical, cost-effective tool.

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NANOTECHNOLOGY DRIVEN FERTILIZER AND NUTRIENT USE EFFICIENCY IN CROPS: A NEXT GENERATION SOLUTION FOR ENHANCED PRODUCTIVITY

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Introduction:

In modern agricultural practices, substantial volumes of fertilizers, pesticides and herbicides are employed with great intensity. This is undertaken to achieve higher production per unit area to feed the growing global population. Despite advancements and discoveries in agriculture, numerous challenges remain unresolved. These challenges constitute environmental pollution, low input use efficiency, decreased food quality, development of resistant weeds, diseases, and insects, low farm incomes, soil degradation, and toxicity. Integrating nanotechnology with agriculture presents a promising alternative. Nano-fertilizers have been proven effective in ensuring that plants receive the right nutrients at the appropriate time for optimizing their growth, yield, and sustainability. Conventional fertilization often leads to nutrient losses through leaching, volatilization, or runoff, reducing efficiency and potentially harming the environment. Researchers are utilizing nanoscale materials to develop nano-fertilizers and nano-carriers. These materials can release their active ingredients in a targeted, slow/controlled, or conditional manner. Release of the active compound is triggered by surrounding environmental stimulus or biological demands. Nutrient uptake by plant roots is significantly improved by this approach. It also minimizes environmental losses effectively. This provides a balanced solution to boost crop productivity while safeguarding natural resources.

Principle:

Nanotechnology in nutrient management utilizes the unique characteristics of materials at the nanoscale, where a high surface area-to-volume ratio enhances interactions with plant tissues. The core concept involves the design and synthesis of nanoparticles that serve as intelligent carriers for essential nutrients. These nanoparticles can be created through chemical, physical, or biological methods. Thereby allowing for meticulous control over their size, shape, and surface characteristics. This precision makes them particularly suitable for encapsulating crucial nutrients *viz.*, nitrogen, phosphorus, potassium, and various micronutrients, either within the nanoparticle structure or by adsorbing them onto the surface. Such encapsulation is vital as it safeguards the nutrients from early degradation and maintains their stability in the soil, ensuring their effectiveness over time.

When applied to soil or directly to plant leaves, these nanoparticles operate through a controlled release mechanism. Environmental factors such as pH, temperature, or moisture act as triggers, gradually releasing the entrapped nutrients in sync with the plant's growth cycle. This coordinated release guarantees that nutrients are accessible when plants require them most. Thus, this approach minimizes the losses due to leaching, volatilization, or runoff. Additionally, nano-carriers can be tailored for targeted delivery to specific areas such as the root zone. Therefore, improving the nutrient uptake efficiency by concentrating the nutrient supply where it is most advantageous.

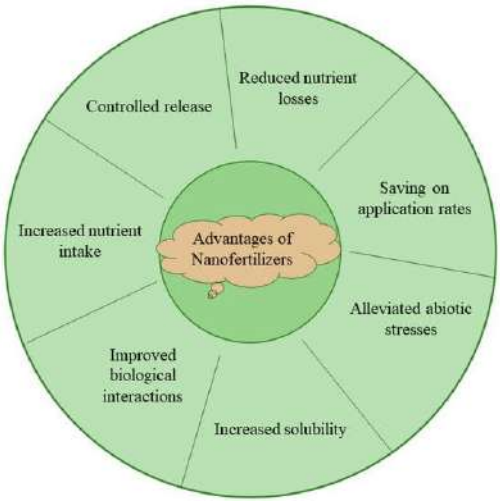

Figure 1: Advantages of Nano-fertilizers over bulk fertilizers. (Source: Ding, *et. al*., 2023)

Apart from targeted nutrient delivery, the use of nanoparticles has been found to enhance the expression of some beneficial enzymes within the plant. These beneficial enzymes include dehydrogenases, esterases, nitrate reductase, and alkaline phosphatase, etc. These enzymes play crucial roles in various metabolic pathways and physiological processes. Application of Nano fertilizers results in better plant growth, greater stress resilience, and enhanced productivity. By functioning as a "smart" delivery system, nanotechnology not only optimizes nutrient management but also promotes healthier plant development.

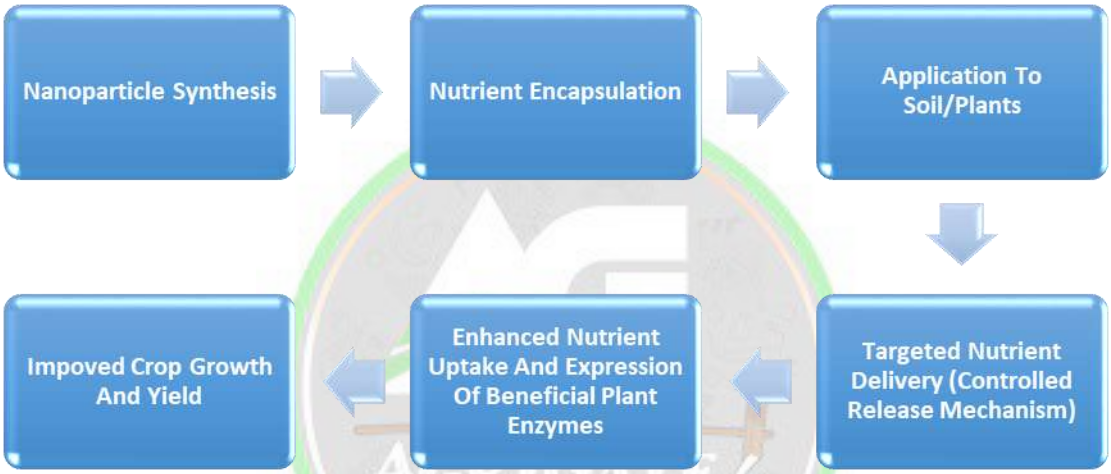

Figure 2: Flowchart showing the process from nanoparticle synthesis to improved crop yield.

