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AgriGate

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An International Multidisciplinary Monthly e-Magazine



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agrigatemagazine@gmail.com



AgriGate

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. 01 – January 2026**” with immense pleasure our team is privileged to dedicate this issue to the Agricultural Youths. The birth anniversary of Swami Vivekananda is celebrated every year on 12 January as **National Youth day**. One of the most popular festivals in India is **Pongal** and is celebrated widely by the Tamil community across the globe. **Pongal and Lohri festival** is celebrated on 14 or 15 January. It is dedicated to the Sun God. Lohri is the first festival of the year which marks the beginning of the harvest season. It is celebrated with full enthusiasm in northern India.

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.

A handwritten signature in black ink, appearing to read 'R. Shiv Ramakrishnan'.

Dr R Shiv Ramakrishnan
Editor-in-chief
AgriGate Magazine

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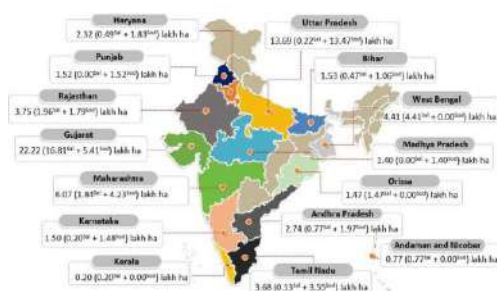
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ADVANCING GENDER INCLUSIVITY IN INDIAN AGRICULTURE: A PATHWAY FOR SUSTAINABLE GROWTH

Article ID: AG-VO6-I01-01**Saikiran Chintakindi^{1*}**

¹Assistant Professor, Dept of Agril. Extension, Chaitanya Deemed to be University,
Hyderabad (T. S.). India

Abstract

Women are integral to Indian agriculture, contributing significantly to crop cultivation, seed management, soil conservation, livestock care, and post-harvest operations, making them essential to household food security and sustainable farming systems. Their deep traditional knowledge of biodiversity, soil behaviour, weather patterns, and climate adaptation strengthens ecological resilience, yet their contributions remain undervalued. Despite their centrality, women face persistent structural barriers such as limited land ownership, inadequate access to credit, technology, markets, and extension services, along with restricted mobility and low representation in agricultural institutions. Advancing gender inclusivity requires targeted interventions that expand women's access to productive resources, promote joint land titles, streamline inheritance rights, and ensure user-friendly, women-centric farm technologies. Strengthening financial inclusion through institutional credit, insurance products, and market linkages enhances economic independence and improves adoption of climate-smart practices. Digital inclusion through ICT tools, smartphone training, and rural connectivity empowers women with real-time information and better decision-making capacity. Supporting women-led agribusinesses through incubation, skill development, value addition, and branding can unlock entrepreneurial potential and diversify rural incomes. Increasing women's participation in governance structures such as FPOs, cooperatives, and local planning bodies ensures more responsive and equitable agricultural policies. Reorienting extension systems to be gender-sensitive through women-exclusive training sessions, flexible schedules, and more women extension workers improves knowledge dissemination and technology uptake. Recognising and

valuing women's unpaid agricultural and caregiving labour through welfare schemes, labour protections, and social security further strengthens their socio-economic position. Building a robust gender-disaggregated evidence base is essential for planning targeted programs and ensuring sustainable, inclusive growth. Enhancing gender inclusivity is thus critical for improving productivity, resilience, and the overall sustainability of Indian agriculture.

Key words: Food security, Gender, Sustainable farming, Women-centric.

Introduction

India's agricultural sector remains the foundation of the national economy, supporting millions of households and ensuring food and nutritional security. Within this vast system, women hold a central and indispensable position. They contribute not merely as supporting labour but as active farmers, resource managers, knowledge holders, and household decision-makers. Their involvement spans crop production, livestock management, seed preservation, post-harvest processes, and ecological stewardship. Recognizing women's contributions is not only a matter of promoting gender equity; it is vital for enhancing sustainability, productivity, and resilience in the agricultural sector.

As agriculture becomes increasingly feminized, persistent inequalities continue to hinder women's progress. Limited access to land ownership, credit, agricultural technologies, extension services, training opportunities, and market linkages restricts their ability to fully realize their potential. These barriers exist despite the fact that women constitute a significant proportion of the agricultural workforce and are often responsible for ensuring household food security. With 2026 declared as the International Year of Women Farmers, there is a timely global and national opportunity to prioritize the concerns of women in agriculture. This moment allows policymakers, institutions, and development partners to focus on long-term structural reforms. The following sections outline the essential reasons why women matter in Indian agriculture and highlight key considerations for creating an inclusive, innovative, and future-ready agricultural system.

Why Women Matter in Indian Agriculture

➤ Key Contributions of Rural Women

Rural women are at the heart of India's agricultural operations and natural resource systems. They play a major role in conserving and managing essential resources such as soil, seeds, water, and biodiversity. Their day-to-day involvement in crop cultivation, weeding,

harvesting, storing, and processing directly influences overall agricultural productivity and household subsistence. Women also take primary responsibility for livestock rearing, fodder collection, and maintenance of small-scale home gardens, which greatly contribute to nutritional security. Their traditional knowledge, especially regarding crop varieties, soil behaviour, local weather patterns, and climate resilience forms a crucial foundation for a sustainable and adaptive agro economy.

➤ **Need for Inclusive Strategies**

To ensure equitable and sustainable development, it is necessary to expand women's access to essential agricultural resources and decision-making systems. This includes secure land and water rights, access to institutional credit, availability of user-friendly technologies and mechanization, and participation in training and extension services. Strengthening women's representation in policy forums and farm-level governance structures is equally important. Tools such as the Women's Empowerment in Agriculture Index (WEAI) play a valuable role in identifying gaps in empowerment and guiding targeted interventions aimed at improving women's participation and agency. Inclusive strategies that support women farmers ultimately contribute to higher productivity, improved family well-being, and stronger local economies.

➤ **Existing Challenges**

Despite their central role, women continue to confront systemic and cultural challenges that limit their agricultural potential. Social norms often restrict mobility, decision-making power, and ownership of productive assets. Many women lack land titles, which in turn limits their eligibility for formal credit, insurance, and government schemes. Their representation in agricultural institutions, research systems, and leadership roles remains low. Although initiatives like the Mahila Kisan Sashaktikaran Pariyojana (MKSP) have strengthened women's capacities and visibility, much remains to be done to transform structural inequalities. Addressing these barriers requires sustained policy attention, gender-responsive programming, and greater institutional support.

Towards an Inclusive and Innovative Agriculture System

A sustainable agricultural future depends on adopting inclusive, innovative, and collaborative approaches that place women at the centre. Building such a system requires convergence among multiple stakeholders, women farmers, farmer producer organizations (FPOs), self-help groups (SHGs), research institutions, extension agencies, policymakers, and

civil society organizations. When diverse voices are included in agricultural planning and implementation, solutions become more practical, equitable, and culturally responsive. Women-led collectives, cooperatives, and producer groups bring unique insights into local farming systems and play a vital role in shaping resilient and community-driven agricultural models. Encouraging multi-stakeholder partnerships and knowledge sharing can act as a catalyst for inclusive growth and transformative agricultural development in India.

Interventions Aimed at Enhancing Gender Inclusivity in Indian Agriculture

A. Securing Land and Resource Rights for Women Farmers

Women's limited ownership of land and productive assets restricts their access to credit, technologies, and extension services. Policies promoting joint land titles, streamlined inheritance procedures, and legal awareness campaigns are essential for improving women's control over resources. Strengthening community-level mechanisms to support women's rights further ensures that they can claim land, irrigation, and common resources without barriers. When women have secure land rights, their bargaining power, investment decisions, and productivity significantly increase.

B. Promoting Climate-Smart and Women-Friendly Farming Solutions

Women face greater climate vulnerabilities due to limited resources and increased workload. Promoting climate-smart practices such as water-efficient irrigation, drought-tolerant crops, organic inputs, and soil-health management can reduce risks and improve sustainability. At the same time, ergonomic and women-friendly farm tools can reduce drudgery and enhance productivity. Ensuring that women are trained in these technologies and given priority in field demonstrations helps in faster adoption and long-term resilience.

C. Expanding Women's Financial Access and Economic Opportunities

Women farmers often face hurdles in obtaining credit, insurance, and market linkages. Improving access to institutional finance, simplifying documentation, and offering gender-responsive insurance products can significantly enhance their economic participation. Equally important is enabling women to engage in value chains through procurement support, market information, storage infrastructure, and transport facilities. When financial and market opportunities become accessible, women are better positioned to invest in technologies, diversify crops, and move toward sustainable economic growth.

D. Advancing Digital Inclusion for Rural Women

Bridging the digital divide is critical for modern agricultural transformation. Digital platforms offering information on weather, markets, inputs, pest management, and government schemes can empower women with timely decision-making support. However, access alone is not enough, women also require training in operating smartphones, using agricultural apps, or adopting digital payment systems. Strengthening rural connectivity, community digital centres, and women-focused ICT training programs ensures that digital innovations reach women equally, leading to more informed and resilient farming practices.

E. Nurturing Women-Led Agri-Business and Innovation

Women's entrepreneurial potential in agriculture remains largely underutilised. Strengthening women-led enterprises requires targeted support such as incubation centres, start-up grants, skill development, branding assistance, and market intelligence. Encouraging innovations in food processing, value addition, seed production, and agri-based services can create new income streams. With structured mentoring and access to technology, women can scale enterprises and contribute significantly to rural economic diversification.

F. Strengthening Women's Voice in Agricultural Governance

Enhancing women's participation in agricultural decision-making requires institutions that actively include them at every stage from planning to implementation. Local bodies, cooperatives, farmer-producer organisations, and extension departments should ensure women's representation in leadership roles and advisory committees. When women farmers are part of governance systems, policies become more responsive to their needs, and programs gain higher acceptance and practical relevance. Creating supportive institutional spaces can help women articulate challenges related to markets, technology, and labour, enabling more effective gender-inclusive interventions.

G. Reorienting Extension Services for Greater Gender Inclusion

Traditional extension systems often overlook women despite their major role in agricultural labour. Reorienting extension services to include women as active participants and future professionals can transform outreach effectiveness. Deploying more women extension workers, organising women-exclusive training sessions, adjusting training schedules to suit women's daily routines, and developing gender-responsive extension materials can ensure

equitable access to knowledge. Community-based approaches such as women's farmer groups and peer-learning networks further improve technology adoption.

H. Recognising, Valuing, and Protecting Women's Agricultural Work

Women contribute extensively to farm labour, livestock care, post-harvest handling, and household food security, yet much of their work remains unrecognised and unpaid. Policies must acknowledge women's roles through accurate labour accounting, welfare schemes, social security coverage, and safety measures. Strengthening labour protections, establishing safe working environments, and recognising unpaid contributions ensure that women receive due value for their work. Formal recognition leads to increased dignity, empowerment, and improved economic outcomes.

I. Building a Robust Evidence Base for Gender-Inclusive Planning

Reliable and detailed data on women's involvement in farming is essential for designing targeted policies. Strengthening gender-disaggregated data collection on land use, labour, technology access, income, credit, and climate vulnerabilities helps policymakers understand structural inequalities. Regular field surveys, digital databases, and systematic monitoring frameworks ensure that gender dynamics are accurately captured. A strong evidence base allows programmes to be planned, implemented, and evaluated with greater precision, leading to better resource allocation and higher impact.

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FATTY ACID METHYL ESTER ANALYSIS FOR AEROBIC BIOCONTROL AGENTS AND ITS USAGE IN PLANT PATHOLOGY

Article ID: AG-VO6-I01-02***P.Ahila Devi and Shanmugapriya, M**

Tamil Nadu Rice Research Institute, Aduthurai

MS Swaminathan Agricultural College and research institute, Eachankottai, Thanjavur District
Tamil Nadu, India***Corresponding Author: P.Ahila Devi**

Introduction

FAME analysis refers to Fatty Acid Methyl Ester analysis, a technique that uses gas chromatography (GC) to identify and quantify fatty acids in a sample after they have been converted to their methyl ester derivatives. This powerful method provides insights into the lipid content of food, the microbial composition of environmental samples, and the lipid metabolism of cells and tissues, making it valuable in fields like food science, microbiology, and agricultural research.

FAME Analysis Works

1. Extraction:

Lipids are extracted from the sample matrix using a solvent.

2. Esterification:

The fatty acids are chemically converted into their methyl ester forms (FAMES) through a process called transesterification or esterification.

3. Gas Chromatography (GC):

The FAMES are then introduced into a gas chromatograph, where they are separated based on their chemical properties.

4. Profilin

g: The GC produces a fatty acid profile, showing the types and amounts of individual fatty acids present in the original sample.

Aerobic microorganism

Aerobic microbes are organisms that require oxygen to survive and generate energy through cellular respiration. They are characterized by their ability to use oxygen as the final electron acceptor in metabolic processes and have enzymes to neutralize toxic oxygen byproducts. Examples include obligate aerobes (which need oxygen), microaerophiles (which need low concentrations of oxygen), and facultative anaerobes (which can use oxygen but also have other methods of energy production).

Types of aerobic microbes

- Obligate aerobes:

These microbes absolutely require oxygen to survive and can only produce energy through aerobic respiration. Examples include *Mycobacterium tuberculosis* and *Bacillus subtilis*.

- Facultative anaerobes:

These microbes have the ability to grow in the presence of oxygen but can also survive and grow in its absence using other metabolic pathways. *Escherichia coli* is a common example of a facultative anaerobe.

- Microaerophiles:

These microbes need oxygen to live, but only in low concentrations. High concentrations of oxygen can be toxic to them. *Helicobacter pylori* is an example of a microaerophile.

- Aerotolerant anaerobes:

These organisms do not use oxygen for their metabolic processes, but they are not harmed by its presence and can survive in an oxygenated environment

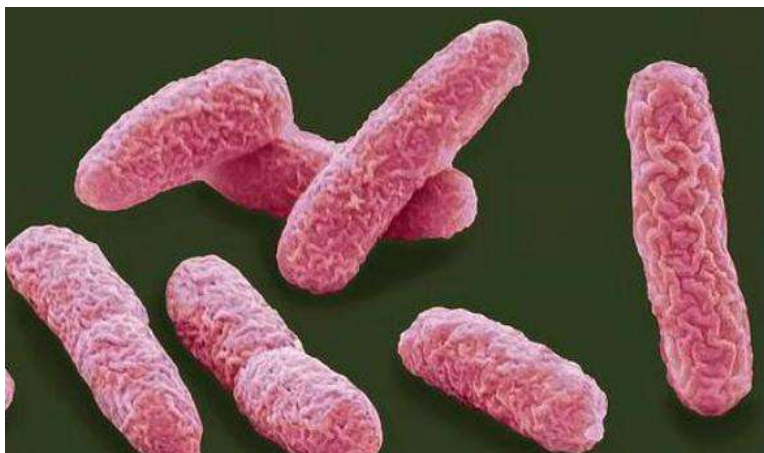


Fig 1. Microscopic view of *Bacillus subtilis*

Applications of FAME Analysis

Food Science:

Determines the total fat content in foods for nutritional labeling. Assesses the quality, taste, texture, and shelf life of food products.

Microbiology:

Identifies microbial communities and distinguishes between different strains, acting as a form of "microbial fingerprinting".

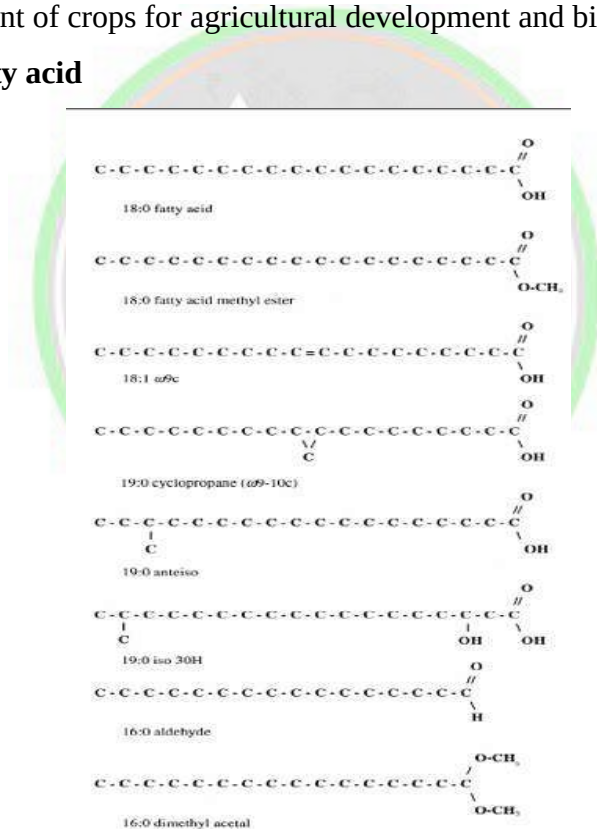
Helps in identifying pathogenic bacteria and tracking environmental pollution.

Biomedical & Agricultural Research:

Studies lipid metabolism, membrane dynamics, and cellular functions in various organisms.

Assesses the lipid content of crops for agricultural development and biofuel feedstock research.

Fig 2. Structure of fatty acid

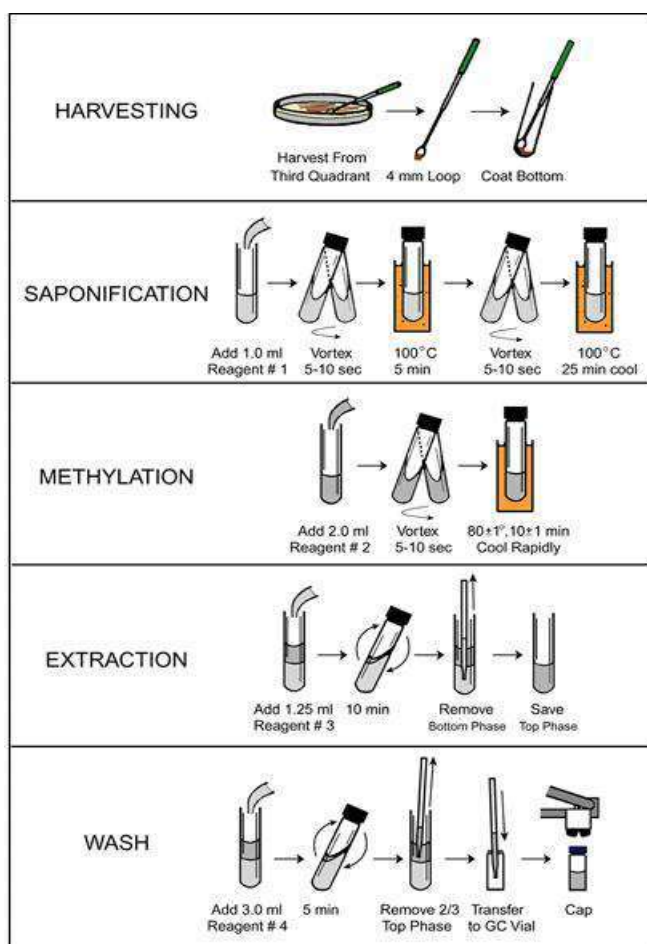


Culturing Of the Bacteria

The most stable and reproducible cellular fatty acid profile is achieved by carefully regulating the growth conditions. Several scientific papers have reported the effects of growth temperature and of different growth media on bacterial fatty acid composition. To minimize

these variables, a specific temperature and growth medium have been chosen for each library. For example, most aerobic bacteria will grow well on Trypticase Soy Broth Agar (TSBA), which consists of 30g Trypticase Soy Broth and 15g of agar (BBL). Those aerobic bacteria, which will not grow well on TSBA, are grown on the medium which would be most commonly used for their growth in the laboratory (e.g. Legionella on buffered charcoal yeast extract, and Haemophilus on chocolate agar). The temperature chosen for the TSBA database was 28°C to enable growth of a wide range of organisms. A separate database, CLIN, uses 35°C and blood agar (Trypticase Soy base) as the standards, with specialized media for specific organisms.

Sampling procedure



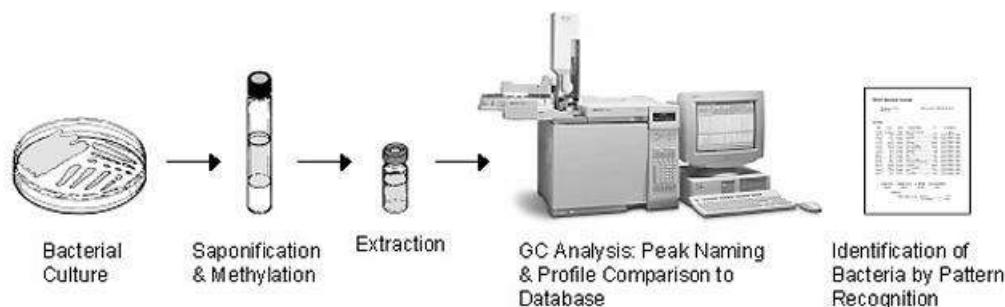
Hardware Factors

The Sherlock MIS Software can only be used with the Agilent technologies 5890, 6890 or 6850 gas chromatographs. The Sherlock System's unique configuration is designed for optimal analysis of Fatty Acid Methyl Esters by gas chromatography. Ultra 2 Column—A 25m x

0.2mm phenyl methyl silicone fused silica capillary column has both the chromatographic performance and the column lifetime desired for routine analysis of bacterial extracts. The column is required to have more than 4,000 theoretical plates per meter for peaks with $k = 7$ to 9. Since the stationary phase is cross linked to the silica tube, there is less noise and drift during temperature programmed runs

Gas Chromatograph

The temperature program ramps from 170°C to 270°C at 5°C per minute. Following the analysis, a ballistic increase to 300°C allows cleaning of the column during a hold of 2 minutes. The flame ionization detector allows for a large dynamic range and provides good sensitivity. Hydrogen is the carrier gas, nitrogen is the “makeup” gas, and air is used to support the flame. Autosampler—Use of an autosampler allows the system to be operated unattended for up to 2 days at a time. Samples are logged into the computerized sample table and all sampling (including STAT samples) is done automatically. Computer—The electronic signal from the GC detector is passed to the computer where the integration of peaks is performed. The electronic data is stored on the hard disk and the fatty acid methyl ester composition of the sample is compared to a stored database using the Sherlock pattern recognition software.



Calibration And Peak Naming

The Sherlock MIS uses an external calibration standard developed and manufactured by Microbial ID, Inc. The standard is a mixture of the straight chained saturated fatty acids from 9 to 20 carbons in length (9:0 to 20:0) and five hydroxy acids. All compounds are added quantitatively so that the gas chromatographic performance may be evaluated by the software each time the calibration mixture is analyzed. The hydroxy compounds are especially sensitive to changes in pressure/ temperature relationships and to contamination of the injection port liner. As a result, these compounds function as quality control checks for the system Retention time

data obtained from injecting the calibration mixture is converted to Equivalent Chain Length (ECL) data for bacterial fatty acid naming. The ECL value for each fatty acid can be derived as a function of its elution time in relation to the elution times of a known series of straight chain fatty acids.

$$ECL_x = \frac{R_{tx} - R_{tn}}{R_{t(n+1)} - R_{tn}} + n$$

Where R_{tx} is the retention time of x ; R_{tn} is the retention time of the saturated fatty acid methyl ester preceding x ; $R_{t(n+1)}$ is the retention time of the saturated fatty acid methyl ester eluting after x . Thus, it is possible, by comparison to the external standard, to compute the ECL value for each compound following an analysis. The GC and column allow windows to be set at 0.010 ECL unit wide giving great precision in resolution of isomers. After naming the peaks in an unknown sample, Sherlock compares the ECL values for the most stable series (e.g. saturated straight chain or branched chain acids) to the peak naming table's theoretically perfect values and may recalibrate internally if sufficient differences are detected. This feature allows the system to be run for up to two days unattended without worrying about drift between runs.

Libraries

The Sherlock libraries consist of more than 100,000 analyses of strains obtained from experts and from culture collections. The cultures were collected from around the world to avoid potential geographic bias. Where possible, 20 or more strains of a species or subspecies were analyzed to make the entry. When chromatographic subgroups were found within a taxon, more strains were obtained to delineate each group. The method of culture and the corresponding library is indicated in the name field of the sample as it is logged into the computer. Analysis of an unknown sample results in an automatic comparison of the composition of the unknown strain to a stored database using a covariance matrix, principal component analysis and pattern recognition software. The covariance matrix takes into account the mole-for-mole relationship of the conversion of one fatty acid to another (e.g. 16:0 to 16:1 due to action of a desaturase), which might occur in relation to a temperature shift or age difference. The pattern recognition software uses calculations of cross terms (e.g. ratios between fatty acid amounts) in addition to the principal component base. The subtle differences between biovars or subspecies depends upon the power of the pattern recognition software to discriminate at this level.

The libraries are open ended (i.e. not limited by a finite set of biochemical assays) and the number of species in them is large and growing. The libraries are only limited by MIDI's ability to obtain adequate numbers of strains to make the entries. Of course, some groups of bacteria are more amenable to fatty acid composition analysis for identification than others. This relates to whether well characterized strains are available and to whether "species" can be justified on the basis of DNA relatedness (e.g. *Escherichia coli* is related at the species level to *Shigella dysenteriae* [see Brenner, Int. J. Syst. Bacteriol. 23: 298-307])

Interpretation of results

RT	Response	Ar/Ht	RFact	ECL	Peak Name	Percent	Comment1	Comment2
1.679	3.453E+8	0.027	—	7.012	SOLVENT PEAK	—	< min rt	
1.785	—	—	—	7.225		—	< min rt	
6.758	771	0.034	1.004	13.619	ISO	1.17	ECL deviates 0.000	Reference 0.009
8.233	12955	0.041	0.973	14.823	15:0 ISO	19.11	ECL deviates 0.000	Reference 0.009
8.370	28869	0.040	0.971	14.713	15:0 ANTEISO	42.48	ECL deviates 0.000	Reference 0.008
9.451	663	0.039	0.954	15.387	16:1 w7c alcohol	0.96	ECL deviates 0.000	
9.850	2118	0.041	0.949	15.627	16:0 ISO	3.05	ECL deviates 0.000	Reference 0.008
10.067	1936	0.040	0.946	15.758	16:1 w11c	2.78	ECL deviates 0.001	
10.465	1913	0.040	0.941	15.999	16:0	2.73	ECL deviates -0.001	Reference 0.007
11.140	2839	0.046	0.934	16.390	ISO 17:1 w10c	4.02	ECL deviates 0.002	
11.294	1631	0.042	0.933	16.479	Sum In Feature 4	2.31	ECL deviates 0.003	17:1 ISO I/ANTEI B
11.555	5794	0.046	0.930	16.631	17:0 ISO	8.17	ECL deviates 0.001	Reference 0.008
11.714	9398	0.043	0.929	16.723	17:0 ANTEISO	13.23	ECL deviates 0.000	Reference 0.007
—	1631	—	—	—	Summed Feature 4	2.31	17:1 ISO I/ANTEI B	17:1 ANTEISO B/i I

ECL Deviation: 0.001 Reference ECL Shift: 0.008 Number Reference Peaks: 7

Total Response: 68887

Total Named: 68887

Percent Named: 100.00%

Total Amount: 65965

Matches:

Library	Sim Index	Entry Name
TSBA60 6.00	0.785	Bacillus-subtilis

Advantages

- **High Precision and Accuracy:** By converting fatty acids into their methyl ester derivatives, the compounds become more volatile, exhibit better thermal stability, and show improved peak symmetry during gas chromatography (GC). This results in more accurate and reliable analytical data compared to analyzing free fatty acids directly.
- **Detailed Fatty Acid Profiling:** FAME analysis provides a detailed breakdown of the types and quantities of individual fatty acids in a sample, including crucial components like *cis* and *trans* isomers and omega-3 and omega-6 fatty acids. This comprehensive profiling is essential for various applications, from nutritional labeling to identifying specific microbial species.