Pros and Cons:

Nano-fertilizers have revolutionized nutrient management through precise delivery mechanisms that release essential nutrients exactly when plants need them. This targeted approach maximizes nutrient absorption thereby boosting crop yields and quality. It also minimizes environmental impacts by reducing nutrient runoff and leaching. By delivering supplements efficiently, nano-fertilizers help optimize resource use. Farmers can achieve superior results using fewer fertilizers, aligning with the principles of precision farming and sustainable agriculture.

The advantages of nano-fertilizers extend beyond improved efficiency. Their design allows for the fine-tuning of nutrient release in response to environmental cues. This ensures that plants receive the optimal dosage throughout their growth cycle. This dynamic nutrient

management system supports enhanced plant growth and higher production quality. It contributes to a reduction in the ecological footprint in agricultural industry.

However, despite these promising benefits, several critical challenges must be addressed to fully integrate nano-fertilizers into mainstream agribusiness. The production costs associated with nano-fertilizers are significantly higher than those of conventional fertilizers. This creates an economic barrier towards their widespread adoption. There remain many unresolved concerns regarding the long-term impacts of nanoparticles on human health and the environment. Current regulatory frameworks are struggling to keep pace with these technological developments, leading to inconsistent guidelines across different regions.

Translating the successful lab results into commercial agriculture introduces further technical obstacles. Without proper management protocols and awareness, the high efficacy of nano-fertilizers could inadvertently lead to over-fertilization. Therefore, in future it can potentially cause harmful environmental effects. Addressing these challenges will require concerted efforts from researchers, industry stakeholders, and regulatory bodies to ensure that the benefits of nano-fertilizers are realized safely and effectively in the field.

Discussion

Integrating nanotechnology into agriculture presents significant potential for sustainable farming. It provides improved nutrient uptake, increased expression of beneficial enzymes responsible for plant growth and high yield. It also decreased environmental pollution and enhanced crop yields. However, effective implementation necessitates overcoming several obstacles. Thorough risk evaluations and strong safety standards must be developed through cooperation among researchers and industry professionals, while open communication and public involvement are crucial to fostering consumer confidence. Regulatory structures must strike a balance between innovation and caution to avert unexpected risks to human and environmental well-being. Although high production costs presently hinder the uptake of nano-fertilizers, economies of scale and continual technological progress are expected to lessen these costs. Moreover, merging nanotechnology with digital agriculture tools, such as remote sensing and precision application methods, can further enhance efficiency and reduce misuse. Ultimately, achieving the full potential of nanotechnology in nutrient management will require a collaborative effort engaging scientists, engineers, policymakers, and farmers.

Conclusion:

Modern agriculture is transformed by nanotechnology, which offers a creative answer for raising nutrient use efficiency and boosting general crop performance. Nano-fertilizers significantly increase plant growth, lower environmental impact, and optimize resource use by enabling accurate, controlled, and focused nutrient delivery. Still, continued research and technological developments are quickly addressing issues like high production costs, potential health risks, and evolving legal environments. The consolidation of cross-disciplinary knowledge from scientists and engineers to government officials and industry players is hastening the development of safer and more efficient nano-enabled technologies. Nanotechnology is ultimately poised to become a cornerstone of global food security programs, changing nutrient management and groundwork for truly sustainable agriculture systems, with consistent dedication to responsible innovation and teamwork.

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DIGITAL EMPOWERMENT IN RESHAPING INDIAN AGRICULTURE FOR A PROSPEROUS FUTURE

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Abstract

Indian agriculture, historically subsistence-based, transformed with the mid-20th century Green Revolution, significantly boosting food production. The 21st century marks another evolution, shifting towards advanced tools for farmer profitability and sustainability. Technology drives this change: farmers use mobile apps for advisories, drones/sensors for precision farming, and Artificial Intelligence for predictions. Digital marketplaces like e-National Agricultural Market also enhance market access. Government initiatives, including Pradhan Mantri Fasal Bima Yojana and the Digital Agriculture Mission, actively support these advancements. However, challenges persist, such as the digital divide, language barriers, poor rural infrastructure, high technology costs, and data privacy concerns. Overcoming these drawbacks through accessible content, practical training, community engagement, and affordable access is crucial for widespread and equitable Information and Communication Technology adoption, steering Indian agriculture toward a resilient and technologically advanced future.

Keywords: Digital Marketplaces, Farmer Income, Government Initiatives, ICT, Indian Agriculture

Introduction

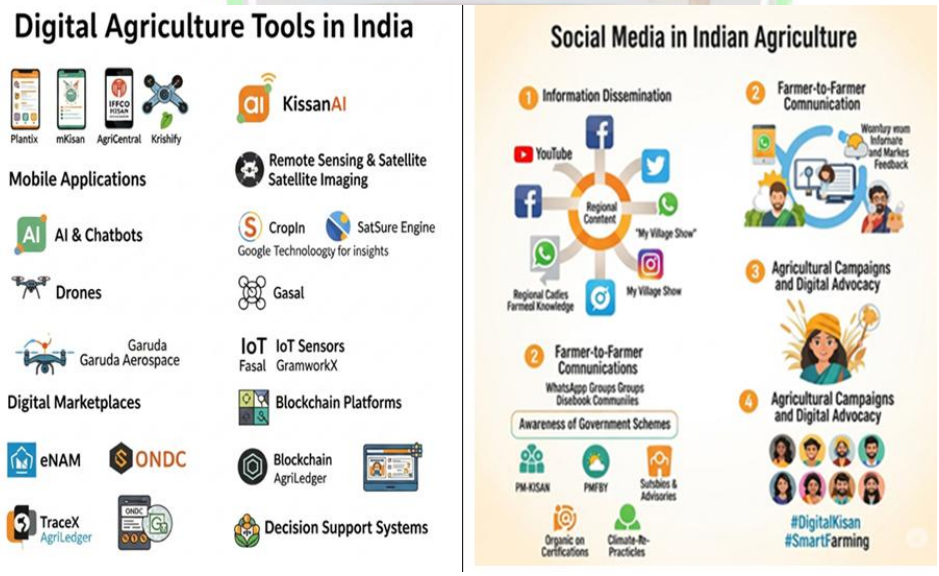
Agriculture has long played an important role in India's history and way of life. For a long time, farming was quite primitive; households raised only enough food to survive, relying

primarily on rain. As a result, they were particularly vulnerable to droughts and hard times. Farmers had frequent difficulty during the colonial period, with low yield and widespread poverty.