- **Identification and Characterization of Microorganisms:** Every microorganism has a unique "fingerprint" or specific FAME profile. FAME analysis serves as a rapid and cost-effective diagnostic tool for:
 - Identifying pathogenic strains in clinical, environmental, and agricultural settings.
 - Tracking disease outbreaks and monitoring shifts in microbial populations.
 - Characterizing new species of bacteria and fungi.
 - Assessing soil health by characterizing soil microbial communities.
- **Nutritional and Food Quality Assessment:** This method is the primary technique for quantifying fat content for nutritional labeling purposes, ensuring regulatory compliance. It provides tangible evidence of quality assurance for food products, as fatty acid composition can influence taste, texture, shelf life, and healthfulness.
- **Biodiesel Quality Control:** FAME are the primary molecules in biodiesel. FAME analysis is used to verify that biodiesel adheres to specific quality standards, ensuring performance, compatibility with existing engines, and compliance with environmental regulations regarding emissions and biodegradability.
- **Versatility in Applications:** The technique is widely used across various fields, including:
 - Biomedical and metabolomics research to understand the link between diet and disease.
 - Environmental studies for monitoring pollution levels.
 - Breeding programs to enhance oilseed quality in crops.
- **High-Throughput and Automation Potential:** FAME analysis can be automated for large-scale studies, making it a valuable tool for commercial and research settings requiring efficient sample processing and rapid results.

TREE TOMATO: FROM BACKYARD PLANT TO FUNCTIONAL FOOD

Article ID: AG-VO6-I01-03**Shivani and Dr. Shweta***

Department of Horticulture, School of Agriculture, Lovely Professional University,
Phagwara, Punjab-144001, India

*Corresponding Author: Dr. Shweta

Introduction

Tree tomato (*Solanum betaceum* Cav.) is an economically important crop belongs to family *Solanaceae* and is native to Andes region. It is also known as tamarillo, tamamoro, tomate de palo, tomate de monte, sima, pepino de arbol, tomate dulce, tomate cimmaron, tomate francès, arvore do tomate and caxlan pix in different regions of the world. It is cultivated widely in South America. It has a diploid set of chromosomes ($2n=2x=24$) however tetraploids can be developed by applying colchicine to the germinating seeds (Pringle and Murray, 1992). Tree tomato is a fast-growing perennial woody shrub cultivated mainly for its fruits and are most commonly used in fruit juices, eaten fresh or cooked and processed. It has a short life span of 6-12 years while vegetative and reproductive growth occurs concurrently (Lewis and Considine, 1999). Tree tomato is a subtropical plant which requires an average temperature of 16-25°C, require high humid conditions and cannot tolerate frost. The flowering is promoted by the cool temperature whereas drought for longer period and high temperature adversely affects flowering and fruiting. It requires well-drained, friable and light soil with a pH of 6-8 and less tolerant to waterlogging conditions. The planting is done in spring season in subtropics and in early spring in the temperate areas. The propagation of tree tomato is done either from seed or from cuttings and it starts bearing fruits in the first to second year after transplanting. The seed germination occurs within five to seven days. The reduction in yield is observed due to diseases like powdery mildew, anthracnose, viruses like tamarillo mosaic virus and pests like root knot nematode, aphid, tree tomato worm and whitefly (Lim, 2015). The yellow fleshed fruits are excellent in

aroma and flavor; hence they are used for preservation purpose and red fruited cultivars are grown for the fresh market. The popular varieties of tree tomato grown across the world are Solid Gold, Ruby Red, Yellow, Goldmine, Inca Gold, Ecuadorian Orange, Oratia Red and Rothamer.



Figure 1. An overview of plant and fruits of tree

Botanical and Reproductive Description

Tree tomato is a shallow rooted, evergreen tree with indeterminate growth habit. Leaves are simple, cordate and alternate with pubescence at both the upper and lower sides having musky smell. Leaves have long petiole with pointed apex and heart-shaped base (Duarte and Paull, 2015). It reaches to a height of two to five meters. Tree tomato has a scorpioid cyme inflorescence having 20-50 flowers. The flowers are pendant, fragrant and hermaphrodite with five petals which are white-creamed, white-pink or reddish having pink-white corolla (Prohens and Nuez, 2000). The individual flowers are pendulous; flower buds, flowers and developing fruits occur within the same inflorescence. The inflorescence is terminal and occurs after every 3-4 node in the plant. It is self-pollinated crop but some extent of cross-pollination is also mediated by wind and bumblebees.

The flowering season lasted for six months i.e. from November to April whereas in tropics, flowering occurs throughout the year. The opening of flowers occurs in the early morning around 8 am to 2pm with the sunrise and exposure of buds to direct sunlight whereas closes in the late afternoon or in the evening. The edible fruit is a fleshy berry having ovoid shape with 5-10cm in length, 3-5cm in diameter and weighs around 50 to 150g. Fruits occur individually or in cluster of five to twelve and contains 220 to 280 seeds which are orange to

deep purple (Manzano, 2005). In tree tomato, the fruit set is very low due to abscission and among all flowers only 12-12.3% leads to fruit set and 3-3.3% are capable of producing fruit (Lewis and Considine, 1999).

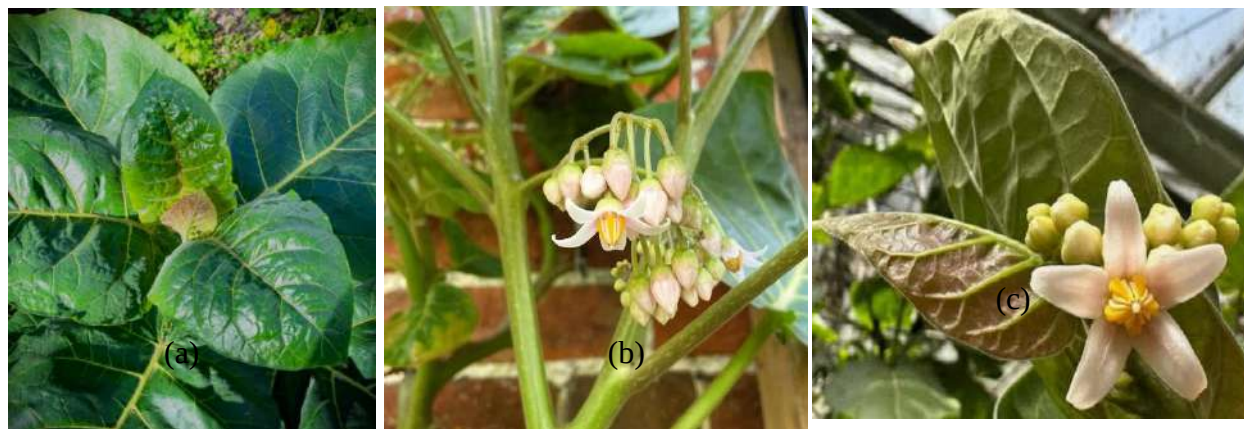


Figure 2. Representation of tree tomato: a) Leaves b) Scorpioid cyme inflorescence c) Flower

The fruit color varies from red, yellow, orange, purple and can also be identified by the leaf color as purple-green leaves produce red-orange fruits whereas yellow-green leaves produce yellow fruits. After 22 to 27 weeks from flowering stage, the fruit maturation occurs and the fruit color changes from green to red, amber and purple during the growth period (Schotsmans et al., 2011).



Figure 3. Variations among fruit color of tree tomato a) Red-colored fruits b) Seeds c) Yellow-colored fruits

Nutritional Importance

Tree tomato is rich in vitamins (A, B, C, E and K), dietary fiber, minerals like magnesium, potassium, iron, phosphorus and low in calories. It contains 0.37-0.65mg/100g of anthocyanin and carotenoids whereas some number of phenolic compounds and flavonoids are

also present. Among anthocyanin pigments, delphinidin and cyanidin are the chief derivatives while zeaxanthin, xanthophyll, β -cryptoxanthin and lutein are the most prominent among carotenoids (Mertz et al., 2010). The mature fruits contain (4.5-9.5g/100g dry weight) of protein, water soluble vitamins like Vitamin B1 (0.15-0.16mg /100g dry weight), Vitamin B2 (0.006mg /100g dry weight), Vitamin C (55.5-60.0mg /100g dry weight), total soluble sugars (6.3 - 27.1g/100g dry weight) and phenolic compounds are predominantly found in larger amount in the peel of purple-red varieties than golden-yellow varieties (Kumar et al., 2024). It is also a vital source of protein and pectin.

Benefits and Uses

- Tree tomato is majorly cultivated for its egg-shaped edible fruits and are important source of raw material in processing industry.
- Fruits are eaten raw as a dessert or are consumed in processed form by making sauces, syrup, ice creams, salads, jams, jellies, liqueurs, cakes, juices and yogurt.
- In Peru, the orange fruits are mixed with hot chilli peppers to prepare sauce and used as an appetizer.
- The oxidation and discoloration occur in fruits if not processed properly and used for making jelly due to presence of high amount of pectin.
- The presence of vitamins helps in improving skin health, eyesight and maintains blood circulation.
- It helps to cure respiratory diseases, boosts immunity, faster healing of wounds, improves bone health and prevent anaemia.
- The fruit pulp is used for making ointment for tonsillitis and leaves are used for treating sore throat by wrapping around the neck.
- It slows down the ageing process, preventing diabetes and protects the body from neurological diseases due to presence of anthocyanin in fruits.
- The proteins in tree tomato decrease the oxidative stress due to antimutagenic effect and prevents the formation of uric acid in the body.
- In Jamaica, it is used to treat liver problems and is called as vegetable mercury.
- It prevents cardiovascular diseases, arthritis and protects the skin against ultraviolet radiations (Rana and Brar, 2019).

Conclusion

Tree tomato is a highly valuable multifunctional crop containing wide range of bioactive compounds which promotes health and well-being. It has a potential for use in pharmaceutical industries and has anti-inflammatory, anti-diabetic and anti-proliferative properties. It has easy transportation and long storage life due to firm flesh and hard rind. It is a source of raw material for processing industries for value-addition and can be formulated into different products.

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AI & DRONES IN AQUATIC ENVIRONMENT MONITORING

Article ID: AG-VO6-I01-04

Alla Bhumika Reddy*

Department of Aquatic Environment Management, College of Fisheries, KVAFSU,
Mangaluru – 575002, India

*Corresponding Author: Alla Bhumika Reddy

Abstract

Aquatic ecosystems are the lifeblood of our planet, sustaining biodiversity, regulating climate, and providing food and livelihoods to billions of people. Yet, these ecosystems are increasingly threatened by human activities, including pollution, overfishing, and the accelerating impacts of climate change. Traditional monitoring methods, while valuable, often lack the speed, scale, and accuracy required to address these challenges. Emerging technologies—particularly Artificial Intelligence (AI) and drone systems—are revolutionizing how we study and safeguard aquatic environments. AI provides the analytical power to process massive datasets and reveal hidden patterns, while drones extend human observation above and below the water's surface. Together, they enable near real-time monitoring of aquatic ecosystems, early detection of environmental threats, and proactive conservation interventions. This paper builds upon existing research by examining case studies, technical applications, ethical considerations, and future directions. By bridging science, society, and policy, AI and drones can become central allies in building a safer, more resilient blue planet.

Keywords: Artificial Intelligence, Drones, Aquatic Monitoring, Pollution, Fisheries, Conservation, Sustainability, Digital Twins, IoT, Aquaculture

Introduction: A New Wave of Technology for Our Waters

Water is life, yet humanity's relationship with aquatic systems has become increasingly strained. Rivers, lakes, wetlands, and oceans are facing growing pressures from industrial activity, agricultural runoff, urban expansion, and climate-driven changes such as ocean

acidification and rising temperatures. According to the United Nations Environment Programme (2021), nearly 80% of wastewater globally enters aquatic systems untreated, while overfishing threatens a third of the world's fisheries. These stressors compromise biodiversity, human health, and food security.

Traditional monitoring approaches—including boat-based sampling, scuba surveys, and laboratory water quality analyses—have provided invaluable insights but often suffer from limitations: high costs, logistical complexity, safety risks, and temporal delays. For example, water quality data often becomes available weeks after collection, reducing its usefulness for urgent decision-making.

In contrast, emerging digital tools powered by AI and drone technology are enabling continuous, scalable, and cost-effective **monitoring**. AI algorithms excel at interpreting complex environmental signals, from satellite imagery to underwater video, while drones (both aerial and submersible) can rapidly cover vast areas that are otherwise inaccessible. Their integration is reshaping marine biology, fisheries management, aquaculture, and environmental governance. This paper provides an expanded analysis of how AI and drones are transforming aquatic monitoring, supported by case studies, technical discussion, and reflections on societal impact.

Smart Guardians: How AI and Drones Watch Over Aquatic Life

AI and drones are redefining the frontiers of aquatic monitoring by enabling scientists to observe species, habitats, and processes at unprecedented resolution. Aerial drones can capture high-resolution imagery of coastlines, estuaries, and coral reefs, while underwater drones—ranging from remotely operated vehicles (ROVs) to autonomous underwater vehicles (AUVs)—navigate beneath the surface. These devices collect imagery, sonar data, and environmental measurements that AI models can process almost instantly.

For instance, Villon et al. (2018) demonstrated that deep learning models could identify coral reef fishes from underwater images with accuracy exceeding 90%. Similarly, Raoult et al. (2020) reported successful drone-based monitoring of marine megafauna such as dolphins and dugongs along Australian coastlines, providing population estimates that informed conservation measures. These technologies reduce the need for invasive sampling, minimize ecological disturbance, and allow researchers to detect ecological trends before crises escalate.

Different types of drones serve complementary purposes: fixed-wing UAVs provide long-duration surveillance over large marine protected areas, quadcopters excel at close-range

reef surveys, and underwater gliders collect continuous water column data across hundreds of kilometers. When integrated with AI-driven analytics—such as species recognition, anomaly detection, and predictive migration modeling—these systems act as ‘smart guardians’ of aquatic ecosystems.

Peering Beneath the Surface: Discovering Hidden Stories in Water

Aquatic environments often conceal vital ecological processes invisible to human senses. Advances in sensor technology allow drones to detect changes in temperature, turbidity, and dissolved oxygen levels—critical indicators of aquatic health. Multispectral, hyperspectral, and thermal cameras mounted on aerial drones provide surface-level insights, while sonar and LiDAR systems extend monitoring below the water column.

A notable application has been in the early detection of harmful algal blooms (HABs), which threaten both human health and marine life. For example, drones equipped with hyperspectral sensors were successfully deployed in Lake Erie to map algal bloom extent, while AI algorithms analyzed spectral signatures to differentiate harmful algae from benign phytoplankton. Such early detection enables authorities to issue timely advisories and mitigate damage.

Another frontier is the use of AI for processing underwater acoustic data. Soundscapes recorded by hydrophones mounted on drones reveal information about species presence, boat traffic, and even illegal fishing activities. Machine learning models trained to recognize species-specific calls are now being used to monitor whale populations in the North Atlantic, providing invaluable insights for conservation planning.

Fighting Pollution and Protecting Fisheries with Technology

Pollution, in its many forms, continues to be one of the gravest threats to aquatic ecosystems. Oil spills, plastic waste, and chemical runoff devastate biodiversity and disrupt food webs. Drones provide rapid, low-cost surveillance of water bodies, while AI algorithms analyze visual data to identify pollutants with remarkable precision.

For example, Topouzelis et al. (2019) demonstrated the use of drones and satellite data to detect floating plastic debris, while Li and Zhao (2021) showed how deep learning can classify microplastics at microscopic scales. These methods reduce reliance on slow and expensive laboratory testing.

Fisheries management is another sector benefiting greatly from AI and drone technologies. UAVs are deployed to monitor illegal fishing, track vessel activity, and estimate fish populations. AI-based forecasting tools help predict spawning events and migration routes, supporting sustainable catch practices. In aquaculture, drones combined with AI optimize feeding schedules, monitor water quality, and detect early signs of disease, reducing losses and improving yields.

When Science Meets Society: Why It Matters for Us All

The impact of AI and drones extends beyond scientific research, shaping societies and communities worldwide. For small-scale fishing communities, access to accurate data ensures more sustainable harvests and safeguards livelihoods. Citizen science initiatives increasingly use consumer-grade drones to monitor local rivers and coastal areas, empowering communities to document pollution events and demand accountability.

AI-powered visualization tools also translate complex scientific datasets into accessible formats. Three-dimensional maps of coral bleaching events or interactive dashboards of pollution levels help raise public awareness and drive policy action. These efforts contribute to environmental justice, ensuring marginalized communities have the evidence needed to advocate for cleaner waters.

However, ethical concerns must not be overlooked. Drone surveillance raises privacy issues, particularly in coastal regions where human activity intersects with environmental monitoring. Moreover, unequal access to technology risks deepening global divides, with wealthier nations benefiting disproportionately from cutting-edge innovations.

The Future Horizon: Where Do We Go from Here?

The future of AI and drones in aquatic monitoring is both promising and complex. One emerging concept is the development of digital twin ecosystems—virtual models of lakes, rivers, and oceans that simulate environmental changes in real time. These models allow researchers to test interventions, predict ecological outcomes, and guide policy decisions with greater confidence.

Drone swarms represent another innovation, offering the possibility of large-scale, coordinated monitoring missions. When integrated with Internet of Things (IoT) sensor networks, drones can provide continuous, multi-layered coverage of aquatic systems. Cloud

computing and edge AI further enhance the speed and scalability of analysis, enabling near-instantaneous response to environmental threats.

Nonetheless, challenges remain. Regulatory frameworks must balance innovation with ethical oversight. Questions of data ownership, privacy, cybersecurity, and environmental impact require careful consideration. Equitable access to these technologies will be essential to ensure benefits are shared globally, not concentrated among technologically advanced nations.

Conclusion

AI and drones are no longer futuristic concepts—they are active partners in the stewardship of aquatic ecosystems. Their capacity to deliver fast, accurate, and wide-scale monitoring bridges the gap between scientific research, policy-making, and community action. From detecting pollution and managing fisheries to engaging citizens and forecasting future scenarios, these technologies offer transformative potential.

However, realizing this potential requires responsible governance, inclusivity, and a commitment to ethical deployment. Technology alone cannot save our waters; it must be integrated into broader strategies that address root causes of environmental degradation. By harnessing AI and drones wisely, humanity has the chance to safeguard aquatic ecosystems and secure a resilient blue planet for generations to come.

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ILLEGAL MINING, REAL ESTATE, AND GOVERNMENT ACTION: THE ARAVALLI CRISIS

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***Dr. R. N. Dhawale¹, Dr. M. S. Dudhare² and Dr. A. A. Bharose³**

1 Assistant Professor, Vilasrao Deshmukh College of Agricultural Biotechnology, Latur

2 Professor, Vilasrao Deshmukh College of Agricultural Biotechnology, Latur

3 Associate Dean & Principal, VDCOAB, Latur

Vasantrao Naik Marathwada Agricultural University, Parbhani PIN-413 512, India

*Corresponding Author: Dr. R. N. Dhawale

Introduction

The Aravalli Range, one of the oldest mountain ranges in the world, holds great ecological, geographical, and cultural significance in India. Stretching across the northwestern part of the country, the Aravallis run through states like Rajasthan, Haryana, and Gujarat. Despite being ancient, this mountain range plays a crucial role in India's natural environment. Understanding the history, current status, and the future of the Aravalli Range can shed light on its importance to both the environment and society. The Aravalli Range, one of India's oldest and most ecologically significant mountain systems, is currently under severe threat. While this ancient range once stood as a protective barrier, a source of water, and an ecological haven, it is now being consumed by **illegal mining, uncontrolled real estate expansion, and insufficient government action**. This has led to the degradation of the range's biodiversity, environmental balance, and long-term sustainability. Let's explore how these issues are contributing to the Aravallis' ongoing destruction and what could be done to prevent further harm.

Past of the Aravalli Range

The Aravalli Range is believed to be one of the oldest mountain systems in the world, with an age of over **2.5 billion years**. This ancient mountain range was once part of the greater landmass called the **supercontinent Rodinia**. The range formed primarily due to tectonic shifts, as the Indian plate collided with the Eurasian plate millions of years ago. Over time, the once-

towering mountains eroded, leaving behind the jagged ridges that characterize the range today. The Aravalli Range stretches about **800 kilometers** from the northeastern part of Gujarat, through Rajasthan, and into Haryana. Historically, the range was vital to the people living in its vicinity. It served as a natural barrier that influenced regional cultures, trade routes, and historical movements. In ancient times, the Aravalli Range was home to various civilizations. The **Indus Valley Civilization** may have had settlements near the foothills of the range, and the region continued to play an important role during the **Mauryan, Gupta, and Rajput** periods. The range's location also served as a strategic advantage during military conflicts. The famous **Rajasthan forts** such as **Kumbhalgarh Fort, Chittorgarh, and Jaipur's Amber Fort** are situated on or near the Aravallis, utilizing the natural rugged terrain for defense.

This article explores the past, present, and future of the Aravalli Range, examining its geological origin, historical relevance, ecological challenges, and the actions required to preserve it for future generations.

As per the new definition of the Aravalli hills that the Supreme Court accepted on November 20, at least 90% of the Aravallis will no longer be protected.



Destruction of Aravallis by mining in Gujarat's Ambaghanta. Photo For Aravallis.

Bengaluru: On Sunday, November 30, a small group of 30-odd citizens including children **gathered** at the Chakkarpur-Wazirabad eco-restoration corridor in Gurgaon, Delhi, under the Aravalli Bachao citizens collective.

"Do you want to breathe? Do you want to drink water? Then save the Aravallis," one of the many posters they held up read.



Ecological Importance of the Aravalli Range

The Aravalli Range is not only an ancient geological feature but also an ecological treasure trove. The range's varied topography, including hills, valleys, and plateaus, supports diverse ecosystems. The flora and fauna of the Aravallis are as varied as the terrain itself. The range has been home to many species, some endemic and others migratory.

Flora:

- The Aravallis host a variety of plant species. The **desert flora** is found in the drier areas, while **tropical dry deciduous forests** and **savanna grasslands** are seen in the more temperate regions.
- **Acacia, Bamboo, and Euphorbia** are common in the lower altitudes, whereas at higher elevations, one might find **oak, teak, and sandalwood** trees.

Fauna:

- The fauna of the Aravalli Range is equally diverse. The region is home to various species of **mammals, birds, and reptiles**. Notable wildlife includes the **Indian leopard, sambar deer, chital, and wild boar**.
- The **Aravalli hill range** also supports a number of bird species, including **eagles, partridges, and hornbills**.

- The area has several **protected wildlife sanctuaries**, such as the **Sariska Tiger Reserve**, which forms part of the Aravalli foothills. It also includes areas for migratory birds such as the **Keoladeo National Park**.

Present Condition of the Aravalli Range

In the present day, the Aravalli Range faces a multitude of environmental challenges that have drastically impacted its health.

1. Deforestation and Loss of Biodiversity:

The Aravalli Range, once home to dense forests, has seen significant deforestation due to urbanization, mining, and agriculture. The growing demand for land and resources has led to widespread clearing of forests, thereby endangering the flora and fauna of the region.

- In Haryana, areas of the Aravalli **have been** extensively deforested for urban expansion, especially in **Gurugram** and surrounding areas.
- Mining operations, particularly for **marble** and **sand**, have exacerbated the destruction of natural habitats and contributed to soil erosion.

2. Water Scarcity:

Water resources in the Aravalli Range are being over-exploited. The natural water systems, including rivers, lakes, and groundwater, are being drained rapidly due to industrialization, excessive agriculture, and rising human populations. A major concern is the depletion of groundwater levels in regions like **Rajasthan** where the Aravallis play a crucial role in recharging the water table.

3. Urbanization and Infrastructure Development:

As the urban sprawl of cities like **Jaipur**, **Delhi**, and **Gurugram** encroaches on the foothills of the Aravallis, the impact of pollution, illegal construction, and unregulated development becomes increasingly severe. Urban expansion has caused the destruction of critical wildlife corridors and led to habitat fragmentation.

4. Climate Change:

The Aravallis are not immune to the effects of **climate change**, which is manifesting in unpredictable weather patterns, rising temperatures, and erratic rainfall. The resulting stresses on the ecosystem make it harder for plants and animals to adapt, further threatening the biodiversity of the region.

The Future of the Aravalli Range

Looking ahead, the Aravalli Range faces significant challenges that require concerted efforts in conservation, policy-making, and sustainable development. However, the future is not entirely bleak, and there are ongoing efforts to preserve and restore this vital range.

1. Conservation and Restoration Efforts:

Several environmental organizations, alongside government bodies, are pushing for stricter enforcement of laws that prevent deforestation and illegal mining. The Indian government has proposed measures to conserve and restore the **Aravalli Eco-Sensitive Zone**, which includes regulations to protect forests, wildlife, and the overall environment. A notable step is the **Aravalli Biodiversity Park** in Delhi, aimed at restoring ecosystems and promoting sustainable practices.

2. Promoting Sustainable Development:

Ensuring that development in and around the Aravalli Range is sustainable is critical. This includes limiting urbanization, enforcing zoning laws, and promoting eco-friendly industries. Additionally, implementing better waste management systems and reducing air and water pollution will go a long way in preserving the region's fragile ecosystem.

3. Awareness and Advocacy:

Local communities and environmental organizations have been at the forefront of raising awareness about the importance of the Aravalli Range. By educating the public and policymakers about the ecological value of the range, it is hoped that future generations will be more inclined to protect it. Engaging local communities in forest management and sustainable agriculture practices is essential for long-term conservation efforts.

4. Restoring Water Sources:

Given the critical role that the Aravallis play in water recharge, future efforts must focus on restoring and protecting natural water systems. Revitalizing **wetlands**, improving **rainwater harvesting**, and ensuring sustainable groundwater management will be key factors in securing water resources for the future.

Illegal Mining: A Major Threat to the Aravallis

Illegal mining has emerged as one of the most pressing threats to the Aravalli Range. In regions like **Rajasthan** and **Haryana**, the mountains are being ravaged by unregulated and unauthorized mining activities. The main minerals extracted are **marble**, **sandstone**, and

minerals like mica. These activities are not only environmentally harmful but also threaten the delicate ecological balance of the area.

Why is illegal mining happening in the Aravallis?

- **Demand for Construction Materials:** The rapid growth of cities like **Gurugram, Jaipur, and Delhi** has created an insatiable demand for construction materials, such as sand and marble, which are easily sourced from the Aravallis. This leads to the unregulated extraction of these minerals, often by local mafias and illegal contractors.
- **Lack of Enforcement:** Although mining in certain areas is supposed to be regulated, the enforcement of these laws is often weak. Many local authorities are either under-resourced or have been known to turn a blind eye to illegal activities. This lack of oversight allows illegal mining to flourish, further accelerating the degradation of the land.