The middle of the twentieth century saw the beginning of a significant shift. India launched the Green Revolution in the 1960s to feed its increasing population. This resulted in the introduction of new, improved seeds, chemical fertilizers, and increased irrigation. This endeavor resulted in a massive rise in crops like wheat and rice, allowing India to feed itself.

Important organizations, such as the Indian Council of Agricultural Research (ICAR), were established at this time to promote scientific farming. Climate change, water limitations, and fluctuating market prices are all new concerns for Indian agriculture today. Farmers are now encouraged to plant a variety of crops (including fruits and vegetables) and to conduct sustainable farming. Farmers are increasingly embracing tools such as smartphone apps, smart sensors (IoT), and even drones to improve their farming practices (Industry Trends, 2020-2024). The primary goal has switched from simply producing more food to really making farmers wealthy.

ICT Tools Used in Indian Agriculture



Strategies for Driving ICT Adoption and Knowledge in Farmers

To assist with this, the government has undertaken a number of major programs. The Pradhan Mantri Fasal Bima Yojana (PMFBY) provides crop insurance, which assists farmers in the event that their crops fail. The Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) provides

immediate cash assistance. Farmers may readily sell their produce for higher prices thanks to online marketplaces like the e-National Agriculture Market (eNAM) (Government Reports, 2023-2024). Furthermore, initiatives such as the Digital Agriculture Mission (started in 2024) seek to establish a strong digital infrastructure for all farming processes. These efforts are driving Indian agriculture toward a strong, prosperous future that employs cutting edge technology.

There are a lot of ICT tools available for adopting smart agriculture practice. But there are still gaps in its use. Therefore, there is a need to think on the strategies that can foster their widespread adoption:

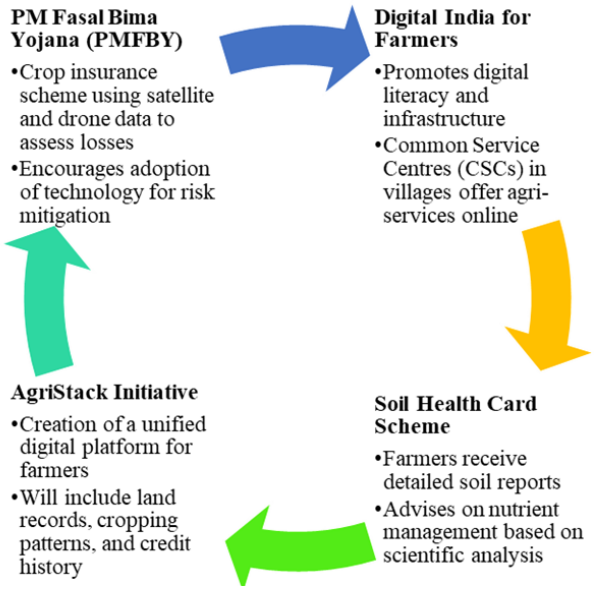
- **Tailored and Accessible Content:** There is a need to develop ICT tools and information in local languages**,** using simple formats like audio, video, and visuals. This helps overcome literacy challenges and makes the content relatable to farmers.
- **Practical Learning:** Hands-on training, workshops, and field demonstrations need to be Organized regularly**.** Allowing farmers to directly interact with and see the benefits of ICT tools in real-world scenarios to promote practical understanding and adoption.
- **Mobilizing Community Networks:** Engage **trusted local leaders, progressive farmers, and extension workers** as "digital champions." Their influence and ability to share experiences can build trust and encourage their peers to embrace new technologies.
- **Utilizing Existing Channels:** Make use of popular communication platforms already familiar to farmers**,** such as WhatsApp groups, community radio, local TV, and social media. These channels can effectively disseminate success stories, tutorials, and important information.
- **Ensure affordability and access:** There is a lot to be done to provide farmers with affordable access to smartphones, data plans, and reliable rural internet. Reducing these financial and infrastructural barriers is crucial for widespread adoption.
- **Encouraging Early Adoption:** Incentivize farmers who are early adopters of ICT tools through subsidies, discounts, or other rewards. This can motivate others to follow suit and try new technologies.
- **Ongoing Support and Feedback:** Establish continuous support systems**,** including helplines, Chatbots, and local help desks. These resources provide immediate assistance to farmers and gather valuable feedback for improving ICT services.

- **Collaborating with Farmer Producer Organizations (FPOs):** Utilize FPOs as platforms for group training and collective access to technology**.** This approach can streamline the adoption process and provide a shared learning environment.
- **Demonstrating Clear Benefits:** Benefits such as increased yields, higher income, or reduced operational costs need to be clearly demonstrated. Farmers are more likely to adopt technology when they see a direct positive impact on their livelihoods.
- **Blending with Traditional Methods:** Integrate ICT with existing traditional agricultural extension services**.** Rather than replacing conventional methods, ICT should enhance them, creating a more comprehensive and effective support system for farmers.