The Environmental Impact of Illegal Mining

- **Deforestation and Habitat Loss:** Illegal mining activities often lead to **deforestation** in the foothills of the Aravallis, destroying vital forest cover that serves as habitat for many species, including leopards, tigers, and various birds.
- **Soil Erosion:** The stripping of topsoil due to illegal mining leaves the land vulnerable to erosion. Over time, this can lead to the complete degradation of the land, preventing vegetation from growing back and affecting local agriculture.
- **Water Pollution:** Mining activities lead to the contamination of nearby water bodies. Chemicals used in extraction processes seep into groundwater, polluting drinking water and further diminishing the region's already limited water resources.

Real Estate Expansion: Encroaching on Aravalli Lands

Another major issue facing the Aravalli Range is the uncontrolled expansion of **real estate development**. As India's urban population continues to rise, cities like **Gurugram, Faridabad, and Jaipur** are sprawling into areas once covered by the Aravalli foothills. **Urbanization** and the **construction of infrastructure** such as highways, malls, and residential complexes have led to encroachments on the Aravalli hills.

The Real Estate Boom and its Impact

- **Unregulated Urbanization:** The areas surrounding the Aravallis, particularly in **Gurugram** and **Faridabad** (in Haryana), have seen rapid real estate development over the last few

decades. Large-scale construction projects often involve the encroachment of environmentally sensitive zones, which were once protected under the **Aravalli Act**.

- **Land Use Change:** The conversion of forested and barren land into residential and commercial areas disrupts the **natural ecosystem**, leading to the loss of biodiversity and natural water recharge systems.
- **Fragmentation of Wildlife Habitats:** The construction of roads, buildings, and other infrastructure splits wildlife corridors, making it difficult for animals to migrate or access necessary resources such as water and food. This fragmentation is particularly dangerous for species like **leopards** and **sambar deer**.

Case Study: Gurugram's Urban Sprawl

Gurugram, a rapidly growing urban hub, is located on the southern edge of the Aravalli Range. As the city expanded, large swaths of Aravalli land were bulldozed for luxury housing, commercial centers, and golf courses. This has resulted in a massive loss of biodiversity, the destruction of natural landscapes, and the depletion of natural resources. The once-green Aravallis have been paved over for development projects, with little regard for the long-term environmental consequences.

Government Action: Insufficient or Inadequate Measures

While the Indian government has passed several laws aimed at **protecting the Aravalli Range** and its ecosystems, enforcement remains a significant challenge. Although there are policies designed to regulate mining, land use, and urbanization, **lack of political will, poor governance, and bureaucratic inefficiency** have undermined these efforts.

Key Government Policies and Actions

- **Aravalli Act (1992):** The **Aravalli Act** was introduced in Rajasthan to restrict mining activities in the Aravalli hills. However, this law is poorly enforced, and illegal mining continues in many areas. Corruption, lack of resources for monitoring, and political influence have all contributed to the ineffective implementation of the law.
- **National Green Tribunal (NGT) Orders:** The NGT has intervened several times to halt illegal mining in the Aravalli region. For example, the tribunal has issued orders for halting mining operations in **Haryana's Aravalli** regions. However, the response to these orders has been sluggish, and enforcement is often lax.

- **Conservation Programs:** The Indian government has initiated some conservation programs, such as the **Afforestation Programme** and the **National Afforestation Programme**, aimed at rehabilitating degraded lands. However, these programs have not been sufficiently implemented in critical Aravalli areas that need urgent restoration.

Why Government Action is Insufficient

- **Weak Law Enforcement:** Despite the existence of laws and regulations, illegal mining and real estate development continue due to weak law enforcement and limited resources for monitoring vast areas like the Aravallis.
- **Political Interests:** In many cases, powerful business and political interests drive real estate and mining projects in the Aravallis. These groups have significant influence, making it difficult for environmental concerns to take precedence over development and economic interests.
- **Lack of Public Awareness and Engagement:** Although there is a growing awareness about environmental issues, many local communities and even government officials may not fully understand the long-term consequences of damaging the Aravalli Range. This lack of engagement has prevented more effective action.

The Way Forward: What Needs to Be Done

To save the Aravalli Range from further destruction, the following measures must be taken:

1. Stronger Enforcement of Environmental Laws

- **Tighter monitoring** of mining and construction activities through advanced satellite surveillance, drones, and ground-level inspections.
- **Strict penalties** for illegal mining and unauthorized real estate development.

2. Public Awareness Campaigns

- **Engaging local communities** in conservation efforts, emphasizing the importance of the Aravallis for water security, biodiversity, and climate regulation.
- **Educating citizens** on the consequences of uncontrolled urbanization and resource extraction.

3. Sustainable Urban Planning

- Cities and towns in and around the Aravallis should adopt **sustainable development models**, focusing on preserving natural landscapes while allowing for urban growth.
- Implementing **green infrastructure** such as **rainwater harvesting**, **eco-friendly buildings**, and **conservation corridors** for wildlife.

4. Government Accountability and Political Will

- Governments must **prioritize environmental concerns** over short-term economic gains and ensure the **implementation of conservation laws** effectively.
- A **multistakeholder approach** should be adopted, involving **local communities, environmental organizations, scientists, and policymakers** to create a sustainable future for the Aravallis.

Conclusions

The Aravalli Range is an invaluable natural resource for India, providing ecological, historical, and cultural benefits. However, its future is at risk due to a combination of deforestation, urbanization, and climate change. The preservation and restoration of the Aravallis will require a concerted effort involving the **government**, local communities, and environmental organizations. Only through sustainable development, conservation, and the reduction of human impact can we ensure the survival of this ancient range for future generations. The Aravalli Range stands at a critical juncture in its long history. Illegal mining, rampant real estate development, and weak government enforcement are rapidly eroding this ancient and ecologically vital range. If this trajectory continues unchecked, the future of the Aravallis will be bleak. However, with effective governance, public awareness, and a commitment to sustainable development, there is still hope for saving this invaluable natural resource. It is crucial for all stakeholders to recognize the importance of the Aravalli Range-not only as a natural wonder but as a vital resource that supports millions of lives. Without immediate action, the region's biodiversity, water resources, and cultural heritage may be lost forever.

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BABY CORN BREEDING: A WONDERFUL VEGETABLE

Article ID: AG-VO6-I01-06**P.M. Goswami^{1*}, Barish Patel² and Lalita Kumari²**

^{1*}Department of Genetics and Plant Breeding, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar (Gujrat), India - 385506

²Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat), India - 388110

***Corresponding Author: P.M. Goswami**

Abstract

Baby corn (*Zea mays* L.) is an emerging high-value vegetable crop derived from immature maize ears harvested before fertilization. Its short duration, dual-purpose use as vegetable and fodder make it economically attractive. Advances in breeding, particularly heterosis breeding and cytoplasmic male sterility, have improved yield, uniformity and quality. With scientific production technologies and improved hybrids, baby corn offers significant potential for crop diversification, farmer income enhancement and sustainable agriculture in India.

Key Words: Baby corn, Maize breeding, Cytoplasmic male sterility, Heterosis, Vegetable maize, Crop diversification, Export potential

1. Introduction

Maize (*Zea mays* L.) is one of the most versatile and widely distributed cereal crops of the world, owing to its wide adaptability, high productivity and multiple end uses. In India, maize ranks third after rice and wheat and is often referred to as the “Queen of Cereals” because of its exceptionally high genetic yield potential. In recent years, diversification of maize utilization has led to the emergence of baby corn as an important vegetable crop. Baby corn consists of young, unfertilized and tender maize cobs harvested at the silk emergence stage. Its increasing demand in domestic as well as export markets, short crop duration and dual-purpose nature have made baby corn cultivation economically attractive. Breeding and production

technologies play a vital role in enhancing yield, quality and profitability of baby corn, making it a promising component of modern agriculture.

2. Botanical Description and Classification of Maize

Maize (*Zea mays* L.) belongs to the family *Poaceae* and is a tall, monoecious, annual C₄ plant with plant height ranging from 1.2 to 4.0 m. The sexes are separated into distinct inflorescences. The male inflorescence (tassel) borne terminally and the female inflorescence (ear) borne axillary with elongated silks. The crop exhibits a determinate growth habit, where the main shoot terminates in the tassel. Floral morphology and pollination behaviour are of great significance in baby corn production, as the crop is harvested prior to fertilization to maintain tenderness and quality.

Maize is generally classified based on kernel characteristics into different groups. Sweet corn (*Zea mays* saccharata) is characterized by high sugar content due to conversion of starch into water-soluble polysaccharides. Dent corn (*Zea mays* indentata) possesses kernels with both soft and hard starch, forming a dent at maturity. Flint corn (*Zea mays* indurata) has hard endosperm and is commonly grown in India. Other types include popcorn (*Zea mays* everta), which has a hard outer hull and completely hard starch, and waxy corn (*Zea mays* ceratina), characterized by waxy, amylopectin-rich starch. These classifications form the genetic base from which suitable genotypes for baby corn are identified and improved.

3. Concept and Characteristics of Baby Corn

Baby corn is the immature, unfertilized ear of maize harvested at the stage of silk emergence, usually one to three days after silk appearance. At this stage, kernels are either absent or extremely soft, making the entire cob edible after dehusking. Baby corn is also referred to as young corn, mini corn or candle corn. Depending on genotype, the cobs may be creamy white to light yellow in color, which is generally preferred by consumers and exporters.

For fresh consumption and processing, ideal baby corn ears measure about 4-9 cm in length and 1.0-1.5 cm in diameter. Uniformity in size, color, tenderness and sweetness are key quality attributes. Baby corn is considered a dual-purpose crop, as apart from marketable cobs, the green biomass left after harvest serves as high-quality fodder for livestock. In India, baby corn can be grown throughout the year under suitable climatic conditions, allowing farmers to harvest three to four crops annually.



4. Importance and Uses of Baby Corn

Baby corn holds immense importance due to its multiple uses and economic advantages. It supports crop diversification and is particularly suitable for peri-urban agriculture because of its high market value and proximity to consumers. Baby corn adds value as a vegetable used in salads, soups, pickles, pakoras and other culinary preparations. It is also widely used in canned and processed forms, preserved in brine, sugar and citric acid solutions.

The crop fits well in intercropping systems, enabling farmers to generate additional income. All by-products of baby corn cultivation are highly nutritious and serve as excellent fodder for livestock. Owing to its uniform quality and increasing global demand, baby corn has strong export potential, contributing to foreign exchange earnings.

5. Nutritional Value of Baby Corn

Baby corn is highly nutritious and its nutritional quality is comparable to or even superior to several seasonal vegetables such as tomato, cabbage, carrot, radish, cucumber and brinjal. It is low in calories and fat, making it suitable for health-conscious consumers. Baby corn provides carbohydrates, dietary fiber, moderate protein, vitamins and essential minerals. Studies have shown that baby corn contributes significantly to a balanced diet and is increasingly being recommended as a healthy vegetable option.

6. Production Technology of Baby Corn

The production of baby corn requires careful selection of suitable genotypes and precise agronomic management. Varieties are selected specifically for baby corn production or grown as secondary crops using sweet corn or field corn types. In some systems, the first cob is allowed to develop into sweet or grain corn, while subsequent cobs are harvested as baby corn.

Sowing is done at closer spacing to encourage prolific ear formation. Timely irrigation, balanced fertilization and effective weed management are essential for achieving high yields. Since baby corn is harvested at an early stage, the crop duration is relatively short, generally 60-70 days.

7. Detasseling and Harvesting

Detasseling, the removal of tassels from maize plants, is a critical operation in baby corn production. Tassel emergence usually occurs 40-45 days after sowing, depending on the variety. Removal of tassels immediately after emergence prevents pollination, thereby maintaining cob tenderness and quality. Studies have reported that detasseling can result in significantly higher marketable baby corn yield compared to non-detasseled crops.

Harvesting of baby corn is done manually before pollination, usually one to three days after silk emergence. Care is taken to avoid breaking the stem and leaves, as multiple ears may emerge sequentially. Frequent harvesting ensures uniform quality and maximizes yield.

8. Economics of Baby Corn Cultivation

The economics of baby corn cultivation depend on cultivar choice, management efficiency and market price. Under well-managed conditions, baby corn hybrids can yield about 15-20 quintals of dehusked baby corn per hectare along with nearly 400 quintals of green fodder. The average cost of cultivation ranges from ₹45,000 to ₹50,000 per hectare.

Market prices of baby corn vary from ₹50 to ₹150 per kg in domestic markets, while green fodder fetches additional income. Net returns of ₹50,000 to ₹75,000 per hectare can be realized within a short crop duration, making baby corn a highly profitable enterprise.

9. Market and Export Potential

Thailand is the largest producer and exporter of baby corn, particularly in canned form. India ranks as the second largest exporter, with major baby corn-producing states including Punjab, Haryana, Karnataka, western Uttar Pradesh, Maharashtra, Gujarat and Meghalaya. Contract farming has played a significant role in expanding baby corn cultivation. Indian

companies have established strong export linkages, with the United Kingdom being a major importer of Indian baby corn. Export prices are significantly higher than domestic prices, enhancing farmer profitability.

10. Breeding Techniques for Baby Corn

Breeding plays a crucial role in improving baby corn yield, quality and adaptability. Selection involves evaluating inbred lines through test crosses, generally at the S_3 or S_4 generation, similar to field corn breeding. Heterosis breeding has been widely exploited to enhance prolificacy, uniformity and yield. Studies using diverse germplasm sources have demonstrated significant heterosis for important baby corn traits.

Reciprocal recurrent selection is also employed to improve both parental populations simultaneously. One of the major challenges in baby corn production is the labour-intensive detasseling process, which has been effectively addressed through the use of male sterility systems.

11. Cytoplasmic Male Sterility in Baby Corn

Cytoplasmic male sterility (CMS) is a maternally inherited trait that suppresses the production of functional pollen due to mutations in the mitochondrial genome. CMS has been reported in over 150 plant species and is stable across environments. In maize, CMS was first reported in 1933 and has since been extensively studied.

CMS-based baby corn cultivation eliminates the need for manual detasseling, saving labour and time. Male sterile lines (A-lines) are maintained using corresponding maintainer lines (B-lines). Three major types of CMS cytoplasm C, T and S are known in maize, differing in their sterility expression and interaction with restorer genes. CMS-based baby corn varieties have gained popularity due to their efficiency and consistency.

12. Achievements and Varietal Development

Several improved baby corn varieties and hybrids have been released in India, including Pusa HM 4, LBCH 3 and IMHB 1532. These varieties exhibit desirable traits such as uniform ear size, attractive color, high yield and suitability for processing. The development and dissemination of such varieties have significantly contributed to the expansion of baby corn cultivation.

The promotion of baby corn in India is closely associated with pioneering farmers and researchers. Notably, Kanwal Singh Chauhan from Haryana is recognized as the 'Father of Baby

Corn' in India for introducing and popularizing the crop, leading to its commercialization and export.

13. Conclusion

Baby corn has emerged as a high-value, short-duration and versatile vegetable crop with immense potential for income generation, nutritional security and export earnings. Advances in breeding techniques, particularly the use of heterosis and cytoplasmic male sterility, have addressed key production constraints and improved efficiency. With appropriate varietal selection, scientific production technology and strong market linkages, baby corn can play a significant role in crop diversification and sustainable agricultural development in India.

14. Future Thrust

Future research on baby corn should focus on developing climate-resilient, high-yielding hybrids with superior cob uniformity, tenderness and nutritional quality. Greater emphasis is needed on CMS-based breeding to eliminate detasseling costs and improve efficiency. Molecular breeding, marker-assisted selection and genomic tools can accelerate varietal improvement. Standardization of processing quality traits, mechanization of harvesting, value addition and strengthening of export-oriented supply chains will further enhance the profitability and sustainability of baby corn cultivation.

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RECENT ADVANCES IN FOOD AND DAIRY TECHNOLOGY: INNOVATIONS, APPLICATIONS AND FUTURE PROSPECTS

Article ID: AG-VO6-I01-07**Shaikh Massarrat Shaikh Ameer**

Assistant Professor, Indian Institute of Food Science and Technology College

Chh.Sambhajinagar, Maharashtra, India

Abstract

The field of food and dairy technology has witnessed significant advancements in recent years, driven by consumer demand for safer, healthier, and more sustainable products. Cutting-edge processing techniques such as high-pressure processing (HPP), pulsed electric fields (PEF), cold plasma, and advanced membrane technologies have revolutionized the preservation and enhancement of food and dairy products by improving microbial safety, nutritional retention, and shelf life. Similarly, microencapsulation, nanotechnology, and biotechnology have expanded opportunities for functional ingredient delivery, probiotic stability, and the development of novel bioactive compounds. The growing interest in functional foods and nutraceuticals has positioned dairy as an essential carrier of probiotics, prebiotics, and bioactive peptides, supporting personalized nutrition and preventive healthcare. Advances in digital technologies, including artificial intelligence, blockchain, and Internet of Things (IoT) applications, are further transforming the industry by enabling real-time quality monitoring, supply chain transparency, and predictive maintenance in processing plants. In parallel, sustainable innovations—such as valorization of dairy by-products, renewable energy integration, eco-friendly packaging, and the rise of plant-based and cultured dairy alternatives—are addressing environmental and ethical challenges. Despite these advances, challenges remain in scaling up novel technologies, ensuring regulatory compliance, and balancing consumer acceptance with affordability. Future prospects lie in greater integration of biotechnology, precision fermentation, and smart packaging systems to enhance product safety and functionality, along with sustainability-focused solutions that reduce the environmental

footprint. Overall, recent innovations in food and dairy technology highlight a transformative era that promises improved product quality, safety, and nutritional value, while aligning with global sustainability and health priorities.

Keywords: Food and Dairy Technology, Functional Foods, Probiotics, Sustainable Processing, Nanotechnology, Precision Fermentation, Smart Packaging

Introduction

Food and dairy technology plays a vital role in ensuring global food security, nutritional well-being, and economic sustainability. The sector has evolved significantly in recent decades, moving beyond conventional preservation and processing methods toward more advanced, science-driven approaches that address consumer preferences, health concerns, and environmental challenges. Dairy products, being rich in proteins, vitamins, minerals, and bioactive components, have long been recognized as an integral part of the human diet. However, modern consumers increasingly demand products that are not only safe and affordable but also functional, sustainable, and tailored to their health needs. This shift has stimulated research and innovation across food and dairy technology.



Advances in processing technologies

Recent advances in processing technologies such as high-pressure processing (HPP), pulsed electric fields (PEF), cold plasma treatment, and advanced membrane filtration have enhanced the microbial safety, shelf life, and nutritional integrity of products without compromising their sensory qualities. In addition, biotechnology and nanotechnology are being employed for the development of probiotics, bioactive peptides, functional foods, and smart delivery systems, expanding the nutritional and therapeutic potential of dairy-based products. At the same time, precision fermentation and cell-based innovations are paving the way for

alternative dairy solutions that align with sustainability and ethical considerations.

Furthermore, digitalization through artificial intelligence (AI), blockchain, and the Internet of Things (IoT) has revolutionized supply chain management, quality control, and traceability, ensuring transparency and consumer trust. The valorization of dairy by-products, the adoption of renewable energy sources, and the use of biodegradable packaging reflect the industry's commitment to sustainable practices and circular economy models.

Innovations and challenges

Despite these remarkable innovations, challenges such as regulatory barriers, high production costs, and consumer acceptance continue to shape the pace of industrial adoption. Nevertheless, the integration of science, technology, and sustainability provides immense opportunities for the food and dairy sector to address global challenges related to nutrition, health, and climate change.

This paper aims to review the recent innovations in food and dairy technology, highlight their practical applications, and explore the future prospects of this rapidly evolving field, with an emphasis on their role in promoting health, sustainability, and economic growth.

Conclusion

The continuous evolution of food and dairy technology reflects the dynamic interplay between consumer demands, scientific innovation, and global sustainability goals. Recent advances in processing techniques, biotechnology, nanotechnology, and digital solutions have reshaped the industry by offering safer, more nutritious, and functionally enhanced products. High-pressure processing, membrane filtration, and pulsed electric fields have demonstrated potential to retain nutritional quality while ensuring microbial safety and extending shelf life. Similarly, innovations in functional foods, probiotics, and nutraceuticals highlight the expanding role of dairy as a platform for health promotion and disease prevention.

The integration of digital technologies such as artificial intelligence, blockchain, and the Internet of Things has created new opportunities for supply chain traceability, predictive analytics, and quality management, enhancing both efficiency and consumer trust. In parallel, the sector's focus on sustainability—through renewable energy adoption, by-product valorization, biodegradable packaging, and the rise of plant-based and cultured dairy alternatives—underscores the commitment to reducing environmental impact while meeting ethical and dietary preferences.

Despite these transformative developments, challenges remain in terms of scalability, regulatory compliance, production costs, and consumer acceptance of novel technologies. Addressing these issues will be critical to unlocking the full potential of emerging innovations. Looking forward, the future of food and dairy technology lies in multidisciplinary collaboration, where advancements in biotechnology, precision fermentation, and smart packaging will converge to deliver products that are safer, healthier, and more sustainable.

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POST-HARVEST MANAGEMENT OF SPICES: PRESERVING AROMA, COLOR AND QUALITY

Article ID: AG-VO6-I01-08***Vasanth S¹ and Arul Prakash A²**

¹ Ph. D scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, HC&RI,
TNAU, Coimbatore.

² Research scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, HC&RI,
TNAU, Coimbatore, Tamil Nadu, India

***Corresponding Autho: Vasanth S**

Introduction

Spices have shaped human civilization for centuries, influencing trade, culture, cuisine, and medicine. From the warm pungency of black pepper to the golden hue of turmeric and the delicate fragrance of cardamom, spices are valued primarily for their aroma, color, flavor, and bioactive compounds. However, these precious qualities are highly sensitive and can be easily lost if spices are not handled properly after harvest. In fact, post-harvest management often determines whether a spice reaches the market as a premium product or as a low-value commodity.

Post-harvest management refers to all operations carried out after harvesting, including harvesting time, curing, drying, cleaning, grading, storage, processing, packaging, and transportation. For spices, these steps are especially critical because their essential oils, pigments, and oleoresins are volatile and susceptible to heat, moisture, oxygen, light, and microbial attack. This article explores the principles and practices of post-harvest management of spices with a focus on preserving aroma, color, and overall quality, using farmer-friendly and industry-relevant approaches.

Importance of Post-Harvest Management in Spices

Spices are typically produced in tropical and subtropical regions, where high humidity and temperature accelerate deterioration. Poor post-harvest handling can lead to:

- Loss of essential oils and volatile compounds
- Fading or browning of natural color
- Development of moulds and mycotoxins
- Insect infestation and contamination
- Reduction in market value and export rejection

Studies suggest that post-harvest losses in spices can range from 15–30%, especially among smallholder farmers. Effective post-harvest management not only reduces losses but also enhances shelf life, safety, export quality, and farmer income.

Harvesting at the Right Stage

The foundation of quality preservation begins at harvest. Spices should be harvested at their optimum maturity stage, when aroma compounds, pigments, and bioactive constituents are at their peak.

- Black pepper is harvested when berries start turning yellow or red.
- Cardamom capsules are picked just before full ripening to retain green color and aroma.
- Turmeric and ginger are harvested when leaves dry and rhizomes mature.
- Chilli can be harvested either green or red, depending on the intended product.

Harvesting too early results in poor flavor and low yield, while delayed harvesting leads to quality degradation, pest damage, and color loss. Gentle handling during harvest is equally important to prevent bruising and mechanical injury, which can accelerate spoilage.

Curing: Developing Flavor and Aroma

Curing is a unique post-harvest process used in certain spices to develop characteristic aroma, flavor, and color.

Curing in Major Spices

- Black pepper: Fresh pepper berries are blanched briefly in hot water and then dried. Blanching cleans the surface, reduces microbial load, and improves black color.
- Vanilla: Curing involves killing, sweating, drying, and conditioning stages, which convert precursors into vanillin and other aromatic compounds.
- Turmeric: Boiling or steaming rhizomes before drying helps in uniform color development, gelatinization of starch, and reduction of raw odor.

Proper curing is essential for activating enzymes and biochemical reactions that enhance the spice's sensory quality. Inadequate curing often leads to poor aroma and uneven color.

Drying: The Most Critical Step

Drying is perhaps the most crucial post-harvest operation in spices. The objective is to reduce moisture content to safe levels (generally 8–12%) to prevent microbial growth and enzymatic degradation.

Traditional Sun Drying

Sun drying is widely practiced due to its low cost, but it has several limitations:

- Uneven drying
- Loss of volatile oils due to prolonged exposure
- Color fading from direct sunlight
- Contamination by dust, insects, and animals

Despite these drawbacks, improved sun drying methods-such as drying on clean mats, raised platforms, or solar dryers-can significantly enhance quality.



Mechanical and Controlled Drying

Mechanical dryers, including hot air dryers, tray dryers, and fluidized bed dryers, offer better control over temperature and humidity.



- Low-temperature drying (40–55°C) is preferred to preserve essential oils and pigments.
- High temperatures cause loss of aroma and discoloration, especially in delicate spices like cardamom and herbs.

Solar dryers are gaining popularity as an eco-friendly option, combining the benefits of sun and controlled drying while reducing contamination.

Preservation of Aroma

Aroma is the defining quality of spices and is mainly derived from essential oils and volatile organic compounds (VOCs). These compounds are highly sensitive to heat, oxygen, and light.

Key Strategies to Preserve Aroma

1. Rapid drying to minimize enzymatic and oxidative losses
2. Low-temperature processing to prevent volatilization
3. Minimizing grinding before storage, as powdered spices lose aroma faster
4. Airtight packaging to reduce oxygen exposure
5. Storage in cool, dark conditions

Advanced methods such as vacuum drying, freeze drying, and inert gas packaging are increasingly used in high-value spice processing to retain maximum aroma.

Preservation of Color

Natural color is a major quality attribute influencing consumer acceptance. Spices like turmeric (curcumin), chilli (capsanthin), saffron (crocin), and paprika derive their value largely from their vibrant pigments.

Causes of Color Loss

- Excessive heat during drying
- Prolonged exposure to sunlight
- Oxidation and enzymatic browning
- Poor storage conditions

Practices to Retain Color

- Blanching or steaming before drying (e.g., turmeric)
- Drying under shade or indirect sunlight
- Using antioxidants and natural preservatives
- Protecting from light using opaque packaging

Maintaining color is especially critical for export markets, where strict visual quality standards apply.

Cleaning, Grading, and Sorting

After drying, spices must be cleaned to remove foreign matter such as soil, stones, stalks, and damaged units. Grading and sorting improve uniformity and market value.

- Manual sorting is common at the farm level.
- Mechanical graders, color sorters, and sieves are used in processing units.

Well-graded spices fetch higher prices and ensure consistency for consumers and processors.

Storage: Maintaining Quality Over Time

Even well-processed spices can deteriorate rapidly if storage conditions are poor. Storage aims to preserve quality by controlling moisture, temperature, oxygen, light, insects, and microorganisms.