S. No.	ICT Tool / Platform	Type	Key Features	Major Benefits
1	mKisan	Mobile Advisory (Govt.)	SMS alerts on weather, pest alerts, crop practices	Timely information delivery
2	Kisan Suvidha	Mobile App (Govt.)	Weather, market prices, input dealers, advisories	Improved farm planning
3	Kisan Sarathi	Digital Extension Platform	Multilingual expert consultation	Personalized guidance
4	National Pest Surveillance System	AI Pest Monitoring	Pest detection, trend analysis	Reduced crop losses
5	eNAM	E-Market Platform	Online mandi trading system	Transparent pricing
6	e-Choupal	Rural Digital Network	Direct farmer–buyer linkage	Better price realization
7	ePashuhaat	Livestock E-Marketplace	Online livestock trading	Wider market access
8	DeHaat	Private Agri Platform	Advisory, input sales, market linkage	Integrated farm services

9	AgriStack	Digital Agriculture Infrastructure	Farmer database, data integration	Policy efficiency & targeted services
10	Kisan Call Centre	Helpline Service	Toll-free expert consultation (Voice/SMS)	Immediate problem solving
11	Drone-as-a-Service Platforms	Precision Agriculture	Crop monitoring, pesticide spraying	Cost reduction & precision
12	IoT Sensor Networks	Precision Farming	Soil moisture, temperature monitoring	Efficient resource use
13	AI-based Crop Advisory Systems	Decision Support	Data analytics, yield prediction	Increased productivity
14	Farm Management Information Systems (FMIS)	Farm Data Management	Record keeping, planning, performance tracking	Better farm management

Source: Ministry of Agriculture and Farmers Welfare. (2025). *Digital Agriculture Mission & ICT Initiatives in Indian Agriculture*. Government of India. Available at: https://agricoop.gov.in



Government Initiatives Using Technology

A. Changes Brought by ICT in Indian Agriculture (2024)

The introduction of ICT in agriculture has contributed tremendously. There is a marked impact on the way farmers practiced agriculture before they were explored to smarter ways though this enhanced technology. The glaring examples of this can be observed as follows:

- **Easy Access to Information:** Farmers now get real-time updates on weather, crop care, and market prices using mobile apps like **mKisan, Plantix**, and Indian Farmers Fertilizer Cooperative Limited **(IFFCO) Kisan** often in local languages.
- **Smarter Farming:** Tools like **drones, Internet of Things sensors**, and **satellite images** help farmers use water, fertilizers, and pesticides more carefully saving money and improving crops.
- **More Crop Production:** With better planning and advice from tech tools, farmers are getting (**20–30%) higher yields** in many places.
- **Stronger Farming Communities:** Apps like **Kissan AI** and platforms like **WhatsApp** and **YouTube** help farmers share ideas, solve problems, and learn new techniques quickly.
- **Less Risk and More Safety:** ICT helps farmers get alerts for bad weather, support with **crop insurance schemes** like **PMFBY (Pradhan Mantri Fasal Bima Yojana),** and early warnings about pests or diseases reducing losses.
- **Enhanced Market Connections:** Digital platforms connect farmers directly with buyers, reducing the number of intermediaries and ensuring farmers receive improved prices for their produce.
- **Greater Financial Access:** Farmers gain easier entry to digital payment systems, agricultural loans, and crop insurance, allowing for more effective risk management.
- **Farmer Empowerment through Knowledge:** Access to scientific information, opportunities for peer learning, and awareness of government schemes become available to farmers, often in their local languages.
- **Building Climate Resilience:** ICT tools, such as advanced weather forecasting and satellite data, assist farmers in adapting to and managing the effects of changing climate conditions

B. Drawbacks of ICT in Indian Agriculture

There has been a marked impact in terms of advancements brought in through the use of ICT in Indian agriculture still there is scope for improvement as there are some factors that still exist as impediments. This can be listed below as follows:

- **Digital Gap:** Many small farmers lack access to smartphones, internet connectivity, or the necessary digital skills.
- **Language and Literacy Barriers:** Digital content often isn't available in all local languages, or its format isn't suitable for farmers with low literacy levels.
- **Infrastructure Challenges:** Poor rural internet connectivity and unreliable electricity supply hinder the smooth adoption and consistent use of ICT.
- **Trust and Awareness Issues:** Farmers may have doubts about new digital tools or simply be unaware of the services that exist.
- **High Technology Costs:** Devices like drones or sensors are too expensive for most small-scale farmers to afford.
- **Data Privacy and Security Concerns:** Unresolved issues remain regarding the protection of personal farming data and overall cybersecurity.

C. Future Scope of ICT in Indian Agriculture

Looking to the major role played by ICT in Indian farming system, there is a lot that can be done to uplift the existing functioning. Therefore, time has come to focus on how this technology blend can be best utilized in times to come.

- **Increased Digital Use:** More farmers, including small and marginal ones, will start using smartphones and the internet for apps, advice, and online buying/selling.
- **Better AI and Machine Learning:** Advanced Artificial Intelligence tools will give personalized advice on crops, weather, and market prices using local information. Voice based AI assistants (like KissanAI) in local languages will become common.
- **More Precision Farming:** The use of drones, IoT sensors, and satellite imaging will grow. This will help farmers make very exact decisions about irrigation, fertilizers, and pest control, even on small farms through shared services.
- **Clearer Block chain for Tracking:** Block chain technology will be used more to track farm products from the farm to the consumer. This is especially for organic and export goods, making the supply chain more honest.

- **Growing Digital Marketplaces and E-commerce:** Online platforms like e- Marketing Agricultural Market (eNAM) and Open Network for Digital Commerce (ONDC) will expand. This will help farmers get better prices and reach buyers across India and worldwide.
- **Smarter Insurance and Loans:** ICT tools will help create data-based crop insurance and allow for faster loan approvals, using real-time risk checks and digital land records.
- **Support for Agri-Startups and Innovation:** More new technology companies in agriculture will start, helped by government programs. Special centers and AI-powered hubs will offer local solutions.
- **Strong Policy and Infrastructure:** Government plans like AgriStack and the Digital Agriculture Mission will ensure a strong and complete digital setup for agriculture

Conclusion

The landscape of Indian agriculture is undergoing a profound transformation, moving beyond its traditional subsistence roots to embrace a technologically advanced future. The initial Green Revolution significantly boosted food production, and now, the integration of Information and Communication Technologies (ICT) is set to bring in an era of enhanced farmer profitability and sustainability. Technology is empowering farmers with unique tools, ranging from mobile applications that provide real-time advisories to the advanced use of drones, sensors, and AI for precision farming. However, widespread and equitable adoption faces constraint like the digital divide, language barriers, and high technology costs. Overcoming these challenges through accessible content, practical training, community engagement, and affordable access is critical. By addressing these drawbacks, India can ensure that its agricultural sector becomes more resilient, prosperous, and globally competitive, truly support technology for the benefit of every farmer.

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ADVANCING HIGH-VALUE AGRICULTURE: INSIGHTS FROM THE 2026 BUDGET

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Abstract

The Union Budget 2026–27 reflects a strategic transformation in India's agricultural policy by prioritizing high-value crop promotion as a pathway to enhance farmer incomes, diversify production systems, and strengthen rural economies. Staple crops like rice and wheat, which guarantee food security but frequently provide farmers with meager financial returns, have historically dominated Indian agriculture. A transition toward market-oriented and income-driven agriculture is shown by the movement toward high-value commodities, such as fruits, vegetables, plantation crops, and spices. With an emphasis on financial priorities, diversification tactics, technical interventions, and regional approaches, this study investigates the reasoning for this change in policy. Additionally, it assesses the social and economic effects of promoting high-value crops, such as increased export competitiveness, employment creation, and revenue. While the approach offers significant opportunities, challenges related to infrastructure, inclusivity, and research investment remain critical. The study concludes that effective implementation and institutional support are essential to realize the full potential of this strategy.

Keywords: High-value crops, Agricultural diversification, Farmer income, Agricultural policy

Introduction

India's economy is heavily dependent on agriculture, which supports a sizable portion of the populace and makes a substantial contribution to rural development. The industry has long battled problems like low productivity, dispersed landholdings, and an over reliance on cereal-based farming patterns, despite its significance. These difficulties have limited income development and made people more susceptible to market and climate hazards. Recent policy frameworks have responded by emphasizing structural transformation through diversification into high-value crops, especially the Union Budget 2026–2027.

A practical strategy to raise farm incomes and strengthen resilience is through high-value agriculture. Compared to grains, crops including fruits, vegetables, spices, and plantation goods yield greater returns per unit area and offer chances for value addition and export. Diversification toward high-value crops considerably increases farm profitability and lowers income fluctuation, according to studies (Birthal et al., 2007). This change is in line with more general development objectives of boosting agricultural output and guaranteeing sustainable rural livelihoods.

Additionally, a shift toward market-oriented agriculture is reflected in the policy's emphasis on high-value commodities. According to Pingali (2012), commercialization and diversification are becoming increasingly important to the development of agricultural systems in emerging nations. By combining infrastructure expansion, technical innovation, and region-specific tactics to support high-value agricultural production, the 2026 budget expands on this viewpoint.

Policy Focus in the 2026 Budget

- **Increased Budgetary Allocation**

The Union Budget 2026–27 demonstrates a strong commitment to agricultural transformation through increased public investment. With substantial allocation to agriculture and allied sectors, the government has emphasized the importance of enhancing productivity and promoting high-value crops. This targeted investment reflects a shift from input-based subsidies toward outcome-oriented expenditure aimed at improving farm incomes.

Diversification in agriculture is greatly aided by public investment. The World Bank (2020) states that in order to help farmers shift to high-value crops, strategic investments in infrastructure, research, and market development are crucial. It is anticipated that the budget's

emphasis on horticulture, plantation crops, and related activities will increase economic returns and enhance sectoral performance as a whole.

Furthermore, more funding makes it possible to build vital infrastructure including processing facilities, storage facilities, and irrigation systems. High-value agriculture, which frequently calls for more intense resource usage and effective supply chains, demands these expenditures. The government hopes to foster an atmosphere that supports sustained agricultural expansion by giving such investments top priority.

- **Crop Diversification Strategy**

A key component of the 2026 budget's agriculture policy is crop diversification. Due to regulatory incentives like minimum support prices and procurement mechanisms, rice and wheat have historically dominated Indian agriculture. Although this strategy guaranteed food security, it also resulted in limited income development and environmental devastation. By encouraging farmers to use more profitable and sustainable agricultural practices, the present policy change seeks to address these problems.

By lowering reliance on a single crop, diversification toward high-value crops improves agricultural resilience. By distributing risk among several commodities, it helps farmers lessen the effects of unfavorable market or weather conditions. Diversified farming methods are linked to increased income stability and better resource use efficiency, according to empirical data (Rao, 2010).

In addition, diversification creates opportunities for value addition and market integration. High-value crops often require processing and packaging, which can generate additional income and employment. As noted by Dev (2012), promoting diversification among smallholders is critical for achieving inclusive agricultural growth and reducing rural poverty.

- **Region-Specific Interventions**

The 2026 budget adopts a region-specific approach to agricultural development, recognizing the diversity of India's agro-climatic conditions. It is advised for various locations to focus on crops that are most appropriate for their unique environmental conditions. This method guarantees the effective use of natural resources while increasing productivity. Localized value chain growth is also aided by region-specific actions. The government can encourage economies of scale and boost supply chain efficiency by concentrating production in particular regions. Such clustering strategies are crucial for boosting competitiveness and

guaranteeing sustainable agricultural development, according to the Food and Agriculture Organization (2023).

Additionally, choosing crops based on local conditions lowers the likelihood of crop failure and enhances agricultural productivity. Because it allows farmers to use crops that are more adaptable to local environmental conditions, this strategy is especially crucial in light of climate change.

- **Promotion of Plantation Crops**

The 2026 budget places particular attention on plantation crops including cashew, coconut, and cocoa because of their high economic worth and export potential. These crops support sustainable land use practices and offer long-term revenue prospects.