Ideal Storage Conditions

- Moisture content below safe limits
- Relative humidity below 60%
- Cool temperatures (below 25°C)
- Clean, dry, and pest-free environment

Storage Containers

- Jute bags lined with polyethylene
- Food-grade plastic containers
- Glass jars for small quantities
- Metal bins with airtight lids

For high-value spices, vacuum packaging and modified atmosphere storage significantly extend shelf life.

Pest and Microbial Management

Spices are vulnerable to insect infestation (beetles, moths) and fungal growth, especially under humid conditions. Mould contamination not only reduces quality but can also lead to mycotoxin production, posing serious health risks.

Control Measures

- Proper drying and moisture control
- Regular inspection of storage areas

- Use of natural repellents like neem leaves
- Fumigation under controlled conditions
- Adoption of hygienic handling practices

Organic and export-oriented spice sectors increasingly rely on non-chemical pest management methods to meet safety standards.

Processing and Value Addition

Processing enhances convenience, shelf life, and market appeal. Common spice processing operations include:

- Grinding and powdering
- Extraction of oleoresins and essential oils
- Blending and formulation
- Packaging for retail and export

However, grinding exposes a large surface area to air, accelerating aroma loss. Therefore, whole spice storage with grinding just before use is often recommended for maximum quality.

Packaging: Protecting Quality Until Consumption

Packaging acts as the final protective barrier between the spice and the external environment. An ideal package should be:

- Airtight and moisture-proof
- Light-resistant
- Inert and food-grade
- Convenient and attractive

Materials such as laminated pouches, aluminum foil packs, and glass containers are commonly used. Eco-friendly and biodegradable packaging options are also gaining attention in sustainable spice marketing.

Transportation and Market Handling

Improper transportation can negate all previous post-harvest efforts. Spices should be transported in clean, dry vehicles, protected from rain, heat, and contamination. Efficient logistics help maintain quality from farm to consumer.

Role of Technology and Innovation

Modern technologies are transforming post-harvest management of spices:

- IoT-based storage monitoring

- Non-thermal processing methods like irradiation and high-pressure processing
- Quality testing tools for moisture, color, and volatile content

These innovations help meet international standards and reduce losses across the value chain.

Conclusion

Post-harvest management is the backbone of spice quality preservation. From harvesting at the right stage to careful curing, controlled drying, proper storage, and effective packaging, each step plays a vital role in retaining aroma, color, flavor, and safety. For farmers, adopting improved post-harvest practices means higher income and reduced losses. For consumers, it ensures access to authentic, flavorful, and safe spices. As global demand for high-quality and sustainably produced spices continues to grow, investing in efficient post-harvest management is not just an option-it is a necessity.

By combining traditional knowledge with modern technology, the spice sector can preserve its rich sensory heritage while meeting the challenges of today's competitive and quality-conscious markets.

ORGANIC NUTRIENT MANAGEMENT IN TRADITIONAL PADDY CULTIVATION

Article ID: AG-VO6-I01-09***¹A. Premalatha, ²S. Saravanakumar and ³Dr.N. Bommayasamy**¹Scientist (Soil Science), ²Scientist (Agronomy) KVK MYRADA, Erode District, TN³Senior Scientist & Head, ICAR KVK - North Goa, India

*Corresponding Author : A. Premalatha

Introduction

Traditional paddy cultivation is an integral component of sustainable rice-based farming systems and plays a crucial role in ensuring nutritional security and environmental sustainability. Indigenous rice varieties are increasingly valued for their superior nutritional quality, medicinal properties, antioxidant content, low glycemic index, and better adaptability to local agro-climatic conditions. These varieties perform well under low-input systems and are highly compatible with organic farming practices.

However, yields in traditional paddy cultivation are often constrained due to inadequate and unscientific nutrient management, imbalanced application of organic inputs, poor nutrient synchronization with crop demand, and limited adoption of biological nutrient sources. Excessive dependence on chemical fertilizers adversely affects soil biological health and grain quality, making them unsuitable for traditional varieties. Hence, scientifically planned organic nutrient management is essential to enhance productivity, soil fertility, and sustainability.

Organic nutrient management in traditional paddy emphasizes improving soil organic carbon, enhancing microbial activity, and ensuring gradual and balanced nutrient release through organic and biological inputs rather than synthetic fertilizers

Principles of Organic Nutrient Management

Organic nutrient management in traditional paddy cultivation is guided by the following principles:

- Enhancement of soil organic carbon and biological fertility

- Synchronization of nutrient release with crop growth stages
- Efficient nutrient recycling through organic residues
- Promotion of biological nitrogen fixation and nutrient solubilization
- Reduction in dependence on external chemical inputs
- Maintenance of long-term soil productivity and ecological balance

Traditional paddy varieties respond favorably to integrated use of organic manures, green manures, biofertilizers, Azolla, and liquid organic formulations.

Organic Sources of Nutrients

Farmyard Manure and Compost

Farmyard manure (FYM) and compost form the primary nutrient base in traditional paddy cultivation. Application of **well-decomposed FYM @ 10–12.5 t ha⁻¹** or **compost @ 5–7.5 t ha⁻¹** during land preparation improves soil structure, increases organic carbon content, and enhances microbial activity. FYM supplies essential macro- and micronutrients and improves cation exchange capacity, enabling better nutrient retention under flooded conditions.

Green Manuring

Green manure crops such as **Dhaincha (*Sesbania aculeata*)** or **Sunhemp (*Crotalaria juncea*)** are raised during the off-season and incorporated at **45–50 days after sowing**. Green manuring contributes approximately **40–60 kg N ha⁻¹** and adds substantial organic matter to the soil. It improves soil aggregation, enhances nutrient availability, and reduces nitrogen losses in puddled soils.

Vermicompost

Vermicompost applied at **2–5 t ha⁻¹** serves as a rich source of readily available nutrients, beneficial microorganisms, and plant growth regulators. Its application enhances root growth, tillering, and dry matter production while improving nutrient mineralization and enzymatic activity in the soil.

Oil Cakes

Oil cakes such as **neem cake or groundnut cake @ 150–300 kg ha⁻¹** are applied as basal or top dressing. These act as slow-release nutrient sources, supplying nitrogen and other nutrients over an extended period. Neem cake also helps suppress soil-borne pests and nematodes while improving soil biological health.

Biological Nutrient Sources

Biofertilizers

Biofertilizers play a vital role in nutrient mobilization and uptake in traditional paddy systems. Seedlings are treated by root dipping for 20–30 minutes in a slurry prepared using:

- Azospirillum @ 2 kg ha⁻¹
- Phosphorus Solubilizing Bacteria (PSB) @ 2 kg ha⁻¹
- Mixed in 40–50 litres of water

This practice enhances biological nitrogen fixation, phosphorus solubilization, root proliferation, and microbial colonization in the rhizosphere, resulting in improved nutrient absorption and early crop vigor.

Azolla

Azolla is an efficient biological nitrogen source in wetland paddy cultivation. Application of **Azolla @ 1 t ha⁻¹ at 7–10 days after transplanting** as a dual crop fixes atmospheric nitrogen and improves phosphorus availability. Later incorporation of Azolla adds organic matter and supports microbial activity.

Liquid Organic and Natural Formulations

Liquid organic formulations such as **Panchagavya, Jeevamrutham and Vermiwash** are applied as **3–5% foliar sprays** at critical growth stages such as **active tillering and panicle initiation**. These formulations enhance chlorophyll content, physiological efficiency, nutrient translocation, and crop resilience. They also stimulate beneficial microbial populations in the phyllosphere and rhizosphere.

Organic Nutrient Management Practices in Traditional Paddy

Land Preparation

During puddling, **FYM @ 10–12.5 t ha⁻¹**, compost, crop residues (**2–3 t ha⁻¹**), and incorporated green manure ensure uniform nutrient distribution and improve soil fertility. Proper land preparation enhances nutrient retention, reduces leaching losses, and creates a favorable environment for microbial activity.

Seedling Treatment

Root dipping of seedlings in biofertilizer slurry before transplanting enhances early root growth, nutrient uptake, and microbial colonization. This practice improves crop establishment and nutrient-use efficiency during early growth stages.

Integrated Organic Nutrient Management

An integrated organic nutrient management strategy ensures balanced nutrient supply and yield stability. A recommended package includes:

- FYM @ 10 t ha⁻¹
- Vermicompost @ 2–5 t ha⁻¹
- Green manure incorporation (Dhaincha/Sunhemp)
- Oil cakes @ 150–300 kg ha⁻¹
- Azospirillum + PSB seedling treatment
- Azolla @ 1 t ha⁻¹ and Liquid organics @ 3–5% foliar spray

This integrated organic nutrient management approach improves nutrient synchronization with crop demand, enhances nutrient-use efficiency, and supports sustainable productivity.

Benefits of Organic Nutrient Management in Traditional Paddy

- **Improved Soil Health:** Enhances soil organic carbon, structure, water-holding capacity, and microbial diversity.
- **Enhanced Nutrient Availability:** Promotes biological mineralization and solubilization of nutrients.
- **Higher Yield and Grain Quality:** Improves tillering, panicle formation, grain filling, aroma, and nutritional quality.
- **Reduced Pest and Disease Incidence:** Strengthens plant health and encourages beneficial organisms.
- **Sustainability:** Reduces reliance on synthetic fertilizers, lowers production costs, and supports eco-friendly farming systems.

Conclusion

Organic nutrient management in traditional paddy cultivation focuses on improving soil fertility through organic and biological processes rather than external chemical inputs. The integration of organic manures, green manures, biofertilizers, Azolla, and liquid organic formulations enhances soil health, improves nutrient-use efficiency, and ensures sustainable crop production. Scientifically planned organic nutrient management not only improves yield and grain quality in traditional paddy but also ensures long-term soil productivity and environmental sustainability. Adoption of these practices contributes to resilient farming systems capable of addressing challenges related to climate change, soil degradation, and food security.

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HARNESSING SILICON-SOLUBILISING BACTERIA FROM PADDY RHIZOSPHERE FOR SUSTAINABLE AND CLIMATE-SMART RICE FARMING

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***A Kanagavalli¹ and T Sherene Jenita Rajammal¹**

¹ Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

*Corresponding Author: A Kanagavalli

Abstract

Although silicon is abundant in soils, its limited solubility restricts its uptake by rice, a crop that heavily depends on Si for growth and stress tolerance. Silicon-solubilising bacteria (SiSB) can convert insoluble silicates into monosilicic acid by acidolysis and related biochemical processes. The present study aimed to isolate SiSB from the rice rhizosphere using Bunt and Rovira medium and assess their silicate-solubilising ability using serial dilution culture and pH monitoring of broth. These isolates are expected to enhance Si mobilisation, uptake and accumulation in rice. The application of SiSB represents an eco-friendly alternative to synthetic fertilizers and may play a pivotal role in improving rice yield, soil health and environmental sustainability. Their combined use with silicon-rich industrial by-products offers further potential for cost-effective and climate-smart agriculture.

Keywords: Paddy, SiSB, Silicic acid, Burnt and Rovira, Rhizosphere

Introduction

Both essential and non-essential silicate minerals are abundant in soil. Despite not being regarded as a necessary component, silicon (Si) is typically touted as advantageous for plants. Bacteria have the ability to depolymerise and solubilise naturally existing Si. There are a number of ways that bacteria break down silicate, including solubilisation by ligands (divalent cations), organic and inorganic acids, alkali (nucleophilic assault), and extracellular polysaccharides. However, it is recognised that the most frequent process by which silicate minerals weather is

acidolysis (Kang et al., 2017). It is commonly known that microbes dissolve and mobilise soil minerals. There have been reports of Si being released when bacteria break down silicate, and silicate-solubilizing bacteria have recently drawn a lot of attention because solubilisation of silicate encourages the uptake of both Si and K, hence lowering the need for potash fertilizer.

Rice is the most significant staple crop in the world and provides half of the world's food needs. As a siliceous plant, rice gathers readily available silica from the soil. For rice to reach its maximum yield, high fertilization rates are necessary. However, overuse of synthetic fertilisers leads to pollution of the air, water, and soil. In the end, 40% of deaths globally are caused by pollution from these three significant sources. Thus, it is essential to gradually replace synthetic fertiliser with beneficial bacteria and biofertilizer. Therefore, the current study's objective was to find and isolate root-associated rhizospheric bacteria that may create phytohormones and solubilise silicate, as well as to investigate how these bacteria affect the mobilisation and accumulation of Si in rice (Kim and Lee, 2017).

Isolation of Si solubilising bacteria (SiSB)

A rhizosphere sample was taken for isolation of SiSB. Ten grammes of rhizosphere were vortexed for two minutes after being diluted with 0.85% NaCl. The serial dilutions up to 10^{-7} , with a sample composition of 1 ml in 9 ml of 0.85% NaCl, each dilution was vortexed continuously for two minutes. Next, a Petri plate containing molten Bunt and Rovira Agar is filled with the diluted inoculum, stirred, and left to solidify. In Bunt and Rovira Agar, the isolated paddy rhizosphere bacteria were cultured for four days at 30°C.

Media composition of Bunt and Rovira medium

The medium has the following contents (g/750 mL): 20 g glucose; 20 g agar; 1 g peptone; 1 g yeast extract; 0,5 g $(\text{NH}_4)_2\text{SO}_4$; 0,4 g K_2HPO_4 ; 0,1 g MgCl_2 ; 0,01 g FeCl_3 ; 250 ml soil extract; 750 ml aquades; pH 6,6-7,0.

pH Measurement in Bunt and Rovira Broth

Prior to and following incubation in Bunt and Rovira broth, pH was determined. The pH of the Bunt and Rovira broth was measured using a pH roll (6,6-7,0) prior to sterilisation. Each culture's pH was determined after seven days of incubation and compared to the pH before to the incubation periods.

Role of SiSB for sustainable agriculture

- Improve silicon uptake naturally

- Strengthen plant resistance to diseases and pests
- Enhance tolerance to drought and salinity
- Reduce dependence on chemical fertilizers
- Increase grain yield and grain quality

Combining SiSB with silicon amendments

Combining silicon-solubilizing bacteria with silicon-rich waste materials, like coalchar or fly ash-derived silica, is another fascinating area of study. In a true soil-microbe cooperation, the amendment acts as a supply of silicon while the bacteria make it accessible to plants.

A greener future for rice cultivation

The application of microbial solutions, such as silicon-solubilizing bacteria, presents a possible route ahead for resource-efficient and climate-smart farming. Using soil bacteria to their full potential not only increases agricultural yields but also fosters safer food, healthier soils, and more sustainable livelihoods.

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BIO-BASED FOOD ADDITIVES: A SUSTAINABLE ALTERNATIVE TO SYNTHETIC ADDITIVES

Article ID: AG-VO6-I01-11**Jatin Dangi*, Rishi Bhardwaj, Anshu Sharma, Anil Kumar Verma**

Department of Food Science and Technology

Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan

*Corresponding Author : Jatin Dangi

Abstract

Food additives are substances intentionally added to foods in little amounts to enhance safety, shelf life, sensory qualities, and sometimes nutritional value. They offer several positive impacts, such as preventing microbial spoilage, reducing food waste, enhancing palatability. However, challenges remain including potential adverse reactions in sensitive individuals, uncertainties about long-term effects of combined additive exposure, continuous toxicological evaluation, and transparent labeling to maintain consumer trust and ensure safe use. Bio-based food additives, derived from natural replenishable resources like plants, microbes and agro-by-products, offer sustainable alternatives to synthetic additives by fulfilling necessary functions such as preservation, coloration and texturization while aligning with clean-label and environmental demands. They elevate food safety, sensory quality and shelf life but pose challenges including high costs, stability issues, regulatory hurdles, and consumer misconceptions about their "natural" safety.

Keywords: Bio-based food additives, Natural additives, Plant-derived ingredients, Sustainable food systems, Food safety

Introduction

Food additives are substances that are not normally consumed as foods themselves but are intentionally added to food so that they perform specific technological functions such as preservation, coloring, flavor enhancement, sweetening, emulsification or texture improvement during processing.

They help in maintaining security, quality, liability, sensory appeal and shelf life of food products and are managed by authorities through standards (Kovalchuk, 2021).

Chemical additives are substances incorporated to food in small quantities during processing, storage or transportation to maintain quality, improve appearance, prevent spoilage and extend shelf life. They help in controlling microbial growth, oxidation, browning and texture changes, thereby ensuring food safety. Common examples include preservatives like sodium benzoate, antioxidants such as BHA and BHT, colorants, flavor enhancers and emulsifiers, all of which are used under strict regulatory limits to protect consumer health.

‘Bio-based Food Additives’ represent the new generation of such additives which are derived from renewable biological sources such as plants, microorganisms, algae and agricultural by-products, instead of petrochemical or purely synthetic origins. They are developed to provide the same or improved functions—like preservation, coloring, flavoring and texturizing—while meeting clean-label, “natural” and sustainability expectations of modern consumers and integrating with environmental and regulatory pressures towards greener food systems.

Types of Bio-Based Additives

Major types include plant-based preservatives and antioxidants (e.g. rosemary extract, green tea polyphenols and essential oils like oregano and thyme), natural colorants (such as beetroot betalains, paprika oleoresin and carotenoids from annatto), bio-based emulsifiers and stabilizers like lecithin from soy or sunflower and hydrocolloids such as guar gum and pectin. Microbial-derived additives form another essential group including organic acids like lactic acid and citric acid produced by fermentation, enzymes used for dough conditioning or juice clarification and vitamins such as riboflavin obtained via microbial biosynthesis. These bio-based additives provide certain health benefits by providing antioxidant, anti-inflammatory, antimicrobial activities, supporting clean-label formulations and reducing synthetic additive intake, but they also present challenges such as changeability in composition, stability issues, higher production cost and the requirement for optimization of extraction and standardization to assure consistent functionality in diverse food matrices.

Positive and Harmful Impacts

Food additives, including bio-based ones, have important positive impacts such as enhancing food safety by restricting microbial growth, slowing oxidation and spoilage and thereby minimizing food waste and improving shelf life and distribution efficiency. They also

improve sensory quality and consumer acceptance by stabilizing colour, flavor and texture and can contribute to health by enabling fortification or incorporation of functional ingredients. However, additives can have harmful impacts when misused, overconsumed or in sensitive individuals; concerns include potential allergenicity or intolerance (e.g. to certain colors, preservatives), possible disruption of the gut microbiota and long-term toxicological risks.

Challenges

Bio-based food additives confront several interrelated challenges that currently limit their full-scale replacement of synthetic additives. High production costs, dependence on variable agricultural raw materials, and scalability issues in extraction or fermentation make many bio-based preservatives and colorants more expensive and less economically attractive, especially for low-margin products. Technically, natural pigments and antimicrobial compounds often show lower potency, narrower application range, poor stability to heat, light, pH and processing, forcing formulators to use higher doses and accept shorter shelf life or quality variation. Regulatory hurdles are another barrier: each new bio-based additive requires extensive safety testing, clear definition and authorization, while “natural/clean label” terms remain poorly standardized, creating unpredictability for both industry and consumers. Finally, market acceptance is not automatic—consumers may acknowledge clean-label products as healthier but are sensitive to price increases and may not understand that “natural” alternatives still function as additives, requiring better communication and evidence-based education.

Future Prospects in India

India's bio-based food additives sector possesses strong growth potential, fueled by rising demand for clean-label, plant-derived ingredients surrounded by expanding processed food markets and health-conscious consumers. The natural additives segment already leads with 52% market share in 2024 and a 7.55% CAGR through 2030 (Anonymous 2025c), outpacing synthetics due to premium pricing tolerance (20-30% higher) for organic/plant-based options in functional foods and beverages.

- Government support via FSSAI regulations facilitates clear labeling, "natural" claims and sustainable sourcing, easing market entry for bio-based preservatives, colors and emulsifiers from spices, herbs and agro-byproducts.
- Innovation in fermentation, enzyme tech and edible films will address scalability, linking with plant-based food boom (34.87% CAGR to USD 21.87 billion by 2030).

- Rich biodiversity and upcycling opportunities from agricultural waste position India as a key exporter, with related nutraceutical/bio-based markets projected to hit USD 30-40 billion by 2027.
- R&D investments and export focus signal bio-based additives becoming mainstream in India's USD 13.86 billion food additives market by 2030.

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ROLE OF ARTIFICIAL INTELLIGENCE-ENABLED ADVISORY SYSTEMS IN AGRICULTURAL EXTENSION

Article ID: AG-VO6-I01-12**Jawahar Annamalai**

Junior Research Scholar in Agriculture Extension Education Department at College of
Agriculture Gwalior, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior,
Madhya Pradesh -474002

Abstract

Artificial Intelligence (AI) has emerged as a ground breaking tool in agriculture, offering innovative solutions to long-standing challenges in agricultural extension. AI-enabled advisory systems integrate technologies such as machine learning, natural language processing, remote sensing, and big data analytics to deliver personalized, accurate, and timely advisory services to farmers. These systems aim to improve decision-making, optimize resource usage, enhance sustainability, and support smallholder farmers who often lack direct access to traditional extension agents. This article examines the role of AI-based advisory systems, their applications, benefits, challenges, and future prospects in agricultural extension.

Introduction

Agricultural extension services are critical for disseminating information, technologies, and innovations from research to farmers. Traditional extension approaches — such as field visits, demonstrations, and group trainings — often face limitations such as insufficient reach, human resource constraints, time lag, and high costs. With rapid advancements in digital technologies, Artificial Intelligence-based advisory systems have the potential to bridge these gaps by providing scalable, real-time, and location-specific advice directly to farmers.

AI refers to computer systems capable of performing tasks that typically require human intelligence, such as learning, reasoning, and problem-solving. In agriculture, AI systems process large volumes of heterogeneous data, including weather, soil, crop health, and socioeconomic information, to generate context-aware recommendations for farmers.

Concept and Working of AI-enabled Agricultural Advisory Systems

AI-enabled advisory systems are digital platforms that analyze multiple data sources — such as satellite imagery, sensor data, historical yields, weather forecasts, and farmer inputs — to produce automated advisory outputs. These outputs are delivered through mobile apps, SMS, voice calls, chatbots, or web interfaces, ensuring accessibility even in remote areas.

Key technologies include:

- **Machine Learning (ML):** Learns patterns from historical and real-time data to predict outputs (e.g., pest outbreaks). [Extension Journal](#)
- **Natural Language Processing (NLP):** Enables chatbots and interactive voice response systems to interact with farmers in local languages (e.g., Ama Krushi chatbot in Odisha). [JCR International](#)
- **Remote Sensing & IoT Sensors:** Collect data on crop conditions and environmental variables for AI algorithms to interpret. [agriculturaljournals.com](#)
- **Decision Support Systems (DSS):** Combine models and AI to provide tailored farming recommendations. [JournalsPub](#)

Applications in Agricultural Extension

1. Personalized Crop Advisory

AI systems evaluate field-level parameters (soil type, crop stage, weather) and generate customized advisories — such as optimal sowing time, fertilizer dosage, irrigation scheduling, and harvest planning — improving relevance and decision quality. [MultiTech Publisher](#)

2. Pest and Disease Detection

Mobile apps and image-based diagnostics use AI image recognition to identify pests, diseases, and nutrient deficiencies from crop images. Apps like *Plantix* enable farmers to diagnose issues quickly and act before significant losses. [Wikipedia](#)

3. Climate-Smart Recommendations

AI forecasts weather and climate risks, enabling advisories on drought risks, rainfall variability, and climate resilient practices. This helps farmers plan activities and manage risk. [ScienceDirect](#)

4. Market Intelligence and Price Forecasts

AI-based systems analyze market trends and commodity pricing to guide farmers on optimal selling periods and locations, improving income certainty. [MultiTech Publisher](#)

5. Multilingual Interactions and Accessibility

Chatbots using NLP — such as the *Ama Krushi* chatbot in Odisha — deliver advisory content in local dialects, expanding the reach of extension messages to diverse farmer groups. [JCR International](#)

Benefits of AI-enabled Advisory Systems

Enhanced Access and Timeliness

AI systems can reach thousands of farmers simultaneously and instantly update advice based on the latest data, overcoming geographical and manpower constraints of traditional extension. [J Exp Agr Int](#)

Improved Decision-making Support

By synthesizing complex data sets, AI advisory tools enhance farmers' ability to make evidence-based decisions, reducing guesswork and uncertainty in farm operations. [MultiTech Publisher](#)

Cost Efficiency

Once deployed, AI advisory systems can disseminate knowledge at a low marginal cost per farmer — making high-quality advisory services affordable to resource-constrained farmers. [JCR International](#)

Sustainable Agriculture Promotion

AI tools help optimize input use (water, fertilizers, pesticides), reducing environmental impact and promoting sustainable farming practices. [ScienceDirect](#)

Challenges in Adoption

Digital Divide and Connectivity Issues

Lack of reliable internet access and low smartphone penetration limits the effectiveness of digital advisory services in many rural areas. [J Exp Agr Int](#)

Digital Literacy and Language Barriers

Many smallholder farmers lack the digital literacy needed to interact with AI platforms, especially if interfaces are not in local languages. [JCR International](#)

Data Quality and Privacy Concerns

The accuracy of AI recommendations depends on high-quality data. Furthermore, data privacy and ownership issues pose ethical and regulatory challenges. [EKB Journals](#)

High Initial Costs and Technical Expertise

Developing and maintaining AI systems require financial investments and technical skills that many extension agencies struggle to afford. [Extension Journal](#)

Case Studies and Research Insights

Ama Krushi Chatbot (Odisha, India)

The *Ama Krushi* chatbot uses NLP to deliver localized agricultural advisories in Odia and Sambalpuri, reaching over 1.5 million farmers. Farmer feedback indicates high accessibility and relevance, though digital divides persist among women and tribal groups. [JCR International](#)

Utilization by Extension Professionals (India)

A study among extension professionals in India found awareness of AI tools is high, but full utilization remains limited due to digital literacy gaps, infrastructure challenges, and cost barriers. [ARCC Journals](#)

Global Research Trends

Scholarly reviews show that AI adoption in agriculture enhances precision farming, crop monitoring, and predictive advisory services, but emphasize the need to address adoption barriers for equitable impact. [Extension Journal](#)

Future Prospects

AI-enabled advisory systems are poised to become integral components of agricultural extension as connectivity improves and technologies become more affordable. Future developments could include:

- ✓ Multimodal AI platforms (voice + text + visuals) for wider accessibility.
- ✓ Integration with IoT and real-time sensor data for precision guidance.
- ✓ Explainable AI systems that build trust by clarifying recommendations.
- ✓ Context-aware AI frameworks that incorporate local knowledge and conditions. [J Exp Agr Int](#)

Conclusion

AI-enabled advisory systems represent a paradigm shift in agricultural extension, offering scalable, data-driven, and farmer-centric advisory solutions. While significant challenges remain — especially in infrastructure, digital literacy, and data governance — AI tools have the potential to democratize access to high-quality agricultural knowledge.

Integrating AI with traditional extension approaches can help build resilient, inclusive, and sustainable agricultural systems that empower farmers and enhance productivity in a rapidly changing world.

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POST-HARVEST MANAGEMENT TECHNOLOGIES TO EXTEND SHELF LIFE IN FLOWER CROPS

Article ID: AG-VO6-I01-13**C N R Santhoshini***

Assistant Professor, Department of Floriculture and Landscaping, College of Horticulture,
Rajendranagar, Hyderabad, SKLTSHU, Telangana-500030, India

Abstract

Flower crops are highly perishable and require careful handling after harvest to maintain quality and freshness. Rapid deterioration occurs due to respiration, moisture loss, microbial growth, and ethylene production. Proper post-harvest management technologies play a key role in extending shelf life and reducing losses in the floriculture sector. This article discusses simple and effective post-harvest practices such as harvesting at the right stage, pre-cooling, use of floral preservatives, cold storage, modified atmosphere packaging, and proper packaging and transportation. Adoption of these technologies helps improve vase life, market value, and export potential of flower crops, thereby increasing farmers' income.

Keywords: Post-harvest management, Shelf life, Cut flowers, Cold storage, Floral preservatives

Introduction

Floriculture is a fast-growing and high-value enterprise in horticulture, providing significant income and employment opportunities. However, post-harvest losses in flower crops are considerably high due to improper harvesting, handling, storage, and transportation practices. Flowers such as rose, carnation, gerbera, gladiolus, lily, and chrysanthemum are delicate commodities and are highly sensitive to environmental conditions.

After harvest, flowers continue to respire and lose water, leading to wilting, fading of colour, petal drop, and reduced vase life. Inadequate post-harvest care not only reduces market value but also affects consumer preference and export quality. Therefore, adoption of scientific post-harvest management technologies is essential to maintain freshness, extend shelf life, and minimize losses in flower crops.

Factors Affecting Shelf Life of Flower Crops

The shelf life and quality of cut flowers depend on several physiological and environmental factors. Important factors influencing flower longevity include:

- High respiration rate after harvest
- Loss of water through transpiration
- Ethylene production and sensitivity
- Mechanical damage during harvesting and handling
- Temperature and relative humidity during storage and transport

Effective management of these factors is crucial for delaying senescence and maintaining flower quality.

Figure 1. Post-harvest handling chain in flower crops



Harvesting at the Right Stage

Harvesting flowers at the correct physiological stage is the first and most critical step in post-harvest management. Flowers harvested either too early or too late often show poor opening and reduced vase life.

Recommended harvesting practices include:

- Harvesting during early morning or late evening hours
- Avoiding harvesting during hot and dry periods
- Using sharp and clean cutting tools to prevent injury

Proper harvesting ensures uniform bud opening, attractive appearance, and longer shelf life of flowers.

Pre-Cooling of Flowers

Pre-cooling is the process of removing field heat from flowers immediately after harvest. It helps slow down physiological and biochemical processes responsible for deterioration.

Common pre-cooling methods include:

- Forced air cooling
- Hydro-cooling
- Vacuum cooling

Pre-cooling reduces respiration rate, delays ageing, and improves storage life, especially during long-distance transportation.

Use of Floral Preservatives

Floral preservatives play an important role in maintaining water uptake, reducing microbial growth, and extending vase life of cut flowers.

Commonly used floral preservatives include:

- Sucrose – provides energy for bud opening and flower development
- Silver thiosulfate (STS) – inhibits the action of ethylene
- 8-Hydroxyquinoline citrate (8-HQC) – controls microbial growth in vase solution

Use of appropriate preservatives significantly improves flower freshness and longevity.

Cold Storage of Flowers

Cold storage is one of the most effective post-harvest technologies for extending shelf life of cut flowers.

Recommended storage conditions:

- Temperature: 2–4°C
- Relative humidity: 90–95%

Cold storage slows respiration, reduces moisture loss, and minimizes microbial activity, thereby maintaining flower quality.

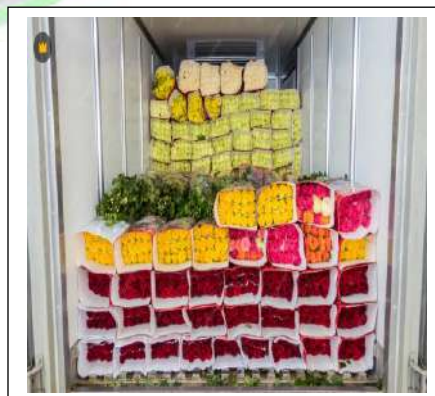


Figure 2. Cold storage of cut flowers

Modified Atmosphere Packaging (MAP)

Modified atmosphere packaging involves altering the gaseous composition surrounding the flowers to slow down physiological processes.

- Oxygen concentration is reduced
- Carbon dioxide concentration is increased

MAP helps delay senescence and is particularly useful for long-distance transport and export of cut flowers.

Packaging and Transportation

Proper packaging is essential to protect flowers from mechanical damage during handling and transportation.

Recommended packaging practices include:

- Use of corrugated fibreboard boxes
- Provision of adequate ventilation holes
- Use of cushioning materials to prevent bruising

Refrigerated transportation helps maintain the cold chain from harvest to market and preserves flower freshness.

Use of Growth Regulators and Natural Compounds

Plant growth regulators such as cytokinins help delay senescence and extend vase life of flowers. In recent years, natural and eco-friendly alternatives have gained importance in post-harvest management.

Natural compounds include:

- Essential oils
- Plant-based extracts

These alternatives are safe, sustainable, and suitable for modern floriculture practices.

Constraints in Adoption of Post-Harvest Technologies

Despite the availability of technologies, several constraints limit their adoption by flower growers:

- Lack of cold chain infrastructure
- High cost of advanced post-harvest technologies
- Limited awareness and technical knowledge among growers

Strengthening extension services, training programs, and infrastructure development is essential to overcome these challenges.

Practical Tips for Flower Growers

- Harvest flowers during cool hours of the day
- Use clean water and containers for handling
- Pre-cool flowers before storage or transport
- Maintain cold chain wherever possible
- Use recommended floral preservatives for better vase life

Conclusion

Post-harvest management technologies play a vital role in extending shelf life and maintaining quality of flower crops. Practices such as harvesting at the right stage, pre-cooling, use of floral preservatives, cold storage, modified atmosphere packaging, and proper packaging effectively slow down deterioration. Adoption of simple and cost-effective post-harvest technologies can significantly reduce losses, improve market value, and enhance farmers' income. Strengthening post-harvest infrastructure and awareness will further support sustainable growth of the floriculture sector.

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BRANDING AND MARKETING STRATEGIES FOR BOUQUET FLOWERS

Article ID: AG-VO6-I01-14**C N R Santhoshini**

Assistant Professor, Department of Floriculture and Landscaping, College of Horticulture,
Rajendranagar, Hyderabad, SKLTSHU, Telangana-500030, India

Abstract

The bouquet flower industry is highly competitive due to the perishable nature of flowers and the presence of numerous small and large sellers. Effective branding and marketing strategies play a vital role in product differentiation, customer loyalty, and expansion of market reach. This article discusses the importance of branding in bouquet flowers and highlights traditional as well as modern marketing strategies adopted by floriculture enterprises. Emphasis is given to visual identity, packaging, pricing strategies, digital marketing, and customer engagement. Successful examples from organized flower brands and local florists are also presented. The article concludes that a strong brand image combined with integrated online and offline marketing strategies can significantly enhance sales and long-term sustainability of bouquet flower businesses.

Keywords: Bouquet flowers, Branding, Floriculture marketing, Digital marketing, Value addition, Consumer behavior

Introduction

Floriculture has emerged as an important component of horticulture due to the increasing demand for flowers for social, cultural, and commercial purposes. Among floral products, bouquet flowers occupy a prominent place as they are widely used for gifting, celebrations, corporate events, weddings, and festivals. However, bouquet flowers are highly perishable and are often subjected to price fluctuations and intense market competition.

In such a competitive environment, branding and marketing strategies play a crucial role in ensuring business sustainability. Branding helps create a unique identity and emotional

connection with consumers, while marketing strategies assist in reaching the target audience and converting interest into sales. Effective branding and marketing improve customer trust, perceived value, and repeat purchases in bouquet flower enterprises.

Branding of Bouquet Flowers

Branding refers to creating a distinct identity for a product through its name, logo, colour scheme, packaging style, and customer experience. In bouquet flowers, branding is strongly associated with emotions such as love, joy, celebration, and elegance.

Key elements of bouquet flower branding include:

- Brand name and logo reflecting freshness, elegance, and emotions
- Consistent colour themes for wrapping papers, ribbons, and tags
- Quality assurance to maintain freshness and uniformity
- Storytelling, such as eco-friendly practices or locally grown flowers

A strong brand identity helps consumers easily recognize the product and builds long-term trust.

Figure 1. Example of branded bouquet packaging with logo and colour theme



Product Differentiation and Value Addition

Product differentiation and value addition increase the attractiveness and perceived value of bouquet flowers. Innovative presentation and customization help florists stand out in a crowded market.

Common methods of value addition include:

- Creative and innovative flower arrangements
- Use of premium and eco-friendly wrapping materials
- Addition of greeting cards, chocolates, ribbons, or soft toys
- Customization based on occasions such as birthdays, weddings, anniversaries, and festivals

Value-added bouquets allow sellers to charge premium prices and cater to specific consumer preferences.

Pricing Strategies

Pricing plays a major role in influencing consumer purchasing decisions. Appropriate pricing strategies help balance profitability and customer affordability.

Common pricing strategies adopted in bouquet flower marketing include:

- Cost-plus pricing in local and unorganized markets
- Psychological pricing (e.g., ₹499 instead of ₹500)
- Premium pricing for luxury and designer bouquets
- Discounts, offers, and bundled products during festivals and special events

Well-planned pricing strategies help attract customers while ensuring sustainable returns.

Offline Marketing Strategies

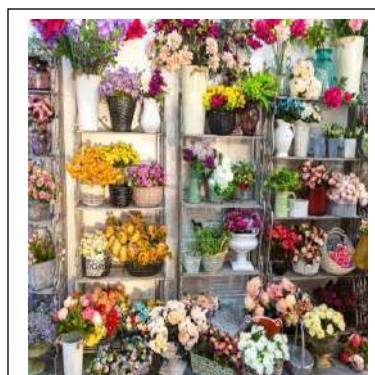
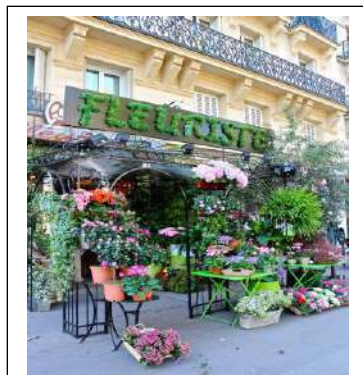
Traditional or offline marketing strategies continue to play an important role, particularly in local and urban markets.

Major offline marketing approaches include:

- Attractive shop displays with colourful bouquet arrangements
- Participation in flower exhibitions, fairs, and trade shows
- Word-of-mouth promotion through satisfied customers
- Tie-ups with event planners, hotels, corporate offices, and gift shops

Offline marketing helps build local brand presence and customer relationships.

Figure 2. Florist shop display with attractive bouquet arrangements



Online and Digital Marketing Strategies

Digital marketing has revolutionized the marketing of bouquet flowers by enabling direct interaction with consumers and expanding market reach.

Popular digital marketing strategies include:

- Social media marketing through Instagram, Facebook, and WhatsApp
- Online ordering through websites and e-commerce platforms
- Influencer collaborations and promotional campaigns
- Customer reviews, ratings, and testimonials

High-quality photographs, short videos, and reels play a crucial role in attracting online buyers.

Figure 3. Instagram marketing page of a bouquet flower brand

Case Examples

Interflora has developed a strong global brand by maintaining quality standards, timely delivery, and premium packaging.

Local Instagram-based florists in Indian cities have successfully expanded their businesses using creative reels, customization, and direct customer engagement.

These examples demonstrate that even small-scale florists can compete effectively through innovative branding and a strong digital presence.

Challenges in Branding and Marketing

Bouquet flower businesses face several challenges in branding and marketing, including:

- High competition and price sensitivity
- Short shelf life of flowers
- Limited marketing knowledge among small florists
- High cost of branding and digital promotion

Capacity building, training programs, and access to digital tools can help overcome these challenges.

Conclusion

Branding and marketing strategies are essential for the success of bouquet flower enterprises in today's competitive market. A strong brand identity, attractive packaging, suitable pricing, and effective use of digital platforms can significantly improve consumer preference and profitability. Integration of traditional and modern marketing approaches ensures wider reach and long-term sustainability. Floriculture students, entrepreneurs, and flower growers should focus on innovative branding and customer-centric marketing to maximize returns from bouquet flower businesses.



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PATENT POLICY IN INDIA

Article ID: AG-VO6-I01-15**¹Sakthi Anand, M. K., ^{*2}V. Krishnan, ²N. Swaminathan, ²V. Ramesh and ³J. Arathi**

¹Ph. D. Scholar, ²Faculty & ³PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

Corresponding Author: V. Krishnan

Introduction

India's approach to intellectual property (IP) regulation presents a pivotal moment as it seeks to reconcile broad access to knowledge and culture with incentives for sustainable innovation. This debate is shaped by global frameworks, such as the TRIPS agreement, and India's own legislative reforms, including the Patents (Amendment) Act, 2005, which have fundamentally altered the national IP landscape. Garrett Hardin's "tragedy of the commons" provides a valuable metaphor for managing public goods, including information, knowledge, and cultural resources. According to Hardin, resources freely accessible to all risk overuse and depletion. Applying this logic, the ideal regime for informational commons should achieve two goals: maximise access and use ("access maximising imperative") while safeguarding long-term sustainability and regenerative potential ("sustainable production imperative"). India's challenge is to balance both, creating a fair, future-facing regulatory framework

2. India's Patent Policy: A Historical Overview

India's patent policy has been uniquely oriented towards development, positioning patents as tools for public welfare rather than solely commercial gain. This vision contrasts with industrialised countries and has shaped India's approach since independence, especially emphasising affordable access to essential goods.

3. Pre-Independence Patent System

The origin of patent law in India dates back to British colonial rule with the Patents and Designs Act of 1856, followed by several legislative reforms culminating in the Indian Patents

and Designs Act, 1911. During this period, patent laws primarily protected foreign industrial interests, providing exclusive rights to inventors without much focus on encouraging Indian innovation or wider public benefit.

4. Post-Independence Reform and Committees

Following independence, India undertook a comprehensive review of its patent system. Two key committees shaped this reform:

- **The Patent Enquiry Committee (1948-50):** This committee concluded that the system failed to promote Indian inventions and primarily benefited foreign patent holders.
- **The Ayyangar Committee (1957-59):** This committee highlighted how foreign patent monopolies increased costs and restricted access to affordable goods in India.

These findings underscored the need for a patent framework prioritizing public interest and development.

5. The Patents Act of 1970

Informed by committee recommendations, the Patents Act, 1970 was enacted to limit patent protection that could impede affordable access to medicines, food, and chemicals. Key features included:

- Granting process patents but excluding product patents in pharmaceuticals, food, and chemicals to prevent monopolies by foreign companies.
- Imposing a shorter patent term than international norms.
- Introducing compulsory licensing to ensure patented inventions were worked (manufactured) in India.
- Allowing the government extensive control to prevent monopolistic practices and maintain public access.

This law harmonised with India's broader science and technology goals to foster indigenous innovation and maintain equity in essential goods supply.

6. Patents in India

A patent is a legal monopoly granted by the state to an inventor over a new and useful invention for a limited time. This exclusive right allows the patent holder to control the manufacturing, use, import, and sale of the invention within India. Indian patent law, governed by the Patents Act of 1970 and its subsequent amendments, provides the legal framework for patents. A patent is territorial; rights are enforceable only within the country that issues them.

The typical duration of protection is 20 years from the date of filing. Patents serve as a key incentive mechanism, encouraging inventors to develop new technologies by granting them exclusivity in exchange for public disclosure

Table 1. Types of Patents

Patent type	Coverage/ Scope	Term (Years)	Common Applications	Indian Equivalent/ Governing Law
1.Utility Patent	Protects inventions related to processes, machines, manufactured articles, compositions of matter, and improvements	20	Scientific innovations, pharmaceuticals, machinery, and industrial products	Patent Act, 1970 (as amended) Recognised as “ <i>Patents for Inventions</i> ”
2.Design Patent	Protects new, original, and ornamental designs applied to articles of manufacture	14	Industrial designs, product aesthetics, packaging	Designs Act, 2000 Grants design registration for 10 years , extendable by 5 years (total 15 years)
3.Plant Patent	Protects new and distinct plant varieties reproduced asexually (excluding tuber-propagated plants)	20	Horticulture, agriculture, floriculture	Protection of Plant Varieties and Farmers’ Rights (PPV & FR) Act, 2001. Grants protection for 18 years (trees, vines) and 15 years (other crops)

However, not all innovations qualify for patents. To be patentable, an invention must fulfil three main criteria it must be new or novel, show an inventive step that is non-obvious to experts, and be capable of practical use. Certain things like scientific principles, laws of nature, and artistic works cannot be patented but may be protected under copyrights.

7. What Cannot Be Patented?

The Indian Patent Act explicitly excludes certain inventions from patentability to uphold public order, health, and ethics. These exclusions encompass frivolous inventions, discoveries or scientific principles with no practical application, processes for medical treatment or agriculture, substances that result only from simple mixtures without new properties, and inventions harmful to public health or morality. Furthermore, atomic energy inventions and claims only related to food or medicinal substances are excluded, though manufacturing processes related to these can be patented. This framework ensures that patent law serves societal development and ethical standards.

8. Patent Application Process

Prospective patentees must provide comprehensive documentation outlining the invention's objectives, existing solutions, the novelty and inventive aspects, practical applications, inventor details, and financial backgrounds in their patent application. These applications undergo official examination to assess compliance with patentability criteria, prior art, and legal formalities before grants are issued.

Applicants seeking patent protection in India must provide:

- A detailed description of the problem addressed by the invention
- Background and status of existing solutions
- Explanation of novel contributions and inventive features
- Description of applications and utility
- Inventor's credentials and funding sources

The patent application undergoes examination for compliance with legal, technical, and novelty standards before grant or refusal.

9. Administration and Enforcement

India's IP regime is administered through the Office of the Controller General of Patents, Designs and Trademarks, operating under the Department for Promotion of Industry and Internal Trade (DPIIT). This office handles registration, examination, dispute resolution, and enforcement of IP rights. Enforcement mechanisms include civil court remedies like injunctions and damages, as well as criminal penalties for violations such as piracy and counterfeiting. Recent initiatives have expanded digital filing, enhanced IP awareness programs, and strengthened anti-piracy efforts.

10. TRIPS Compliance and Policy Evolution

To comply with TRIPS, India introduced significant legislative reforms including Notable amendments include:

- Introduction of product patents in pharmaceuticals and chemicals (post-2005)
- Extension of patent term to 20 years from filing date
- Strengthening examination and opposition procedures
- Incorporation of safeguards like compulsory licensing to protect public health

India's intellectual property framework represents a dynamic balance between fostering innovation and protecting public interests while adapting to global trade obligations. The patent system, foundational to IP rights, rewards innovation through exclusive commercial rights while carefully excluding inventions detrimental to society. Supported by a robust administrative infrastructure and evolving legislative reforms, India's IP regime continues to underpin the nation's technological advancement, cultural vitality, and economic growth.

11. Indian Law on Patents

The law governing Patents in India is the Patent Act, 1970 as amended in the years 1995 and 1999, along with the patent rules, 1972. Patent Act do not define the term '*Patent*' [s.2 (m)], it simply states that '*Patent*' means a patent granted under this Act and includes for the purposes of sections 44, 49, 50, 51, 52, 54, 55, 56, 57, 58, 63, 65, 66, 68, 69, 70, 78, 134, 140, 153, 154 and 156 and Chapter XVI, XVII & XVIII, and a Patent granted under the Indian Patents and design Act, 1911 (2 of 1911); the Patents (Second Amendment) Bill, 1999 states that "Patent means a patent granted under this Act".

Patent Act 1970 envisages that '*any invention*' that has a commercial application and which are not exempted under the Act are eligible for grant of patent. S.2 (j) the Act defines 'invention' as:

Any new and useful –

1. Art, process, method or manner of manufacture;
2. Machine apparatus or other Articles;
3. Substance produced by manufacture, and includes any new and useful improvement of any of them, and an alleged invention.

12. The Second Amendment Bill, 1999: Major Changes and Implications

The Second Amendment Bill of 1999 brought significant and impactful changes to the

Indian Patents Act, 1970, particularly refining the definition of “invention” and modifying key provisions concerning patentability and the rights conferred by a patent.

The Bill introduced a new, clearer definition of “invention,” replacing the more general definition of the 1970 Act. Under clause 2(j) of the 1999 Bill, an invention is defined as “a new product or process involving an inventive step and capable of industrial application.” This modernized formulation aligns more explicitly with international standards, emphasizing novelty, inventiveness, and industrial applicability as the core requirements for patentability.

Section 3 of the Patents Act addresses the types of inventions that are not patentable. The Second Amendment Bill proposed important modifications to this section, especially focusing on expanding the grounds for exclusion to incorporate concerns about morality, public health, and environmental protection.

Specifically, the Bill amended clause (b) of Section 3. The original provision prohibited patenting inventions whose primary or intended use would contravene law or morality or be injurious to public health. The Bill broadened this language by adding that inventions whose “primary or intended use or commercial exploitation” could be contrary to law or morality or could cause serious prejudice to human, animal, or plant life, health, or the environment would also be non-patentable (clause 3(a) of the Bill). This adjustment recognizes the environmental and safety implications of inventions, reflecting a more comprehensive approach to public welfare.

Another significant amendment lies in clause 3(b) of the Bill, which adds to the non-patentable category any “discovery of any living thing or non-living substance occurring in nature.” This closes loopholes where natural substances, previously considered non-patentable, might have been patented if presented as discoveries without sufficient modification.

In contrast, the Bill proposed the omission of section 3(g) of the original Act, which excluded from patentability certain testing processes used to improve machinery efficiency during manufacturing. The rationale for removing this clause relates to the shift in policy to better accommodate technical advancement through process patents.

Furthermore, the Bill made clear exclusions for mathematical methods, business methods, computer programs, and algorithms (clauses 3(j) to 3(o)). These provisions seek to prevent “patenting” of abstract ideas and methods that traditionally fall outside the scope of patent law due to their intangible nature.

Clause 3(j) particularly excludes plants and animals other than micro-organisms, whether whole or in parts such as seeds or species, including essentially biological processes for their production or propagation, from patent protection. This safeguards biodiversity and traditional agricultural practices from excessive privatization while providing patent protection for micro-organisms relevant to industrial innovation under certain conditions. Clause 3(m) excludes “mere schemes or rules or methods of performing mental acts or playing games,” further emphasizing the non-patentable nature of abstract human activities.

13. Term of a Patent

Regarding the duration of patent protection, Section 53 of the Patents Act governs the patent term. A standard patent remains in force for 14 years from the date of filing, contingent upon the timely payment of renewal fees. However, for patents related to food, medicine, or drugs, the term is shorter: it lasts either 5 years from the date the patent is granted or 7 years from the date of patent filing, whichever period is shorter. This differential term considers public health concerns and access to essential medicines.

Table 2. Indian Patent Act 1970

Features	Description	Examples / Highlights
1. General Principle of Patent Grant	a. Patents are granted to encourage inventions and ensure their commercial use in India. b. Not granted merely for import monopolies.	Promotes <i>Make in India</i> rather than <i>Import Monopoly</i> .
2. Principle of National Treatment	Foreigners can apply for and obtain patents in India without restrictions.	Ensures global participation in Indian innovation.
3. Inventions Not Patentable	Not allowed if: i. Frivolous / against natural laws ii. Against law, morality, or public health iii. Mere discovery of principle/abstract theory iv. New use of a known substance/ process without novelty v. Mere admixture without new properties	<i>Example:</i> Discovering that salt dissolves faster in warm water is not patentable. <i>Example:</i> A farmer's ploughing method is not patentable.

	vi. Simple rearrangement of known devices vii. Process for testing/manufacturing efficiency viii. Agricultural/ horticultural methods ix. Medical/surgical/ curative treatments of humans, animals, or plants	
4. Search for Novelty	Patent search must include global prior publications, not just Indian records.	Prevents granting patents for already existing inventions abroad.
5. Patentability in chemicals, Food & Drugs	Only methods/ processes of manufacture are patentable, not the final product.	A new process to synthesise aspirin is patentable. An aspirin tablet itself is not patentable.
6. Term of Patent	General inventions: 14 years; Food, drugs, medicines: 7 years from filing or 5 years from sealing (whichever is shorter).	Highlights stricter control in sensitive sectors (health, food).
7. Licensing Provisions	Compulsory License: After 3 years, others can apply to use the patent. License of Right: In the food, drug, medicine, and chemical sectors → after 3 years, any person can use it as a matter of right.	Ensures affordable access to essential goods.
8. Royalties	For food, drug, medicine patents → royalty to patentee cannot exceed 4% of net ex-factory bulk sale price.	Keeps medicine prices affordable.
9. Use by Government	Govt. can use patented inventions to avoid scarcity and control prices.	Ensures public welfare over monopoly.
10. Appeals	All appeals are handled only by the High Court.	Provides judicial oversight and accountability.

14. Rights of the Patentee

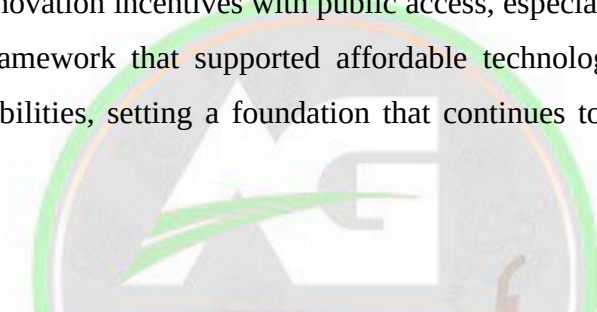
The Patents Act grants exclusive rights to the patentee, their agents, or licensees to make, use, exercise, sell, or distribute the patented invention within India. When the patent concerns a product (an article or substance), these exclusive rights extend to the manufacture, use, sale, or

distribution of that product. For process patents (methods or processes to manufacture an article or substance), the rights include exclusive use or exercise of the process within India. These protections enable innovators to commercially exploit their inventions while preventing unauthorized use, thus incentivizing further research and development.

15. Illustrative Case: India as the “Pharmacy of the Developing World”

India’s restrictive product patent regime enabled domestic pharmaceutical firms to develop low-cost generic medicines, significantly increasing access to essential drugs worldwide. This approach was critical during the HIV/AIDS crisis when affordable antiretroviral drugs produced in India were distributed globally. India’s pre-TRIPS patent policy was a deliberate strategy to transform the patent system into a development-oriented tool.

By balancing innovation incentives with public access, especially in critical sectors, India carved out a robust framework that supported affordable technology diffusion and nurtured domestic research capabilities, setting a foundation that continues to influence its evolving IP landscape.