In areas like Kerala, where plantation crops constitute a substantial portion of the agricultural economy, the promotion of these crops is especially pertinent. Farmers' revenues can be greatly increased by increasing production through better management techniques and improved varieties. Plantation crops have a significant potential for value addition and export expansion, according to research (Sharma, 2015).

Additionally, plantation crops boost agro-based businesses, generating jobs and advancing rural development. The government hopes to increase these crops' contribution to the economy as a whole by fortifying their value chain.

Role of Technology and Innovation

Innovation and technology are essential elements of the strategy for promoting high-value crops. To increase productivity and efficiency, the 2026 budget places a strong emphasis on precision farming, digital agriculture, and data-driven decision-making. Farmers may increase agricultural yields, cut expenses, and optimize input utilization with the help of these technology.

Digital systems that provide current information on market prices, weather, and pest control can help farmers make well-informed decisions. The Food and Agriculture Organization (2023) states that the use of digital technologies can significantly boost agricultural productivity and sustainability.

Furthermore, improving market access and supporting supply chains depend on innovation. Technologies including cold storage, transportation networks, and processing facilities are essential to maintaining the quality of high-value crops and reducing post-harvest

losses. The government wants to make agriculture more competitive and efficient by incorporating technology.

Economic and Social Implications

- **Income Enhancement**

Increasing farmer incomes is one of the main goals of high-value crop promotion. These crops present chances for value addition and yield greater returns per unit area. Diversification into high-value agriculture considerably increases farm profitability, according to empirical research (Birthal et al., 2007).

Furthermore, compared to raw produce, value-added products like packaged goods and processed foods can bring in more money. Farmers are able to increase their economic well-being and obtain a greater portion of the value chain as a result.

- **Employment Generation**

High-value agriculture generates jobs in rural regions but requires a lot of labor. Both expert and unskilled labor are needed for tasks including cultivation, processing, and marketing, which support jobs in rural areas.

This is especially crucial for dealing with the problems of migration and underemployment. High-value agriculture can lessen the need for rural residents to relocate to cities by creating jobs locally (Dev, 2012).

- **Export Competitiveness**

High-value crops are a crucial part of India's trade strategy because of their significant export potential. Products including plantation vegetables, nuts, and spices are highly sought after in global marketplaces.

Increasing export competitiveness requires raising quality standards and streamlining the supply chain. Infrastructure and market development investments are essential for integrating farmers into global value chains, according to the World Bank (2020).

- **Rural Development**

By boosting economic activity and enhancing infrastructure, the promotion of high-value crops supports more extensive rural development. An environment that is conducive to agricultural growth is produced by investments in processing, storage, and transportation facilities.

These advancements help the economy as a whole in addition to farmers. High-value agriculture might be crucial to attaining inclusive growth by bolstering rural economies.

Challenges and Criticisms

The development of high-value crops faces a number of obstacles despite its potential advantages. The restricted ability of smallholder farmers to adopt new technologies and techniques is one of the main issues. The shift to high-value agriculture may be hampered by a lack of resources and finance availability.

Infrastructure constraints are another major obstacle. Rural areas frequently lack effective transportation and storage infrastructure, which is necessary for high-value commodities. Farmers might not be able to fully benefit from diversification without sufficient infrastructure (World Bank, 2020).

Concerns have also been expressed over the necessity of ongoing funding for agricultural research and development. Increasing productivity and tackling issues like climate change require innovation. The long-term viability of high-value crop promotion may be jeopardized in the absence of sufficient research support.

Conclusion

India's agricultural strategy has undergone a dramatic change with the Union Budget 2026–2027, which places a major focus on promoting high-value crops. The government wants to make agriculture a more lucrative and sustainable industry by promoting diversification, utilizing technology, and implementing region-specific tactics. Although the strategy presents significant chances for increasing revenue, creating jobs, and expanding exports, its success hinges on efficient execution and infrastructure support. It will be crucial to address issues with research, capacity building, and inclusivity.

In conclusion, India's agricultural environment might be completely transformed by high-value crop promotion. However, the ability of institutions, farmers, and policymakers to collaborate in converting policy vision into workable results will be critical to its success.

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AN UNKNOWN HERBAL PLANT: VELVET BEAN AND ITS NUTRITIONAL IMPORTANCE

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Abstract

Underutilized legume comprises vital nutrients with a higher proportion of protein (23-43) equal to soybean, and lima bean and greater than chickpea and green pea. In addition, it has a good calorific value, carbohydrates, vitamins, and minerals. The presence of bioactive components such as polyphenols and flavonoids increases the market demand in pharmacological industries at the global level. It exhibits several pharmacological properties like antioxidant, anti-inflammatory, anti-diabetic, antimicrobial, and antihypertensive. It has a higher concentration of antinutritional compounds like L-DOPA, phytates, tannin, oxalate, hydrogen cyanide, and trypsin inhibitors. These barriers prevent the consumption of velvet beans, and they can be reduced by both conventional and modern methods. The methods include dehulling, boiling, soaking, cooking, roasting, toasting, fermentation, sonication, and acid and alkali treatment. Each method has a distinct effect on the method of removal of antinutrients and it has an impact on its reduction percentage. It is considered an alternative protein source to animal protein, hence extraction of protein from velvet beans has a better scope to isolate and concentrate protein and its peptides. This flour has been utilized in food formulations like bread, crackers, food mix, beverage mix, mucuna milk, and traditional foods like moin moin, chapatti, and mash.

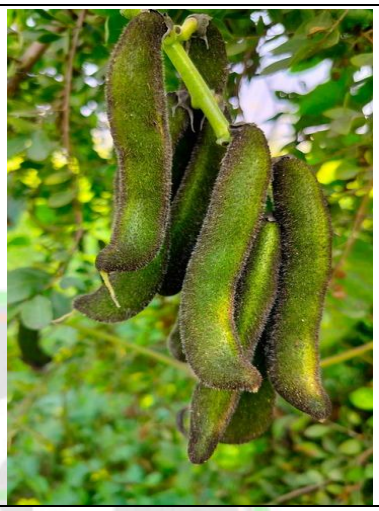
Introduction

Velvet bean (*Mucuna pruriens*) is a tropical legume native to Africa and tropical Asia widely naturalized and cultivated. It is a diploid tropical legume (2n = 2x = 22) that belongs to the phaseoloid clade of the Leguminosae family. It belongs to the family of Fabaceae also called Leguminosae, subfamily: Faboideae tribe and Phaseoleae subtribe: Erythrininae. Its English common names include monkey tamarind, velvet bean, Bengal velvet bean, Florida velvet bean, Mauritius velvet bean, Yokohama velvet bean, cowage, cow itch, lacuna bean, and Lyon bean. Its belong to the family *Fabaceae* and genus *Mucuna*, a vigorous annual climbing legume with long and slender branches. The plant is notorious for the extreme itchiness it produces on contact, particularly with the young foliage and the seed pods. *Mucuna pruriens* known as "Velvet Bean," it is an important herb used in the Indian system of Traditional medicine. It is mainly used as a drug to promote muscle mass and body weight and is advocated as Aphrodisiac. It has agricultural and horticultural value and is used in herbalism.

Description

Mucuna pruriens is an annual climbing shrub with long vines that can reach over 15 metres (50 feet) in length. When the plant is young, it is almost completely covered with fuzzy

hairs, but when older, it is almost completely free of hairs. The leaves are trip innate, ovate, reverse ovate, rhombus-shaped or widely ovate. The sides of the leaves are often heavily grooved and the tips are pointy. In young specimens, both sides of the leaves have hairs. The stems of the leaflets are 2–3 millimetres long. Additional adjacent leaves are present and are about 5 mm long.

	
Velvet bean flower	Velvet bean unripened fruit
Velvet bean matured fruit	Velvet bean seeds

The flower heads take the form of axially arrayed panicles. They are 15–32 centimetres long and have two or three, or many flowers, which can be white, lavender, or purple. The accompanying leaves are about 12.5 mm long; the flower stand axes are from 2.5–5 mm. The bell is 7.5–9 mm long and silky. The sepals are longer or of the same length as the shuttles. The crown is purplish or white. The flag is 1.5 mm long. The wings are 2.5–3.8 cm long.

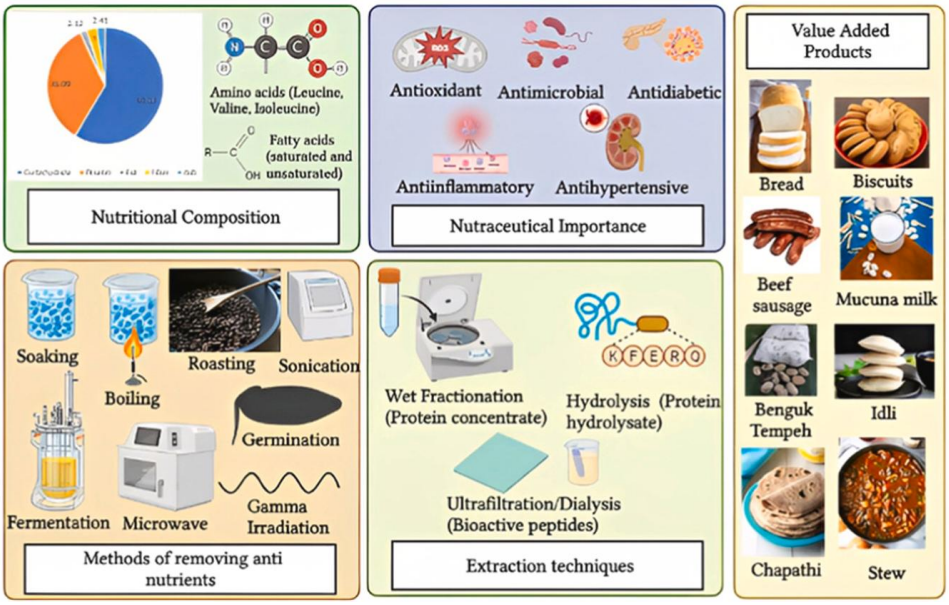
In the fruit-ripening stage, a 4–13 cm (2–5 in) long, 1–2 cm wide, unwinged, leguminous fruit develops. There is a ridge along its length and the husk is covered in loose, orange hairs that cause a severe itch if they contact skin. The pods carry up to seven seeds, which are shiny black or brown drift seeds. They are flattened uniform ellipsoids, 1–1.9 cm long, .8–1.3 cm wide and 4–6.5 cm (2–3 in) thick. The *hilum*, the base of the *funiculus* (connection between placenta and plant seeds) is a surrounded by a significant *arillus* (fleshy seed shell). The dry weight of the seeds is 55–85 grams (2–3 ounces)/100 seed.s

Chemistry

Seeds extract mainly contained amino acids, saturated fatty acid, polyunsaturated fatty acid, protein, carbohydrates, minerals, and used as a medication of various degenerative disorders. In *Mucuna pruriens*, a non-protein amino acid L- 3, 4-dihydroxyphenyl alanine (Levodopa, or L-DOPA), is found in seed extracts. In Central America, it is used as a coffee and also as a staple food by tribal people in Guatemala and India. Mucuna pruriens also possess valuable medicinal properties like anti- diabetic, anti-epileptic, and anti-microbial activities, anti-cancers. Some studies show its importance in cardiac and cancer, but not much evidence is available. It requires more clinical studies for better outcomes. The seeds of the plant contain about 3.1–6.1% L-DOPA. *M. pruriens* var. *pruriens* has the highest content of L-DOPA. An average of 52.11% degradation of L-DOPA into damaging quinones and reactive oxygen species was found in seeds of *M. pruriens* varieties.