INTEGRATED DISEASE MANAGEMENT: A SMARTER WAY TO PROTECT CROPS

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***Saswat Das and Dr. Rini Pal**2nd Year, M.Sc. (Ag) Plant Pathology, College of Agriculture, OUAT, BBSR, Odisha, India

Senior Scientist (Plant Pathology), AICRP on Rice, RRTTS, OUAT, Chiplima, Odisha, India

*Corresponding Author: Saswat Das

Abstract

Integrated Disease Management (IDM) is a sustainable, science-based approach that integrates cultural, biological, genetic, physical, and judicious chemical methods to keep plant diseases below economically damaging levels. Rather than relying on a single control tactic, IDM considers plant nutrition, physiology, host resistance, environmental conditions, and economic feasibility, with strategies adapted to local agro-ecosystems. Its success depends on accurate disease identification, understanding of pathogen and host biology, regular monitoring, use of economic thresholds, and evaluation of management outcomes. IDM has evolved from traditional and chemical-based practices into a modern, holistic system focused on sustainability and resilience. Today, its effectiveness is enhanced by advances in pathogen biology, reliable biocontrol agents, improved fungicide resistance management, and the integration of precision agriculture, digital disease surveillance, and climate-smart practices, making IDM a robust and future-ready disease management strategy.

What is Integrated Disease Management (IDM)?

Integrated Disease Management (IDM) is a sustainable, science-based approach to plant disease control that combines cultural, biological, genetic, physical, and chemical methods to keep diseases below economically damaging levels (FAO, 2020). It is better viewed as a **comprehensive management strategy** rather than a simple approach to controlling pests or diseases. It is a **multidirectional methodology** that integrates plant-related traits such as nutrition, physiology, host resistance, and economic considerations (Colmenarez et al., 2016).

The different methods are used according to the needs, suitability and applicability of the region and the farmer.

For the success of an integrated management programme, we need to undertake various measures such as identifying disease pest and the harm they cause, comprehending the biology of the pest and the host, conducting routine monitoring, developing economic thresholds to take necessary action, choosing suitable combinations of management techniques, and assessing the results (Abbas et al., 2022).

History of IDM

1. Ancient and Traditional Era (Pre-1900s)

- **2500 B.C.:** Sumerians used sulfur compounds to control insects and mites.
- **1500 B.C.:** Chinese records described cultural controls, such as manipulating planting dates.
- **300 A.D.:** First recorded use of biological control in China, using predatory ants in citrus orchards.
- **1755:** Tillet used common salt (brining) to control wheat bunt.
- **1882:** Millardet discovered **Bordeaux mixture** (copper sulfate and lime) to control grapevine downy mildew, marking a major milestone in chemical disease management.
- **Late 1800s:** Outbreaks like the Irish Potato Famine (1840s) spurred the development of plant pathology as a formal discipline. ★ ★ ★ ★ ★

2. Scientific Foundation and Chemical Era (1900–1960s)

- **1900–1930s:** Systematic research began on non-chemical approaches like sanitation and crop rotation.
- **1929:** Wetzel first classified disease control principles into four categories: **exclusion, eradication, protection, and resistance**.
- **1930s:** Introduction of synthetic organic compounds for pathogen control.
- **Post-WWII:** Rapid adoption of broad-spectrum synthetic pesticides (like DDT) led to nearly 100% reliance on chemicals for a period.
- **1959:** Stern et al. introduced the concept of "**Integrated Control**", combining biological and chemical methods based on economic thresholds.

3. Emergence of the Integrated Paradigm (1960s–1980s)

- **1962:** Rachel Carson's ***Silent Spring*** raised global awareness of pesticide pollution,

driving a shift toward ecological disease management.

- **1968:** The National Academy of Sciences (NAS) expanded disease management principles to include **avoidance and therapy**.
- **1972:** The term "**Integrated Pest Management**" (IPM) was formalized by the U.S. Council on Environmental Quality, providing the conceptual framework for IDM.
- **1976:** The IPM concept was fully refined at the XV International Congress of Entomology, moving from "control" to "management".

4. Modern IDM and Technological Integration (1990s–Present)

- **1990s:** Widespread adoption of transgenic crops (e.g., virus-tolerant squash in 1994).
- **Late 20th Century:** Focus shifted to holistic agro-ecosystem management, integrating host resistance, bio-control agents, and **precision** chemical use.
- **2020s (Current Trends):** IDM now incorporates digital and precision tools, including:
 - **Genomic Tools:** Using CRISPR for molecular breeding of broad-spectrum resistant cultivars.
 - **Precision Agriculture:** Use of AI, drones, and remote sensing for early disease detection and localized treatment.
 - **Nanotechnology:** Development of nano-fungicides for targeted, lower-toxicity delivery.

Components of IDM

- ❖ **Cultural practices** (inoculum reduction and prevention): It means making the crop less available, less attractive, less edible for the pest (Abbas et al., 2022). Crop rotation, timely sowing, appropriate plant spacing, residue management, and irrigation timing are examples of practices that alter the environment to make it less conducive to pathogens and lessen carryover between seasons (Sahane & Shivay, 2021; Ahmed et al., 2024).
- ❖ **Host-plant resistance:** The most economical part of IDM is frequently cultivating resistant or tolerant varieties; when paired with other strategies, even partial resistance can significantly slow outbreaks (Islam et al., 2024; Ahmed et al., 2024).
- ❖ **Biological control:** Biocontrol agents (BCAs) like *Trichoderma spp.*, *Bacillus spp.* and beneficial rhizosphere microbes can suppress soil- and foliar pathogens and promote plant health when properly formulated and deployed (Sahane & Shivay, 2021). Their use is environment friendly, but control is gradual.

- ❖ **Physical or mechanical control:** These methods prevent the pathogen from reaching the host by creating an unfavourable environment for it. Mechanical methods include burning, screens and barriers, trapping devices, the use of hand and bag nets, sanitation, hand picking/manual removal etc. Physical techniques include temperature, sound, refrigeration, removal of pathogen sources, hot water treatment and radiation (Katan, 2000)
- ❖ **Judicious, targeted chemical use.** Fungicides and bactericides are retained as strategic tools in IDM but applied only when monitoring and thresholds indicate need, using recommended rates and rotating modes of action to slow resistance evolution (Islam et al., 2024; Yin et al., 2023).

Why IDM is more effective at present times?

- Improved knowledge of pathogen biology, epidemiology, and host-pathogen interactions has made IDM more successful today by enabling more accurate timing and integration of management techniques (Yin et al., 2023).
- Biological control agents have become more dependable and effective at the field level thanks to improvements in strains, formulations, and delivery systems of microbes like *Bacillus* and *Trichoderma* (Kumar et al., 2023; Yao et al., 2023).
- IDM-based strategies are more sustainable than sole chemical control because increased knowledge of fungicide resistance mechanisms has encouraged prudent chemical use, resistance monitoring, and rotation of modes of action (Yin et al., 2023).
- Additionally, the preventive and predictive elements of IDM under changing climatic conditions have been reinforced by the increased focus on soil health, climate-smart agriculture, and digital disease surveillance tools (FAO, 2020; Shahane & Shivay, 2021).

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LEAFY SEADRAGONS – A LIVING MASTERPIECE OF THE OCEAN

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S.J Evengelin Hepzibah Mariam¹, D.Manimekalai², V.Visitha¹, S.Kavi Revanth¹

¹Department of Aquatic Environment Management, Tamil Nadu Dr.J.Jayalalithaa Fisheries University, Fisheries College and Research Institute,Thoothukudi, Tamil Nadu, India

²Assistant Professor and Head i/c,Department of Aquatic Environment Management,Tamil Nadu Dr.J.Jayalalithaa Fisheries University,Fisheries College and Research Institute,Thoothukudi

*Corresponding Author: S.J Evengelin Hepzibah Mariam

Abstract

The leafy seadragon (*Phycodurus eques*) is one of the most visually striking and unique marine creatures inhabiting the temperate coastal waters of Australia. Often described as an “ocean masterpiece,” it possesses elaborate leaf-like appendages that provide exceptional camouflage, allowing it to blend seamlessly into kelp beds and seagrass meadows. This remarkable adaptation enables predators to pass by without detection. This article highlights the evolutionary adaptations of the leafy seadragon, with particular emphasis on its morphology, habitat preference, feeding ecology, and distinctive reproductive behaviour. In addition, the ecological importance of the species and the major threats it faces are discussed.

Keywords: Leafy seadragon; Camouflage; Mimicry; Marine conservation

Introduction

The leafy seadragon (*Phycodurus eques*) is one of the ocean’s most unusual and visually captivating creatures. Belonging to the family Syngnathidae, which includes seahorses and pipefishes, it is renowned for the leaf-like appendages that cover its body and allow it to mimic drifting seaweed. These appendages enable the animal to blend effortlessly into kelp forests and seagrass beds as it moves with ocean currents. Endemic to southern Australia, leafy seadragons are commonly found among seagrass meadows and rocky reefs. Despite their relatively small size, they play an important role in maintaining local marine ecosystem balance.

Popularly known as “leafies,” they are the marine emblem of South Australia and are a major focus of regional marine conservation efforts.

LEAFY SEADRAGONS

Morphology



Adult leafy seadragons are typically green to yellowish-brown in colour, often marked with thin bands or stripes across the body. They can reach lengths of up to 35 cm, making them relatively large compared to pipefishes. Transparent dorsal and pectoral fins provide gentle propulsion, allowing slow and nearly silent movement.

Leafy seadragons lack caudal and pelvic fins. Their body colour may vary depending on habitat, ranging from greenish to dull gold or tan. Instead of scales, they possess a rigid exoskeleton composed of bony plates with pointed spines that offer protection. The small head bears a long, tubular snout that functions like a vacuum, enabling the animal to suck in small prey. They also possess unique circular gill openings with tufted gills.

Habitat and Distribution

Leafy seadragons inhabit rocky coastal waters at depths of approximately 20–25 m and rarely venture beyond 50 m. They are commonly observed drifting among kelp blades and clumps of *Sargassum*, which they closely resemble. They are also found near piers and jetties sheltered by seaweed growth, as well as in areas with rocky substrates and sandy patches.

They are frequently associated with seagrasses such as *Amphibolis antarctica* and *Posidonia* species, as well as brown algae and kelps including *Ecklonia radiata*, *Macrocystis angustifolia*, and several *Cystophora* species. Leafy seadragons spend more time over *Posidonia* seagrass compared to other seagrasses or kelps. This species is endemic to the temperate waters of southern Australia and is most commonly found off the coasts of South Australia, southern Western Australia, and western Victoria, particularly around locations such as Rapid Bay and the Fleurieu Peninsula.

Feeding Ecology

Leafy seadragons feed by sucking prey into their small mouths using their elongated, pipe-like snouts. They lack both teeth and a stomach, feeding primarily on mysid shrimp, as well as other small crustaceans, plankton, and larval fishes. Mysid shrimp, their preferred prey, feed on red algae that grow in shaded kelp forest environments.

Leafy seadragons feed almost continuously while slowly moving across large areas in search of food. Prey is swallowed whole through suction created by expanding a joint in the lower snout, a mechanism similar to the action of a pipette.

Reproductive Biology

Leafy seadragons exhibit seasonal reproduction, breeding during the warmer months in the Southern Hemisphere. The breeding season typically begins in spring (October) and continues until late summer (February), coinciding with rising coastal water temperatures.

During courtship, females deposit approximately 250–300 bright pink eggs onto a specialized brood patch located on the underside of the male's tail. The male fertilizes and incubates the eggs for 6–8 weeks. During incubation, the egg colour gradually changes from bright pink to purple or orange.

Hatching occurs in small batches, with males assisting the process by shaking their tails and rubbing against seaweed or rocks. Hatchlings measure 4–7 mm in length and are fully independent at birth. Initially, they consume nutrients from the remaining egg capsule before feeding on small zooplankton such as copepods and rotifers. As they grow, their diet shifts to juvenile mysids. Sea dragons typically reach 20 cm within one year and attain full maturity by two years of age.

Lifespan

Leafy seadragons are estimated to live between three and ten years, with an average lifespan of approximately six years for individuals that reach maturity. Only a small proportion of hatchlings survive beyond the early life stages, as juveniles are highly vulnerable to predation by fish, crustaceans, and sea anemones.

Camouflage and Mimicry

Leafy seadragons display colouration ranging from green and yellow to brown and red, closely matching their surrounding algae and kelp habitats. This background matching is the primary mechanism of camouflage, allowing them to remain nearly invisible among seaweed. In

addition to colouration, behavioural adaptations enhance camouflage. Leafy seadragons move slowly and gently, drifting with water currents in a manner that mimics the motion of seaweed. They often remain stationary for extended periods, further reducing the likelihood of detection by predators.

Leafy seadragons are also a classic example of masquerade mimicry, in which an organism resembles an inanimate object. Predators perceive them as floating or anchored seaweed rather than potential prey, allowing them to effectively “disappear” within their environment.

Threats to Survival

The primary threats to leafy seadragons include natural disturbances such as storms and increasing human pressures, particularly illegal collection for the aquarium trade. Unlike seahorses, leafy seadragons lack prehensile tails and cannot anchor themselves to kelp, making them vulnerable to strong waves that may wash them ashore.

Climate change is expected to increase the frequency and intensity of storms, exacerbating natural threats. However, illegal harvesting poses the greatest risk, as leafy seadragons are highly valued for their appearance and can fetch prices exceeding AU\$15,000 on the black market.

Conclusion

Phycodurus eques, commonly known as the leafy seadragon, is a remarkable marine species distinguished by its specialised morphology, unique reproductive strategy, and exceptional camouflage. Its close association with kelp and seagrass ecosystems highlights both its ecological importance and vulnerability to environmental change. Habitat degradation, climate change, and illegal collection underscore the urgent need for comprehensive conservation strategies to protect this iconic species.

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MADRAS PEA PUMPKIN (MUSUMUSUKAI KEERAI) BOON TO SIDDHA MEDICINE

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Dr.M. Venkatraman

Assistant Professor (Horti), School of Agricultural Sciences,
Dhanalakshmi Srinivasan University, Trichy, India

Introduction

Musumusukai Keerai (*Mukia maderaspatana*), a traditional Siddha medicinal herb, is highly valued for treating respiratory issues like chronic cough, asthma, bronchitis, and nasal congestion. It acts as an effective expectorant to expel phlegm, while also aiding digestion, reducing inflammation, and helping manage diabetes.



Musumusukai Keerai leaf and fruit

Key Health Benefits of Musumusukai Keerai

Respiratory Relief: Known as an excellent expectorant, it is widely used in Tamil Nadu to treat chronic colds, asthma, tuberculosis, and wheezing by removing phlegm from the respiratory tract.

Digestive Health: Its carminative and anti-inflammatory properties help reduce bloating, gas, indigestion, and acid reflux.

Anti-inflammatory & Pain Relief: It aids in reducing body pain, inflammation, and joint pain.

Other Benefits: It is used to manage high blood pressure, diabetes, vertigo, and toothaches. It is also considered beneficial for improving skin health and reducing wrinkles.



Nutrient Rich: The leaves are rich in vitamins, including ascorbic acid and phosphorus, providing strong antioxidant properties.

Common Uses

Dosage: Generally consumed as a decoction, soup, or in powdered form (mixed with water).

Precautions: While generally safe, it is advised to avoid giving this to children without professional advice, as it may affect metabolism.

It is best known for its effectiveness in removing stubborn, accumulated phlegm (*kōḷai*) during rainy seasons.

MANGROVES: GUARDIANS OF COASTAL ECOSYSTEMS

Article ID: AG-VO6-I01-19

V. Visitha ^{1*}, D. Manimekalai ², S. Kavi Revanth ¹, S. J. Evengelin Hepzibah Mariam¹

¹PG Scholar, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu

²Assistant Professor, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute,

Thoothukudi, Tamil Nadu, India

*Corresponding Author: V. Visitha

Abstract

Mangroves are intertidal habitats essential for preserving the health and balance of coastal areas. Commonly known as the “protectors of ecosystems “ mangroves shield shores from erosion, storm impacts and tidal forces while fostering rich biodiversity. These habitats function as nurseries and breeding sites for fish, crustaceans and various marine species supporting coastal fisheries and community livelihoods. Furthermore mangroves play a role, in combating climate change by sequestering carbon serving as important blue carbon reservoirs. Despite their ecological and socio-economic importance, mangrove ecosystems are under increasing threat from coastal development, aquaculture expansion, pollution, and climate change. This article highlights the ecological functions, ecosystem services, and conservation significance of mangroves, while emphasizing the need for sustainable management, community participation, and effective policy frameworks to ensure their long-term protection and resilience in the face of environmental change.

Keywords: Mangroves ,Intertidal habitats ,Coastal protection ,Biodiversity ,Conservation

Introduction

Mangroves are remarkable ecosystems that grow where land meets the sea in tropical and subtropical regions. They shelter a rich variety of plants and animals and are among the most

productive ecosystems on Earth. By providing safe nursery grounds for fish and prawns, mangroves support coastal biodiversity as well as the livelihoods of communities that depend on fishing, crabbing, and shellfish farming.

Mangroves help to protect our planet by storing carbon, improving water quality, and stabilizing shorelines. Their importance has gained global attention as part of nature-based solutions for sustainable development and climate adaptation. However, increasing industrial and urban activities now place these ecosystems under serious threat, with heavy metal pollution posing a growing risk to the long-term health of mangrove forests.

Unique characteristics of mangrove plants:

1) Specialized root adaptations that provide mechanical stability.

Mangrove roots change in form and depth depending on the species and the harsh coastal conditions they face—such as soft soils, constant waterlogging, strong winds, and wave action. To survive in these unstable environments, many mangroves grow visible, above-ground roots like prop and buttress roots that help keep the trees firmly anchored.

For example, species such as *Rhizophora mangle* and *R. Apiculata* use strong prop roots to stabilize themselves in loose mud. These roots not only hold the trees upright during tides and storms but also trap sediments, helping new soil to form and strengthening the coastline. Research shows that these root systems can even reduce the force of storm surges, acting as natural coastal barriers.

Other mangroves, including *Heritiera littoralis* and *Xylocarpus granatum*, develop broad buttress roots in response to wind stress. These roots provide extra support while also improving the movement and uptake of water and nutrients from surface soils. In contrast, mangroves growing on firmer, higher ground usually do not need such specialized root structures.

2) Anaerobic conditions:

Mangroves live in muddy, waterlogged soils where oxygen is scarce. To cope with this, they have evolved special roots that act like breathing systems, drawing oxygen from the air and delivering it to underground tissues. Some of this oxygen is used for respiration, while the excess leaks into the surrounding soil through tiny air spaces, a process known as radial oxygen loss. To avoid wasting too much oxygen, mangrove roots develop a protective outer layer that limits this leakage. When conditions become stressful—such as during long periods of flooding or

pollution—the roots strengthen this barrier. This adaptation helps mangroves carefully control gas and water movement, allowing them to survive in extreme, oxygen-poor environments.

3) Tidal inundation:

Mature mangrove trees survive in waterlogged, oxygen-poor soils by developing unique root systems that help them breathe. One of the most important of these is the pneumatophore—an upright, pencil-like root that grows above the soil from underground cable roots. Found in mangrove groups such as *Avicennia*, *Sonneratia*, *Bruguiera*, and *Xylocarpus*, pneumatophores are specially adapted to take in oxygen from the air.

When the tide is low, these exposed roots absorb atmospheric oxygen through tiny pores called lenticels. Inside, large air spaces allow oxygen to move down to submerged roots that would otherwise suffocate. In some species, these air spaces make up nearly half of the root's volume, allowing continuous oxygen supply by diffusion.

Pneumatophores have large air spaces and reduced conducting tissue to aid gas exchange. Their structure is shaped by salinity and flooding, with moderate salt favoring growth and high salinity limiting it. Early lignification and Casparian strips regulate water and salt movement, enabling mangroves to survive flooded, oxygen-poor, saline coastal environments.

4) Halophilic nature:

Mangrove ecosystems are made up of salt-tolerant plants (halophytes) that grow between land and sea, and salinity strongly influences their growth. While most mangrove species prefer moderate salinity, each has a different tolerance range, with some stressed by low salinity and others able to withstand very high salt levels. Importantly, many mangroves can also grow in freshwater, showing greater adaptability than once thought. In well-drained, nutrient-rich conditions, mangroves may even lack typical aerial roots, as seen in species like *Sonneratia*. Overall, mangroves show remarkable flexibility, allowing them to survive across diverse coastal environments and changing salinity conditions.

5) Salinity balance:

Mangroves thrive in salty intertidal zones by carefully managing salt in their cells. They use strategies like filtering salt, secreting it, or storing it in vacuoles to survive high salinity. Some species even accumulate salts to balance water and osmotic pressures, giving them a survival advantage.

Maintaining the right potassium-to-sodium balance is crucial, as too much sodium can harm cell proteins. Mangroves regulate this through specialized channels and transporters, moving excess sodium out of cells or into vacuoles. They also produce organic compounds like sugars, amino acids, and starch to maintain osmotic balance.

Additionally, some species conserve water, excrete excess salt, and use mucilage in xylem vessels to aid water transport. These combined strategies allow mangroves to survive and thrive in challenging, salty environments.

The Ecological and Protective Roles of Mangroves

1) Carbon accumulation:

Mangrove roots are the hidden strength of these forests. Growing in soft, muddy, and oxygen-poor coastal soils, mangroves invest heavily in their roots to stay firmly anchored and alive. In fact, roots can make up nearly half—or even more—of a mangrove’s total biomass.

These roots do more than hold trees in place. Because mangrove soils are waterlogged and low in oxygen, carbon stored in the roots breaks down very slowly. Over time, this carbon becomes locked into the soil as mangrove peat, turning mangrove forests into powerful long-term carbon sinks. Many mangroves store far more biomass below ground than above it, a unique trait compared to other forests.

Interestingly, much of this underground carbon comes from dead fine roots that decompose extremely slowly and accumulate in the soil. Beyond carbon storage, dense root systems create shelter and food for animals and help trap sediments, building soil and even expanding coastlines. In this way, mangrove roots quietly support both nature and climate from beneath the surface.

2) Microbial Communities in Mangrove Ecosystems:

Mangrove roots are the hidden strength of these forests. Growing in soft, oxygen-poor soils, they provide strong anchorage and can make up nearly half or more of a mangrove’s total biomass. Because waterlogged soils slow decomposition, carbon stored in roots accumulates as mangrove peat, making these forests powerful long-term carbon sinks. Dead fine roots contribute greatly to below-ground carbon storage. In addition, dense root systems trap sediments, support wildlife, and help build and stabilize coastlines, quietly benefiting both ecosystems and climate.

3) Nursery Grounds for Fisheries and Marine Life

Mangroves serve as vital nurseries where dense root systems provide a safe shelter for

young fish to survive and grow away from large predators like sharks and rays. While some species like gobies live there year-round, many reef fish—including snappers, jacks, and the endangered Goliath grouper—utilize these habitats as juveniles before migrating to deeper waters. Seasonal shifts also influence this environment, with the rainy season bringing in freshwater species like gar while pushing some marine fish offshore.

4)Role of mangroves in coastal protection:

While tsunamis transform into powerful surges in shallow water, mangroves have a limited ability to reduce their height or force. Field studies show that massive waves can uproot and wash away entire forests, sometimes across widths exceeding 500 meters. Consequently, mangroves are not reliable barriers on their own; however, they save lives primarily by acting as a buffer zone that keeps human construction and communities further inland.

5)Mangroves as a biodiversity hotspot

Mangroves are highly productive ecosystems where land and sea meet, providing sheltered nurseries for fish, crabs, and other marine life that support coastal fisheries. They also support diverse terrestrial and aerial species, including insects, reptiles, mammals, and migratory birds. Despite harsh conditions, many organisms have adapted to survive in mangroves. By linking land, rivers, and oceans, mangroves sustain rich biodiversity and are vital to healthy coastal ecosystems.



Mangroves as a biodiversity hotspot

Socio-economic importance of mangroves:

Mangroves are vital to the livelihoods of millions of people, providing food, fuel, income, and significant economic value. Coastal communities often depend directly on mangroves, as seen in Brazil's Caeté estuary, where fishing, crab harvesting, and mangrove

wood support most families. Mangrove crabs alone sustain over half the population through harvest and trade. While overuse has damaged forests in many areas, examples like Malaysia's Matang Mangroves show that sustainable management can balance livelihoods and conservation. Protecting mangroves is essential to ensure these benefits continue for future generations.

Management and conservation:

Mangrove forests are highly valuable coastal ecosystems in tropical and subtropical regions. They support rich biodiversity, sustain fisheries, provide livelihoods, and contribute to local economies. However, increasing human activities such as urbanization, pollution, aquaculture, and deforestation have caused major mangrove loss, with about 35% disappearing in the late 20th century. Today, gradual degradation threatens the ecosystem services mangroves provide. Raising public awareness through education is essential, as understanding their role in coastal protection, biodiversity conservation, and carbon storage can encourage stronger support for mangrove conservation and benefit coastal communities.

Conclusion

Mangroves are vital ecosystems that support biodiversity by providing habitat and nursery grounds for many species. They also protect coastlines by storing carbon, reducing wave energy, preventing erosion, filtering pollutants, and supporting fisheries. However, human activities are rapidly destroying mangroves, threatening these benefits. Conserving and sustainably managing mangroves is essential to protect nature, coastal communities, and future generations.

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MARINE SNOW - THE HIDDEN RAIN OF THE OCEANS

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S. Kavi Revanth^{1*}, V. Rani², D. Manimekalai³, S.J. Evengelin Hepzibah Mariam¹,
V. Visitha¹

¹Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu

²Dean i/c, Dr. M. G. R. Fisheries College and Research Institute, Thalainayeru, Tamil Nadu.

³Assistant Professor and Head i/c, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu.

*Corresponding Author: S. Kavi Revanth

Abstract

Marine snow consists of dead phytoplankton, fecal pellets, mucus, bacteria, and mineral particles. It serves as the primary food source for deep-sea life and contributes to carbon sequestration through the biological carbon pump. This article explores its formation, composition, ecological significance, seasonal patterns, research methods, and climate change impacts.

Keywords: Marine snow, Particulate Organic Matter, Carbon Pump, Seafloor

Introduction

Marine snow is a continuous rain of small organic and inorganic particles that moves from the ocean surface to deeper waters. It plays a key role in marine ecosystems and global carbon cycles. Beneath the ocean's surface, marine snow forms a continuous, invisible rain of organic and inorganic particles drifting from sunlit surface waters to the dark depths. This process connects the productive upper ocean with the nutrient-poor deep sea, forming a critical part of the ocean's food web. Marine snow supports microbial communities, feeds deep-sea animals, and removes carbon from the atmosphere via the biological carbon pump.

What Is Marine Snow ?

Marine snow refers to a steady rain of microscopic particles sinking through the ocean's water column. It includes dead plankton, feces and mucus from macroorganisms, bacterial colonies, mineral particles, and debris. These microscopic particles aggregate into larger, snowflake-like flakes that vary in size, shape, and composition based on their origin and environment. Marine snow acts as food, habitat for microbes, and a vehicle for transporting carbon and nutrients to the deep sea.