Nutritional composition of velvet beans

Mucuna pruriens contains the essential nutrients required for human metabolism and to maintain health well -being. The mucuna composition ranges between 42.79 and 64.88 g/100 g DW crude carbohydrate, 23–43 g/100 g DW crude protein, 4.1–14.39 g/100 g DW crude lipid, 5.3–11.5 g/100 g DW crude fiber, and 2.9–5.5 g/100 g DW ash content. Mucuna seeds are considered as nutritionally potential due to higher protein content. Comparably mucuna seeds have the equal nutritional quality to soybeans, rice bean, and lima beans, higher than chickpea, common bean, green pea, pigeon pea, lentils, peanuts, and black beans hence it is treated as a cheap and alternative source of protein .



The mucuna species are rich sources of iron (0.06–0.95 mg/g), calcium (0.76–5.30 mg/g), potassium (0.13–0.19 mg/g), and phosphorus (0.02 mg/g). These nutrients play major roles in the repair and maintenance, as well as regulation of the human body. In particular, the potassium content in mucuna can play a significant role in preventing heart diseases like high blood pressure. The combination of calcium and phosphorous can improve the conditions of osteoporosis. The other minerals such as zinc, magnesium, and selenium could have a positive impact on diabetes mellitus condition.

Mucuna seeds possess a good amount of amino acids which is a basic building block of proteins. It comprises of both essential amino acids such as histidine (18.32–40.81 mg/g protein), isoleucine (30.76–66.35 mg/g protein), leucine (72.47–103.51 mg/g protein), lysine (27.22–57.28 mg/g protein), methionine (25.51–51.74 mg/g protein), threonine (10.91–37.40 mg/g protein), tryptophan (29.22–61.62 mg/g protein), and valine (35.71–72.74 mg/g protein), and non-essential amino acids such as alanine (49.11–81.31 mg/g protein), arginine (38.39–71.27 mg/g protein), aspartate (63.11–110.44 mg/g protein), cystine (2.33–13.79 mg/g protein), glutamic acid (81.57–125.76 mg/g protein), proline (5.89–33.98 mg/g protein), serine (25.67–91.22 mg/g protein), and tyrosine (1.21–18.51 mg/g protein) present in such a proportion that could be able to meet the dietary recommendations of an individual. Leucine, followed by valine, and isoleucine; glutamic acid, followed by aspartate, and alanine ranks highest in essential and non-essential amino acids

Mucuna Pruriens Benefits and Uses

Ayurveda recognizes Mucuna as a source of nourishment and rejuvenation for the tissues, bestowing a foundation of balanced energy and well-being. Perhaps best known for its affinity for the nervous system and reproductive organs, Mucuna's magical benefits extend throughout the entire body:

- **Promotes a healthy nervous system.** As a rejuvenating herb, Mucuna has a profoundly nourishing and rejuvenating effect. It can minimize the effects of stress while supporting a calm and stable nervous system.
- **Supports motor skills and coordination.** Mucuna's work in the nervous system directly affects the muscles as well, encouraging fluid muscular movements, proper sensation, coordination, and keen motor skills.
- **Supports healthy digestion and elimination.** Because it promotes smooth muscle contractions, Mucuna can help foster healthy digestive function and promote proper elimination.
- **Provides significant nutritional content.** Mucuna helps to support and maintain balanced blood sugar levels that are already in the healthy range. The seeds themselves are considered to be high in dietary nutrition, with nutritive values similar to other commonly consumed legumes.The green pods and whole beans are traditionally boiled and eaten in the Himalayas.
- **Natural source of levodopa (L-dopa).** Mucuna's naturally occurring levodopa is an essential precursor of the neurotransmitter dopamine, which contributes to brain and nervous system health. Dopamine plays an important role in behavior, cognition, voluntary movement, sleep, mood, working memory and earning.

Is Mucuna Safe?

In one study involving a derivative of *Mucuna pruriens*, mild adverse effects primarily of a gastrointestinal nature were reported. These included mild and rare experiences of nausea, abdominal discomfort, vomiting, and insomnia.In excess, Mucuna can cause headaches, movement disorders, fatigue, tremors, fainting, and thirst. *Mucuna pruriens* should also be avoided in patients with psychosis, schizophrenia, glaucoma, heart arrhythmias, chronic nerve pain, and stomach ulcers. Because of the potential for additive effects or interaction, use caution in patients who are taking antidepressants, MAOIs, antidiabetic drugs, or anesthesia. If you are

taking prescription medication of any kind, it is always best to check with your doctor before introducing an herbal regimen.

Long term effects

Generally, Mucuna is considered safe for many to take long term. One study that looked at the long term effects of high daily doses of Mucuna over a decade's span found that there were some reports of mild gastrointestinal disturbances. Overall, these seemed to be transient in nature.

Conclusion

Mucuna species contains many varieties, among them *Mucuna pruriens* variety has been found to have higher l-DOPA content, a predominant bioactive compound responsible for various pharmacological properties. Bioactive compounds such as 9,12-octadecadienoic acid, polyphenols, flavonoids, and secondary metabolites such as phytic acid, tannins, and saponins have been reported for their strong antioxidant and anti-inflammatory properties. Novel processing, and production techniques need to be studied in future to improve the production, consumption, industrialization, and commercialization of underutilized legumes in food, and feed, pharmaceutical, and nutraceutical industries. The bioavailability of both macro and micronutrients could be increased by the new intervention technique called biofortification where the nutritional value of crops can be enhanced with the help of breeding, transgenic techniques, or agronomic practices. This technique had been applied only in primary crops such as rice, wheat, and maize, and the future studies on underutilized legumes like mucuna seed needs to be performed. The implementation of this technique in underutilized legumes would enhance the utilization of seeds in food and feed industries and might reduce malnutrition in developing countries.

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