Microscopic view of Marine Snow



Marine snow falling into the deep abyss

Components of Marine Snow and Their Ecological Roles

Component	Source	Ecological Function
Dead phytoplankton	Photic zone blooms	Primary organic carbon source
Zooplankton fecal pellets	Grazing zooplankton	Rapid carbon transport to depth
Mucus (salps, larvaceans)	Gelatinous plankton	Particle aggregation & fast sinking
Bacteria & microbes	Colonization of particles	Decomposition & nutrient recycling
Mineral particles	River runoff, dust	Increases density and sinking speed
Microplastics (increasingly)	Anthropogenic input	Alters sinking behavior, pollutant transport

Formation Process

Marine snow primarily originates in the sunlit photic zone, where phytoplankton perform photosynthesis. Dying plankton release sticky compounds that cause particles to clump together. Zooplankton grazing produces fast-sinking fecal pellets that collect other particles. Mucus from gelatinous animals like salps and larvaceans, bacterial secretions, and mineral particles from

river runoff also contribute. These processes create a vital link between surface production and deeper waters.

Sinking Mechanism

Marine snow sinks at rates determined by particle size, density, and biological activity. Denser aggregates with minerals or fecal pellets sink faster than loose, fluffy ones. Microbes decompose organic matter during descent, releasing nutrients while some particles fragment and slow down. A fraction reaches the seafloor, sustaining deep-sea communities and forming a biological bridge between surface productivity and the abyss.

Factor	Effect on Sinking	Mechanism
Particle size	Larger = faster	Higher mass and drag balance
Mineral ballast	Faster sinking	Increases density
Fecal pellet content	Faster sinking	Compact structure
Microbial degradation	Slows sinking	Fragmentation and mass loss
Turbulence	Variable	Can break or aggregate particles

Microbial Communities

Each marine snow particle hosts a dynamic microbial ecosystem of bacteria, fungi, protozoa, and viruses that decompose organic matter. This activity breaks down complex compounds into simpler molecules, recycling nutrients like nitrogen, phosphorus, and iron. Microbial processes vary with depth, particle age, and conditions, transforming marine snow into a mobile micro-ecosystem.

Food for Deep-Sea Life

In lightless deep-sea environments, marine snow provides the main food source. Benthic organisms such as sea cucumbers, brittle stars, amphipods, polychaete worms, and microbes depend on these particles for organic carbon and nutrients. Higher predators benefit indirectly through sustained food webs. In some areas, deposits create nutrient hotspots that support scavengers and filter feeders, highlighting marine snow's role in deep-sea biodiversity.

Role in Carbon Pump

Marine snow drives the biological carbon pump by transporting photosynthetically fixed carbon from surface phytoplankton to the deep ocean. This sequesters atmospheric CO₂ for

centuries, often via burial in sediments. Understanding marine snow dynamics is essential for predicting ocean responses to climate change and global carbon levels.

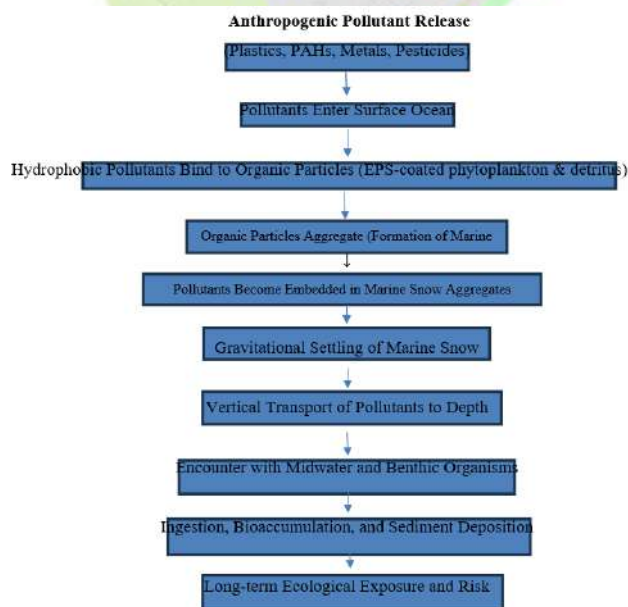
Variations

Marine snow production follows phytoplankton blooms, creating seasonal pulses that fuel deep-sea food supply. Polar regions show dramatic variations due to ice dynamics, while tropical areas have steadier flows. Coastal zones experience boosts from nutrient runoff and upwelling. These patterns influence deep-sea feeding, reproduction, and ecology.

Region	Pattern	Ecological Impact
Polar oceans	Strong seasonal pulses	Feeds benthic fauna after blooms
Temperate oceans	Spring and fall peaks	Supports seasonal reproduction
Tropical oceans	Continuous low-level flux	Stable deep-sea food supply
Coastal zones	High and variable	Influenced by runoff and upwelling

Marine Snow as a Vector for Pollutant Transport

Marine snow serves as a vector for the vertical transport of pollutants by adsorbing microplastics, hydrophobic organic contaminants, and trace metals onto its sticky organic surfaces. As these aggregates sink, attached pollutants are transferred from surface waters to the mesopelagic and benthic zones, increasing bioavailability to deep-sea organisms and promoting trophic transfer. A fraction of these contaminants ultimately accumulates in sediments, linking surface pollution to long-term deep-sea ecosystem exposure.



Research Methods

Studying marine snow challenges traditional sampling due to its fragility and deep-sea location. Sediment traps capture sinking particles over time. Underwater cameras, optical counters, submersibles, ROVs, and AUVs with laser imaging provide in-situ data on size, composition, and microbial activity, advancing knowledge of its dynamics and carbon role.

Method	What it Measures	Advantage
Sediment traps	Particle flux	Long-term quantification
Optical imaging	Size and abundance	Non-destructive
ROVs/AUVs	In-situ observation	Real-time deep-sea data
Laser particle sensors	Particle size spectra	High precision
Molecular tools	Microbial communities	Biogeochemical insight

Climate Impacts

Climate change alters marine snow through warmer waters that speed microbial decay, reducing sequestration. Ocean acidification affects shell-forming plankton, changing particle density and sinking rates. Shifts in circulation, stratification, nutrients, and oxygen levels disrupt production and microbial communities, threatening deep-sea life and climate regulation.

Conclusion

Marine snow sustains deep-ocean ecosystems and regulates Earth's climate via the biological carbon pump. As climate change intensifies, protecting this process through research is vital for ocean health and planetary carbon balance.

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MICROPLASTICS IN INDIAN AGRICULTURE: A HIDDEN THREAT FROM DRIP IRRIGATION AND PLASTIC MULCHING

Article ID: AG-VO6-I01-21**Sushmitha R*****B. Tech Energy and Environmental Engineering, AEC & RI, TNAU, Coimbatore -03*****Corresponding Author: Sushmitha R**

Abstract

Contemporary agricultural practices such as drip irrigation and plastic mulching are widely praised for improving crop yields and resource efficiency in Indian farming systems. However, these methods also contribute to a largely unnoticed problem: the accumulation of microplastics in farmland soils across regions such as Tamil Nadu, Maharashtra, and peri-urban areas. Exposure to sunlight and mechanical stress causes agricultural plastics to fragment into micro- and nanoplastics. These particles can be absorbed by plant roots and transported through vascular tissues to edible parts like fruits and leaves. This soil-to-food transfer raises concerns about food safety and potential long-term health effects, including inflammation and endocrine disruption. Addressing this emerging issue requires sustainable alternatives such as truly biodegradable mulch films and effective filtration of irrigation water to limit microplastic entry into Indian agroecosystems.

Keywords: Microplastics, drip irrigation, plastic mulching, food chain, human health, agri-solutions, Indian agriculture

Introduction

Agriculture, the backbone of global food security, continuously adopts new technologies to improve productivity and conserve resources. In India, where over half the population depends on farming, such innovations are essential to address water scarcity and yield limitations across diverse agroclimatic zones. Drip irrigation and plastic mulching have become widely adopted due to their benefits in water efficiency, weed control, and yield improvement, particularly in high-value crops such as vegetables, bananas, and strawberries. However, alongside these

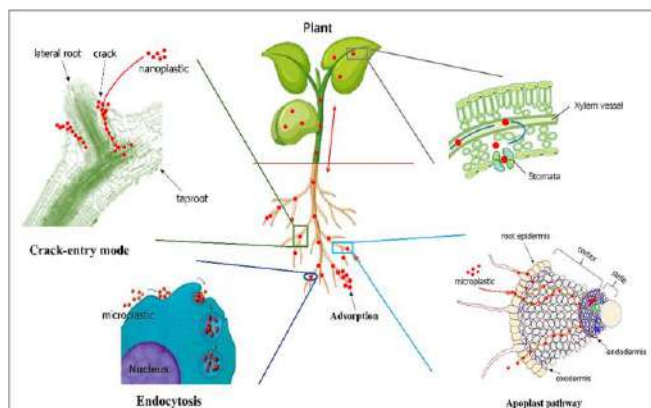
benefits lies a growing but often overlooked environmental concern: the accumulation of microplastics in agricultural soils. This article examines this emerging challenge by tracing how agricultural plastics degrade, how microplastics move within plants, and how they ultimately enter the food chain. Once associated mainly with oceans, microplastic pollution is now increasingly recognized as a terrestrial issue, with agriculture identified as a significant yet under-studied contributor. By linking farm efficiency with environmental responsibility, this article highlights the hidden costs of plastic-dependent farming practices in Indian crop systems and peri-urban agriculture.

The "Perfect" Farm's Hidden Flaw

Modern farms often symbolize efficiency, particularly in India's intensive vegetable and fruit production systems. Fields of vegetables, fruits in states like Tamil Nadu and Maharashtra showcase rows of healthy crops, with precisely calibrated drip irrigation systems delivering water directly to plant roots and expansive plastic mulch films conserving moisture and inhibiting weed growth. These practices, supported by government schemes in Punjab, Haryana, Maharashtra, and Tamil Nadu, have revolutionized vegetable and fruit cultivation, especially in polyhouse farming, enhancing water efficiency and reducing labor while boosting yields. Yet this success hides an environmental cost. Pipes, mulch films, and greenhouse coverings gradually degrade and release microplastics into soil. In regions with extensive plastic use, research on soil contamination from drip irrigation remains limited despite its widespread adoption. This creates a paradox: practices intended to improve sustainability in water and yield management inadvertently contribute to long-term soil pollution. The issue is intensified in peri-urban areas near cities such as Bengaluru and Bhopal, where recycled wastewater introduces additional microplastics from urban sources.

From Macro to Micro: The Breakdown Mechanism

Agricultural plastics degrade under continuous exposure to sunlight, heat, and mechanical stress. Ultraviolet radiation weakens polymer structures, while tillage, machinery movement, wind, and rainfall accelerate physical breakdown. Over time, large plastic materials fragment into microplastics (less than 5 mm) and nanoplastics. Studies show that polyethylene mulch films can begin fragmenting within months, especially when not fully removed after harvest. Irrigation water further contributes to contamination, particularly when sourced from surface water or treated wastewater.



The Unseen Journey: Plastic Translocation in Plants

Once present in soil, microplastics and nanoplastics can enter plants and move into the food chain. Research indicates that small plastic particles can enter plant roots through natural openings, newly emerging lateral root sites and damaged root zones, through "crack-entry" mechanisms. After entry, these particles may be transported through xylem and phloem tissues along with water and nutrients. This movement allows microplastics to accumulate not only in roots but also in stems, leaves, and fruits. Evidence from food crops such as wheat, lettuce, tomato, brinjal, and chilli suggests that edible plant parts can contain plastic particles. In Indian systems using drip fertigation and plastic mulching, this internal transport highlights a direct pathway from soil contamination to human consumption.

Implications for Human Health and Food Safety

The presence of microplastics in food raises important food safety concerns. Microplastics can carry chemical additives and adsorbed pollutants, which may be released during digestion. Human exposure is already widespread, with microplastics detected in water, salt, honey, sugar, and other commonly consumed items. Studies suggest that ingested microplastics may trigger inflammatory responses, disrupt endocrine function, and potentially affect reproductive health. While long-term effects are still under investigation, detection of microplastics in human tissues highlights the urgency of addressing this soil-to-food pathway.

Cultivating a Plastic-Free Future: Agri-Solutions

Reducing microplastic contamination requires preventive and practical solutions suited to Indian farming conditions. One promising option is the use of biodegradable mulch films (BDMs) as alternatives to conventional plastics. However, their degradation depends on soil

properties, climate, and material composition, and incomplete breakdown can still leave residues. Strong certification standards and continued research are therefore essential.

Irrigation water management is equally important. Since water can act as a carrier of microplastics, especially in peri-urban farms, filtration before irrigation can significantly reduce contamination. Policy support, farmer incentives, and investment in water treatment infrastructure are critical to prevent further accumulation and protect long-term soil and food quality.

Tiered Recommendations for Microplastic Management in Indian Agriculture

To make these solutions practical and accessible, we propose a tiered approach that distinguishes between immediate actions farmers can take and longer-term institutional responsibilities. This structure ensures realistic implementation, avoiding overly idealistic or expensive measures that may be unattainable for smallholder farmers.

What Farmers Can Do Now:

- **Proper Removal of Mulch Films:** Farmers should ensure complete and timely removal of plastic mulch films after harvest, especially in food crops.
- **Avoid Repeated Reuse of Degraded Pipes:** Drip irrigation pipes in peri-urban farms should not be reused beyond their recommended lifespan; farmers must replace worn-out sections promptly to minimize microplastic shedding during operation.
- **Simple Mesh Filtration for Irrigation Inlets:** Install low-cost, ISI-certified screen filters (e.g., 120-micron mesh) at the inlet of drip systems to trap sand, silt, and microplastics from recycled wastewater, protecting emitters and reducing soil contamination. These filters are durable, easy to maintain, and affordable for smallholders.

What Institutions Must Do:

- **Standards for BDM Certification:** Develop and enforce national standards for biodegradable mulch films (BDMs), similar to existing seed certification under NSC and PPV&FRA, to ensure they fully degrade in Indian soils without leaving residues. This would promote reliable alternatives for high-value crops.
- **Pilot Microplastic Monitoring in Agri Soils:** Launch government-led pilot programs, integrated with the ongoing soil health card initiative, to monitor microplastic levels in

agricultural soils across key regions like Coimbatore, Bhopal, and peri-urban Bengaluru. This data can inform policies on plastic use and wastewater reuse.

- **Policies for Sustainable Practices:** Enact policies mandating the phased reduction of single-use plastics in agriculture, incentivizing BDM adoption through subsidies, and regulating recycled wastewater use with mandatory filtration. These measures should align with India's broader waste management goals under EPR (Extended Producer Responsibility).

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NEW US TARIFFS REGIME AND ITS IMPLICATIONS FOR INDIAN AGRICULTURAL TRADE

Article ID: AG-VO6-I01-22**M. Prahadeeswaran**

Associate Professor (Agricultural Economics), Department of Agricultural Economics,
Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Abstract

The recent US tariff regime on Indian exports has plunged the bilateral trade relationship into a period of uncertainty in India's trade sector. Bilateral goods trade reached approximately \$131.84 billion in 2024-25, while the imposition of cumulative tariffs of up to 50 per cent on most Indian goods, beginning in mid-2025, marked a dramatic shift. This reciprocal action, largely justified by the US citing India's own high tariffs and geopolitical disputes over Russian energy purchases, targets key Indian exports. While non-agricultural sectors like textiles, gems, and leather faced an immediate crisis with sharp export declines, the agricultural trade was also significantly affected, threatening products like processed foods and dairy. However, a partial and selective rollback of tariffs on over 200 agricultural lines in November 2025, exempting items like tea, coffee, and spices has offered a modest relief. India's stance remains firm and a pursuit of diplomatic resolution, emphasizing the need for a reversal of the punitive duties to restore market predictability and protect rural livelihoods. This article explores the structure of the new tariffs, analyzes the differential impact on agricultural and non-agricultural trade, and assesses India's strategic response to this evolving trade challenge.

Key Words: US Tariffs, India-US Trade, Agricultural Exports, Reciprocal Tariffs, Bilateral Trade Agreement.

Introduction

Economic relationship between India and the United States has been characterized by growing trade, strategic cooperation and shared geopolitical objectives. Yet, this positive trajectory encountered a serious issue with the escalation of trade barrier in 2025. The US

introduced a new, aggressive tariff regime that fundamentally altered the market access dynamics for Indian goods. This article examines the structure and implications of this new tariff regime, focusing particularly on its differential impact on Indian agricultural trade, a sector critical for the livelihoods of millions in India. Imposition of high tariffs, reaching up to 50 per cent on certain goods, has introduced considerable friction.

The US has consistently been one of India's most significant trading partners. For the fourth consecutive year, it remained India's largest trading partner in the fiscal year 2024-25, with bilateral trade in goods valued at approximately \$131.84 billion. India's exports to the US stood at around \$86.5 billion, resulting in a substantial trade surplus for India, estimated at approximately \$45.7 billion in goods. Pharmaceuticals, precious stones and jewellery, electrical machinery, mechanical appliances, textiles, and leather products are the key non-agricultural exports to US. Major agricultural exports to US are processed foods, spices, tea, coffee, cashew nuts, and marine products. The economic significance of the US market for India is immense, as it accounts for about 18 per cent of India's total merchandise exports. This deep integration shows that any unilateral policy shift by the US has an immediate and profound effect on Indian exporters, supply chains and domestic employment in labor-intensive sectors.

The Old (Pre-2025) Tariff Structure

Before 2025 tariff escalation, the trade was governed by a standard structure. The US applied relatively low Most Favored Nation (MFN) duties on most Indian products, with many goods enjoying zero or minimal tariffs. India, on the other hand, maintained higher average tariffs, especially on agricultural imports, with an average simple tariff of 17 per cent and a trade-weighted average of 39 per cent for agriculture, while it was less than 10 per cent by US. This disparity was a long-standing point of contention for US.

The New (2025) Tariff Regime

The current tariff regime, implemented in phases in 2025, dramatically increased the cost for Indian exporters. The new structure consists of three main components:

Tariff Component	Date Effective (Approx.)	Rate on Goods (Cumulative)	Justification/Reason
Baseline Duty	April 2025	10%	General global tariff adjustment.
Reciprocal Tariff	August 2025	25%	Retaliation against India's high

			domestic tariffs and previous trade disputes.
Secondary Penalty Tariff	Late August 2025	50%	Additional punitive levy citing India's continued purchase of Russian crude oil and defence equipment.

This cumulative 50 per cent tariff for most non-exempted products made Indian goods among the most heavily taxed in the US market, surpassing those from China (around 30 per cent) and Japan (around 15 per cent). The U.S. justified its 2025 tariff hikes using Section 232 (National Security) and Section 301 (Unfair Trade).

Impact on Non-Agricultural Trade

The non-agricultural trade segments, which constitute the bulk of India's exports to the US, bore the immediate and most significant brunt of the 50 per cent tariff hike. The Global Trade Research Initiative (GTRI) reported that India's overall exports to the US dropped sharply by 28.5 per cent in the five months following the steep tariff hikes. Labor-intensive sector like textiles and apparel was among the hardest hit. Orders were reportedly redirected to competing nations like Vietnam and Bangladesh, where tariffs are significantly lower. Production centers in major textile hubs faced steep declines in turnover. Gems and Jewellery is another critical sector for employment, which saw margins severely squeezed, forcing exporters to offer deep discounts or seek alternative markets in the Gulf and Europe. Similar to textiles, leather and footwear dominated by Small and Medium Enterprises (MSMEs), saw its competitive edge eroded, leading to significant revenue losses and concerns over job security.

Significantly, the US exempted a few strategic sectors to safeguard its own supply chains and domestic consumer interests. India's generic drug industry, which supplies nearly 50 per cent of the US market, was exempted. The Nifty Pharma Index even saw positive gains, reflecting its insulated position. Similarly, semiconductors, energy resources and critical minerals were also exempted, which shows the US priority to secure key technological and energy supply lines.

Impact on Agricultural Trade

The agricultural sector, representing a smaller but socio-economically vital segment of

Indian exports, faced a complex and bifurcated impact. The initial 25 per cent reciprocal tariff, and subsequently the 50 per cent tariff, hit high-value agricultural exports. Processed foods and dairy, which tend to have relatively higher profit margins, became immediately less competitive due to the elevated landed costs, dampening the post-pandemic recovery for many smaller Indian producers and cooperatives. Traditional staples like certain spices, tea, and cashew nuts also became less attractive to US buyers, threatening India's agri-trade surplus.

The Partial Reprieve (November 2025)

In a significant development in November 2025, the US announced a partial rollback, exempting over 200 agricultural product lines from the reciprocal tariff regime. This move, driven in part by US concerns over rising domestic food prices and supply chain disruptions, offered relief for Indian staples. Commodities like coffee, tea, spices (including ginger, turmeric, and curry mixes), certain tropical fruits, fruit juices, and cocoa are exempted. This created a level playing field for these items, allowing Indian exporters to compete more effectively against rivals from Latin America and Southeast Asia. The Commerce Ministry projected gains, though marginal, as India's share in the US import basket for these exempted items is currently narrow.

Despite the exemptions, the fundamental challenges remain. India has almost no presence in the largest US agricultural import categories, such as tomatoes, citrus fruits, and most fresh fruits. Separately, the US has recently signalled fresh tariffs on Indian rice, alleging "dumping." Indian exporters, however, downplay the impact, noting that US demand for premium Basmati rice is niche and demand-driven by the diaspora, and any hike would primarily raise costs for American consumers.

India's Stand on Reversal Tariff

India's official stance on the new tariff regime is unequivocally against the measures, which it has strongly denounced as unfair, unjustified, and unreasonable. India has consistently used diplomatic channels to seek an early rollback of the tariffs, stressing that its foreign policy, including energy purchases from Russia, is based on strategic autonomy. Crucially, India has refrained from outright retaliation with commensurate tariffs on US goods, aiming to keep the door open for negotiation and prevent a full-blown trade war. India is currently engaged in protracted negotiations with the US on a two-track approach: a framework trade deal to immediately address the tariff issue and a comprehensive Bilateral Trade Agreement (BTA) for long-term cooperation. The goal is to secure the removal of the additional 25% "secondary

penalty tariff" and seek concessions on the "reciprocal tariff" through the BTA, with the aim of finalizing the first tranche of the agreement in the near future.

Indian policymakers argue that high tariffs on agricultural imports are a necessary shield to protect millions of small, vulnerable rural households from global price volatility, a core issue of food security and rural stability in India. The government has also been urged by trade think tanks to expedite the roll-out of export promotion missions and financial support schemes to mitigate the impact on the worst-hit sectors like textiles and leather.

Under the WTO Agreement on Safeguards, India has already notified the Council for Trade in Goods of its intent to suspend concessions (i.e., impose retaliatory tariffs) on U.S. products. A major limitation on the WTO's performance is that its Appellate Body, which remains paralyzed because the U.S. has blocked new appointments.

Conclusion

The new US tariff regime, characterized by a steep, cumulative 50 per cent duty on a wide range of Indian exports, represents the most significant trade shock to the bilateral relationship in recent memory. Non-agricultural sectors like textiles and gems experienced an immediate and crippling decline, pushing exporters to seek new markets. For the agricultural sector, the initial blow was significant, but the selective tariff rollback in November 2025 has offered a partial but vital reprieve, especially for traditional Indian exports like spices and tea. This selective exemption, however, highlights that India's long-term agricultural gains will depend less on preferential tariffs and more on scaling up operations, strengthening cold-chain infrastructure, and diversifying its export basket into high-value fresh produce. India's response is a pragmatic mix of diplomatic outreach to reverse the tariffs and domestic support for affected industries, all while actively negotiating a framework trade deal. The outcome of these negotiations will determine if the partnership can overcome this crisis, restore predictability to trade flows, and once again set its sights on the ambitious target of \$500 billion in bilateral trade.

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NOVEL TECHNIQUE : ULTRAFILTRATION

Article ID: AG-VO6-I01-23**G.Amuthaselvi**

Assistant Professor, Department of Food Process Engineering, AEC&RI, TNAU, Coimbatore
Tamil Nadu, India

Introduction

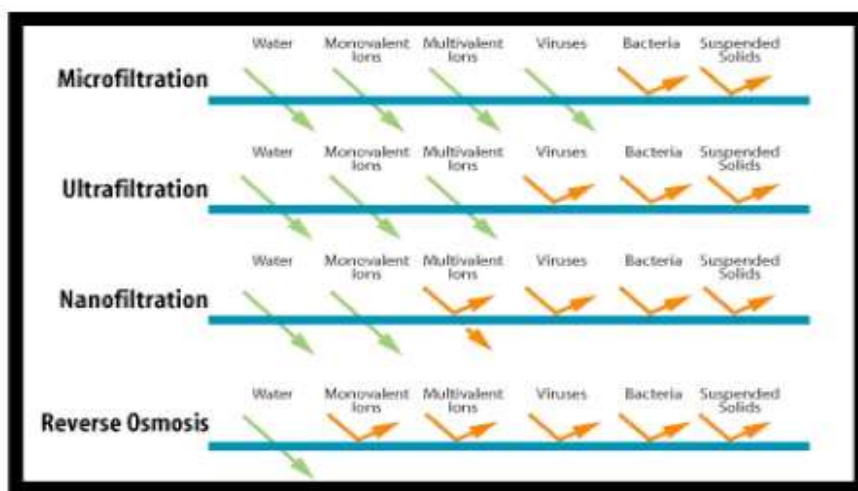
Ultrafiltration is a variety of membrane filtration in which hydrostatic pressure forces a liquid against a semi permeable membrane. Suspended solids and solutes of high molecular weight are retained, while water and low molecular weight solutes pass through the membrane. This separation process is used in industry and research for purifying and concentrating macromolecular solutions, especially protein solutions. Ultrafiltration is not fundamentally different from microfiltration, nanofiltration or gas separation, except in terms of the size of the molecules it retains. Ultrafiltration is applied in cross-flow or dead-end mode and separation in ultrafiltration undergoes concentration polarization.

Industrial applications are designed for crossflow separation, where a feed stream is introduced into the membrane element under pressure and passed over the membrane surface in a controlled flow path. A portion of the feed passes through the membrane and is called permeate. The rejected materials are flushed away in a stream called the concentrate. Crossflow membrane filtration uses a high cross flow rate to enhance permeate passage and reduce membrane fouling

Cross flow filtration

The principle of cross flow filtration can be applied to concentrate suspensions of fine particles or colloidal material or to fractionate solutions of macromolecules. The term micro filtration is generally used for particles in the size range of 0.5 to 10 μm . Cake filtration could be used for some of these materials, but a cake of 1 μm particles would have a high resistance to flow, and the filtration rate would be very low. Ultrafiltration (UF) covers a wider size range, from 0.5 μm particles down to molecules about 10^{-3} μm in size. The terms hyperfiltration and

nanofiltration are sometimes used for separations when the osmotic pressure has a major effect on the flux. A distinguishing feature may be the type of membrane used: purification of salt water by reverse osmosis takes place by a solution-diffusion mechanism in the dense polymer layer, but separation of large molecules may be achieved by a screening action in nanofiltration membranes with very small pores.



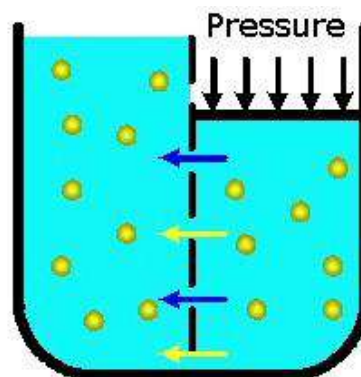
Membrane Process Characteristics

Definitions

Ultrafiltration is a low pressure membrane process used to separate high molecular weight compounds from a feed stream. The filtration technique involves passing water through porous and hollow fibre membranes.

Ultrafiltration is widely used in industry wherever fine filtration (down to 0.01 microns), disinfection, or the removal of organic contaminants is needed. Some examples of compounds effectively removed by ultrafiltration include paint pigments, ink, colloidal silica, tannins, and lignins. In general, salts and low molecular weight species can pass through the membrane while suspended solids become concentrated on the other side of the membrane surface.

Ultrafiltration, also referred to as convection, is fluid flow through the membrane, forced by a difference in pressure on the two sides of the dialyzer (pressure gradient).



UF is a low pressure (5 - 150 psig) process for separating larger size solutes from aqueous solutions by means of a semi-permeable membrane.

Ultrafiltration is a membrane process that is quite similar to reverse osmosis. It is a pressure driven process where the solvent and when present, small solute molecules pass through the membrane and are collected as a permeate. Larger solute molecules do not pass through the membrane and are recovered in a concentrated solution. The solutes or molecules to be separated generally have molecular weights greater than 500 and up to 100 000 or more, such as macromolecules of proteins, polymers, and starches as well as colloidal dispersions of clays, latex particles, and micro organisms.

Types of Membranes

The ideal membrane for cross flow filtration would have a high porosity and a narrow pore size distribution, with the largest pores slightly smaller than the particles or molecules to be retained. An symmetric membrane is preferred, with a thin selective skin supported on a thicker layer with large pores to decrease the hydraulic resistance. Some commercial membranes have a continuous gradation in pore size.

Several kinds of polymers are used for ultrafiltration membranes, including cellulose acetate, polyacrylonitrile, polysulfone, polyamide, and polyimide. The skin thickness and average pore size can be varied by changing the casting conditions or postcasting treatment.

Ultrafiltration membranes have a range of pore sizes in the selective layer, and they are often characterized by a molecular weight cutoff based on measurements of fraction rejected versus molecular weight. Molecules larger than the cutoff size are almost completely rejected, but there is a wide range of sizes for which partial rejection occurs. Rejection curves for some membranes. Since the fraction rejected for a given molecular weight varies with the molecular shape, the solvent permeation rate, the shear rate near the surface, and the extent of membrane fouling.

Ultrafiltration and microfiltration membranes are also made from sintered stainless steel or other metals and from porous carbon or alumina. The usual methods of preparation give membranes with fairly large pores (1 to 100 μm), but partially filling the surface layer with zirconium oxide or other inorganic material produces asymmetric membranes with controlled pore size. The advantages of inorganic membranes over polymer membranes are that they can operate at higher temperatures and can better stand chemical cleaning or sterilization treatment.

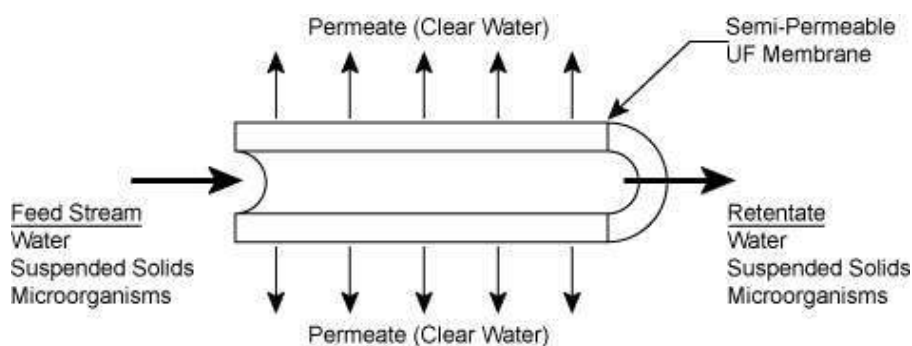
Several types of equipment are available for laboratory use and for commercial UF installations. Small samples may be processed with flat circular membranes supported on a porous disk in a cylindrical cell. A magnet-driven stirrer above the membrane provides crossflow of the solution. Rectangular cells can also be used with solution recirculated through the small gap between the membrane and the top of the cell. These devices are useful for preliminary tests, but performance data are not directly applicable to large units.

Types of Equipment for Ultrafiltration

Ultrafiltration requires fewer membrane modules and lower pressures for operation – making ultrafiltration the least costly of the three to operate. For industrial applications, large areas, are obtained using modules with many tubular or hollow –fiber membranes or by using large sheets in a filter press arrangement or a spiral – wound unit.

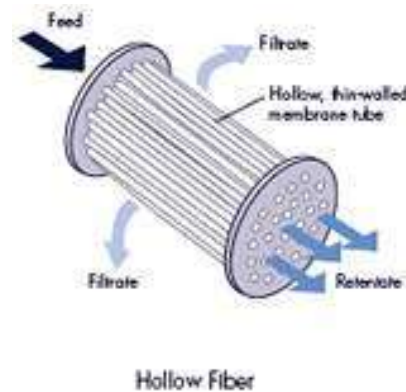
Tubular membranes

The feed solution flows through the membrane core and the permeate is collected in the tubular housing. Tubular membranes are 5 to 25 mm inside diameter and up to 3m long, and velocities of 1 to 5 m/s are used to give turbulent flow and good mass transfer. The polymer membranes are supported by porous metal or ceramic tubes, and several tubes are clustered in a cylindrical shell. Alumina membranes are available as single tubes or as monolithic multichannel elements of the type shown in fig.(29.23). Separation occurs in the layer of oxide particles bound to the alumina, and the pores in the support are large enough to have little resistance to permeate flow. Tubular membranes have the advantages of easy membrane replacement and the feasibility of mechanical cleaning, but the ratio of surface area to volume is relatively low. Generally used for viscous or bad quality fluids. System is not very compact and has a high cost per m² installed.



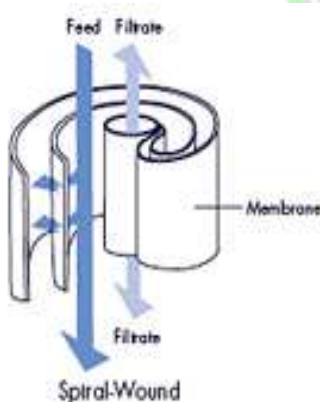
Hollow –fiber UF membranes

A hollow fiber module consists of a bundle of membrane tubes. Feed flows through the inside of the individual tubes. Shear is minimized due to the open flow channels but requires high pumping capacities to produce large enough tangential flow rates to maintain high permeate rates. The modules contain several small (0.6 to 2 mm diameter) tubes or fibers. The feed solution flows through the open cores of the fibers and the permeate is collected in the cartridge area surrounding the fibers.



Hollow –fiber UF membranes have diameters of 0.2 to 2.0 mm, and hundreds or thousands of fibers are sealed in each cylindrical module. Flow through the fibers is usually laminar, but the velocity is kept high to give high shear at the wall and improve the flux. The area per unit volume is greatest for the smallest fibers, but these are most susceptible to plugging by suspended matter in the feed, and the fibers used are generally larger than those in reverse – osmosis units. The filtration can be carried out either “inside-out” or “outside-in”

Spiral wound modules



Spiral wound modules consist of alternating layers of membrane and separator screen wound around a central core.

Spiral- wound modules of the type used for reverse osmosis are widely used for Ultrafiltration. They are not as prone to plugging as hollow –fiber units, since the entrance is a narrow slit about 1 mm wide, but prefiltration of the feed solution is recommended. The velocity in the feed channels corresponds to laminar flow, but the flow disturbances caused by the spacers make the pressure drop and the mass transfer greater than for true laminar flow. It consists of large consecutive layers of membrane and support material rolled up around a tube. Maximizes surface area. Less expensive, however, more sensitive to pollution.

Permeate flux for Ultrafiltration

The performance of a UF membrane can be characterized by the permeate flux, the percent rejection, and the concentration of solute in the retentate stream. The permeate flux often

decreases with time because of membrane fouling, but fouling may increase the rejection. We deal first with the performance of a clean membrane and solutions with significant osmotic pressure. The water is assumed to pass by laminar flow through the small pores of the selective layer, and the driving force is the pressure difference Δp minus the difference in osmotic pressures across the membrane $\Delta \pi$. The flux is proportional to the void fraction ε and the square average pore size, D . The pores are at random angles to the surface, and the nominal thickness of the active layer L is multiplied by a tortuosity factor τ . A modified Hagen-Poiseuille equation gives the volume flux v , which is the superficial permeate velocity normal to the surface:

$$v = \frac{(\Delta p - \Delta \pi) D^2 \varepsilon}{32 L \tau \mu} \quad \text{-----} \quad 1$$

Where ε is the void fraction of the membranes. In SI units, the flux has units of m^3/s , m^2 or m/s , but more common units are $\text{L}/\text{m}^2 \text{ h}$.

It is difficult to get independent measurements of ε , D , τ and L for use in equation 1, but these characteristics are incorporated in the membrane permeability Q_m , the flux of pure water at room temperature per unit pressure drop, or the -membrane resistance R_m , which is the reciprocal of Q_m :

$$Y = Q_m \Delta p = \Delta p / R_m \quad \text{-----} \quad 2$$

The use of R_m is preferred when one allows for the additional hydraulic resistance of the gel layer that may form on the surface at high flux. The general equation for ultrafiltration is

$$v = \frac{(\Delta p - \Delta \pi)}{R_m + R_{gel}} \quad \text{-----} \quad (3)$$

For operation above room temperature, or for a permeate that is not pure water, the membrane resistance can be corrected for the change in permeate viscosity by

$$R'_m = R_m (\mu/\mu_o) \quad \text{-----} \quad (4)$$

R'_m is the corrected resistance, and μ_o is the viscosity of water at room temperature.

Concentration Polarization

The osmotic pressure difference $\Delta \pi$ depends on the solute concentration, particularly if the permeate flux is high and the solute diffusivity is low. Fig. (29.26) shows concentration gradients for UF system with partial rejection of the solute. The concentration just inside the pose C_m is lower than the concentration at the surface C_s by the factor K , the equilibrium partition coefficient. There is a similar discontinuity in solute concentration where the selective

layer joins the large-pore support. For cylindrical pores and spherical molecules, $K = (1-\lambda)^2$, where λ is the ratio of molecular size to pore size. A low value of K contributes to a high rejection, and there is a further effect of wall friction on the solute diffusivity, which may make the rejection quite high even the molecules are less than one-half the size of the pores

The osmotic pressure for solutions of polymers, proteins, and other large molecules increases strongly with concentration, as shown for a few examples in Fig.29.25. This can make $\Delta\pi$ a significant fraction of Δp even when the osmotic pressure of the feed solution is negligible.

In the Ultrafiltration, the large change in concentration near the surface requires integration to get the concentration profile. The basic equation states that the flux of solute due to convection plus diffusion is constant in the boundary and equal to the flux of solute in the permeate

$$vC + D_v \frac{dc}{dx} = vC_2 \quad \text{-----}(5)$$

This is integrated assuming constant D_v with the boundary conditions $C=C_s$ at $x=0$ and $C=C_1$ at $x=\delta$, the thickness of the concentration boundary layer. The term D_v/δ has the units of length per time and is defined as the mass –transfer coefficient K_c :

$$v = \frac{C_s - C_2}{C_1 - C_2} = \frac{v\delta}{D_v} = \frac{v}{K_c} \quad \text{-----}(6)$$

For the simple case of complete solute rejection, $C_2=0$ and Eq.(29.5) becomes

$$v = k_c \ln \frac{C_s}{C_1} \quad \text{-----}(7)$$

Because of concentration polarization, the permeate flux is a nonlinear function of Δp , and a trial – and error solution is needed to calculate v for a given Δp . However, when there is completed rejection of solute and no gel resistance, Δp for a specified v can be obtained directly by using Eqn.(7) to get C_s and osmotic pressure data to get $\Delta\pi$, which is added to the term $(\Delta p - \Delta\pi)$ from equ.(3) to give Δp .

A typical plot of v versus Δp . The permeate flux with pure water feed is proportional to Δp , but with a dilute solution the permeate flux is zero until the pressure drop exceeds the small osmotic pressure of feed solution. As Δp increases C_s also increases, but π goes up faster, leading to a curved plot with $\Delta\pi$ a large fraction of Δp at high concentration. In some cases a maximum flux is reached when C_s becomes equal to the solubility and a precipitate or gel layer forms at the surface. In other cases C_s the maximum flux is less than the solubility, because the rejected

molecules form a surface layer with appreciable hydraulic resistance. This is likely to happen with a solution of high molecular weight polymer that has only moderate osmotic pressure but can form a tangled mass of overlapping molecules at the membrane surface. The terms R_{gel} and Δp_{gel} can be applied to this layer even though there is no real gel present.

When the maximum flux is reached, the flux is limited by the rate of mass transfer back to the bulk solution. A sudden increase in Δp , say from point b to point c, gives a temporary increase in permeate flux, but this decreases to the maximum steady-state value as the gel layer becomes thicker. Because a thick gel layer may compress with time, increasing the pressure drop can actually decrease the flux.

Application of Ultrafiltration

Ultrafiltration is widely used in the food processing and pharmaceutical industries to separate and concentrate solutions of proteins or drugs. It is also used to recover chemicals in the textile and paper industries as well as in waste treatment and water purification. An example from the dairy industry is the use of ultrafiltration to concentrate the proteins in skim milk. Data for a hollow – fiber UF module are shown in Fig 29.27. The limiting flux increases with the feed velocity, reaching a limit at pressure differences of 10 to 20 lb/in² (69 to 138 kPa.) These ultrafiltrations were carried out at 60°C to take advantage of the better mass transfer and lower frictional pressure drop resulting from the lower viscosity. Higher temperatures would denature the protein.

Ultrafiltration systems generally operate somewhat below the limiting flux to avoid gel formation. The flux increases with velocity past the membrane surface because of the increase in k_c , and the flux is lower for high bulk concentrations, as indicated equation (7). The change in flux with concentration for some protein and polymer solutions is illustrated in fig.29.28. Such plots are often extrapolated to zero flux to get C_g , but when the plots are curved or the data cover only a small range, extrapolation may not be accurate. At low concentrations the plot of flux versus $\ln c$ must curve to approach the pure water flux as a limit. At moderate concentrations, changes in viscosity and diffusivity may affect k_c and the slope of the plot.

Batch operation with recycle is often used for concentrating solutions by ultrafiltration, since the permeate flow in a UF module is generally much less than the feed flow, and there is only a small change in concentration per pass. Solution from the feed tank is pumped through the module at high velocity and the retentate is recycled to the tank. The concentration in the tank

gradually rises as the volume of solution decreases, and the run is continued until the desired concentration is reached (perhaps a 5-10 fold increase in concentration). A similar concentration change might be achieved in a single pass if a very small feed rate were used, but the mass transfer rate would be low, especially near the discharge end, making the operation impractical. With batch operation and recycle of retentate, the flow rate and Δp may be adjusted during the run to avoid gel formation caused by the increasing concentration and solution viscosity. Feedback control systems can keep the concentration at the wall constant at a value less the gel concentration.

For large –scale commercial applications, continuous operation is recommended with several feed- and – bleed units in series. Each UF module operates with a large recycle rate to maintain high velocity, and a small bleed stream of the retentate is sent to the next unit. Many parallel lines of UF units are needed for large feed rates.

Partial rejection of solutes: In many applications of UF, the membrane selected has some pores that are larger than the solute molecules, and the solute is only partially rejected. The fraction rejected R is sometimes defined using the feed and permeate concentration:

$$R_F = 1 - \frac{C_p}{C_F} \text{ ----- (8)}$$

Since the concentrations change along the length of a separator, a more fundamental definition of R is based on the local retentate and permeate compositions C_1 and C_2 (see Fig. 29.24):

$$R = 1 - \frac{C_2}{C_1} \text{ ----- (9)}$$

The rejection R depends mainly on the ratio of solute size to pore size to λ , which determines the partition coefficient K , and on the ratio v/k_c , which determines the concentration polarization effect. From equation (6) and (9)

$$C_s = \left(C_1 - R + R \left(\exp \frac{v}{k_c} \right) \right) \text{ ---- (10)}$$

If diffusion in the membrane is negligible and solute is carried through the pores by the permeate flow, the permeate concentration is the same as that in equilibrium with C_s :

$$C_2 = KC_s \text{ ----- (11)}$$

Combining equations (9), (10), and (11) leads to

$$\frac{1-R}{R} = \frac{K}{1-K} \exp \frac{v}{k_c} \text{ -----(12)}$$

When equation (12) applies, the rejection approaches 1-K as v/k_c approaches, zero and the rejection decreases with increasing flux because of concentration polarization. For UF of a very dilute Dextran solution with a tubular membrane, the rejection varied from 77 to 93 percent with decreasing flux, in good agreement with equation (12) and $K = 0.044$.

When filtering solutions of moderate or high concentration, the maximum flux is low, and molecular diffusion in the pores may become important. The basic equation for solute flux in the selective layer is similar to equation (5) for mass transfer in the boundary layer, but the diffusion term adds to the convective term:

$$v c_2 = v c - D_e \frac{dc}{dy} \text{ -----(13)}$$

Where

$$De = \frac{D_{pore} \epsilon}{\tau} \text{ -----(14)}$$

y- distance from membrane surface

Integrating equation (13) and assuming the same partition factor at both boundaries of the selective layer leads to

$$\frac{C_2}{C_s} = \frac{K \exp(vL/D_e)}{K - 1 + \exp(vL/D_e)} \text{ -----(15)}$$

Where L is the thickness of the selective layer.

Where the term vL/De is less than 2.0, solute diffusion has a significant effect on the rejection. Because diffusion lowers the rejection at low permeate flux and concentration polarization is important at high flux, the fraction rejected is predicted to go through a maximum with permeate flux. The diffusion effect should be quite pronounced if the active layer is very thin, say 0.1 to 0.2 μm , but there are not enough data to confirm this.

When one is dealing with a mixture of solutes or colloidal particles, a gel layer formed from one material may increase the rejection for a solute of lower molecular weight. Also, after a gel layer has formed, operation at high pressure may compress this layer and make it less permeable to smaller solutes as well as to solvent.

Diafiltration

Diafiltration is a process for removing salts and low-molecular-weight solutes from a solution of macromolecules. It differs from dialysis in that a pressure difference is used to force

salt solution through the membrane while the large molecules are left behind. In a typical application, a batch of dilute protein solution is concentrated in an ultrafiltration module that does not change the salt concentration but increases the ratio of protein to salt. Diafiltration is carried out by adding deionized water continuously to the feed tank while pumping the solution through the same UF module until the desired low salt concentration is reached.

Sometimes a final ultrafiltration step is needed to obtain a more concentrated protein solution. For small batches, diafiltration can be carried out by intermittent addition of water to the feed tank, through this is less efficient than continuous addition.

When the volume of retained solution is kept constant, the change in salt concentration can be calculated by a simple material balance.

$$V \frac{dc}{dt} = -Fc(1-R) \text{ ----- (16)}$$

Where V = Volume of solution in feed tank

F = Permeate flow (also feed flow if V is constant)

R = fraction rejected

c = salt concentration

When there is no rejection of the salt, R=0 and equation (16) is integrated to

$$\ln \frac{c}{c_o} = -\frac{Ft}{V} \text{ ----- (17)}$$

Thus for $c/c_o = 0.05$, the volume of water to be added is 3.0 times the initial volume. The time for diafiltration is calculated from the amount of water removed and the permeation rate, which should be constant because the protein concentration does not change. The change in salt concentration should not affect the permeability.

If diafiltration is carried out after the desired protein concentration had been reached by ultrafiltration, the volume of retained solution would be low and the required volume of diafiltration water would be a minimum. The permeate rate, however, would be quite low and the total filtration time would be large. If diafiltration was started with a large volume of dilute protein solution, the permeate rate high but a large amount of water would be needed. The optimum starting concentration can be determined if the flux-versus –concentration relationship is known and there is no progressive membrane fouling. When equation (7) applies, the optimum

is $C_{opt} = C_g / e$

Membrane Fouling:

A common problem in the operation of ultrafiltration units is the gradual decrease in the permeate flux caused by membrane fouling. On start-up, there is usually a high initial flux corresponding to the pure water permeability and then a rapid decline to a much lower value, limited by concentration polarization. This is often followed by a gradual decline in the rate of permeate flow over a period of several hours, resulting from some type of membrane fouling. Molecules or particles slightly smaller than the pore size may enter the membrane but become blocked at constrictions in the pores. Some molecules in the feed may be strongly adsorbed on the pore walls, reducing the diameter of the channels and increasing the membrane resistance. Deposits can form at the surface of the membrane by precipitation or by adsorption.

If the flux decline is caused by surface fouling or by compaction of the gel layer, the membrane can usually be cleaned by reversing the flow, or, for tubular membranes, by mechanical cleaning. For internal fouling, cleaning with chemical solutions may be required. If the mechanism of fouling can be identified, changes in the solutions chemistry, pretreatment of the membrane surface, or careful choice of operating conditions may greatly prolong the period of satisfactory operation. For example, a change in pH may decrease the amount of adsorption, or operating with a relatively low pressure drop may give a smaller initial flux but a greater average flux because of less plugging of the pores.

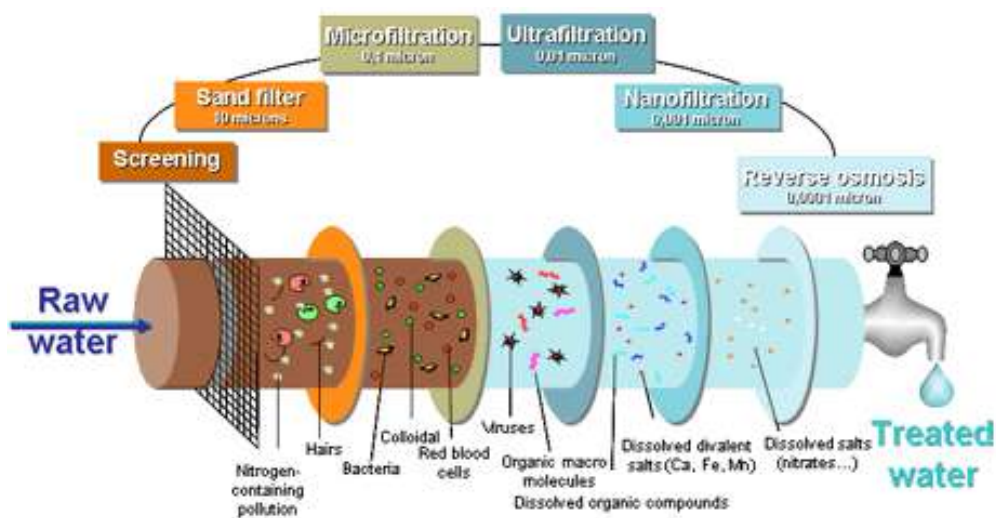
In commercial UF modules, high flow rates are used to obtain good mass transfer, and the frictional pressure drop on the feed side may be 1 to 2 atm. This makes the flux near the inlet much greater than near the outlet, since the overall Δp is only a few atmospheres, and the frictional pressure drop on the permeate side is quite small. To get a more uniform flux and decrease the chances of gel formation and fouling, the permeate space can be packed with small beads and the permeate recycled in parallel flow with the feed to keep Δp about the same over the length of the unit.

Examples of UF Applications			
Application	Permeate	Concentrate (Retentate)	Benefits of UF
Potable Water	Potable water free of suspended solids, turbidity, bacteria and large viruses	Water, particulate solids	Certified for 4-log removal of bacteria, <i>giardia</i> , <i>cryptosporidium</i> and

			viruses from drinking water. Turbidity < 0.1 NTU
Oily Wastewater	Oil free (< 50 mg/L) water	Water, suspended solids, insoluble metal hydroxides, etc.	Consistent permeate water quality even when feed composition subject to upsets. Highly concentrated oil emulsion for waste disposal.
Electrocoat Paint	Water, dissolved salts and solvents	Water, paint resins and pigments	Allows the recovery of valuable paint resins and pigments.
Milk	Lactose and salts solution	Protein concentrate	Protein concentration at lower energy cost than evaporation.
Whey	Lactose and salts solution	Whey Protein Concentrate (WPC)	Protein concentration at lower energy cost than evaporation.
Apple juice clarification	Low turbidity, clear juice	Juice, suspended solids, pulp, colloidal haze particles.	Removes suspended solids and turbidity while allowing the passage of juice, sugar and taste.
Reuse of municipal wastewater	Water free of suspended solids, bacteria & viruses Turbidity < 0.1 NTU SDI ₁₅ < 3	Water, particulate solids	Polishes biologically treated municipal effluent for discharge, reuse, or feed to reverse osmosis

Example of Ultrafiltration unit for water purification

A universal procedure which can be installed alone or incorporated in a more complex treatment process, **Ultrafiltration clarifies and disinfects the water in one single step.**



Ultrafiltration is commonly used to disinfect surface water from rivers and lakes for use in drinking water plants due to its ability to remove bacteria, viruses, and cysts (up to 6 and 7 log reduction). Ultrafiltration produces the highest quality water for the least amount of energy. The result of ultrafiltration is perfectly pure, disinfected water with a turbidity of less than 0.1 NFU.

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GENETIC ENHANCEMENT OF MUNGBEAN (*VIGNA RADIATA* L.) THROUGH ADVANCED BIOTECHNOLOGICAL INTERVENTIONS

Article ID: AG-VO6-I01-24**Ravi Ranjan Kumar*, Kumari Rajani, Jai Prakash Prasad and Bal Krishna**

Bhola Paswan Shastri Agricultural College, Purnea (Bihar Agricultural University, Sabour)
Tamil Nadu, India

*Corresponding Author: Ravi Ranjan Kumar

Abstract

Mungbean (*Vigna radiata* L. Wilczek) serves as a vital short-season legume and a primary dietary protein source across South and Southeast Asia. However, its productivity is severely constrained by pervasive biotic challenges, most notably Mungbean Yellow Mosaic Virus (MYMV), and abiotic stresses such as drought and salinity. While traditional breeding methods have contributed to incremental improvements, progress remains inherently slow, largely hindered by the crop's narrow genetic base. To overcome these limitations, modern biotechnological tools are now enabling a paradigm shift in mungbean improvement. Marker-assisted selection (MAS) accelerates breeding by using molecular tags to precisely introgress critical traits, such as MYMV resistance, into elite backgrounds without the lengthy cycles of conventional crossing. Genetic transformation techniques allow for the direct insertion of beneficial foreign genes, offering solutions for complex traits like insect resistance. Most revolutionary is the advent of genome editing, particularly CRISPR-Cas9 technology, which facilitates precise, targeted modifications within the plant's own genome to enhance inherent tolerance mechanisms. Together, this suite of advanced biotechnological approaches provides an unprecedented, integrated strategy to rapidly develop resilient, higher-yielding mungbean cultivars, thereby enhancing food security and farmer livelihoods in regions dependent on this crucial crop.

1. Introduction

Mungbean is a crucial component of sustainable agriculture, valued for its nitrogen-fixing ability

and nutritional profile, containing 20-25% protein, essential amino acids, and minerals (Nair et al., 2013). Global production faces stagnant yields, averaging 0.5-0.8 tons per hectare, far below the estimated potential of 1.5-2.0 tons/ha (FAO, 2022). Biotechnological approaches offer precision and speed, enabling direct manipulation of the genetic architecture to introgress complex traits without linkage drag (Fig. 1).

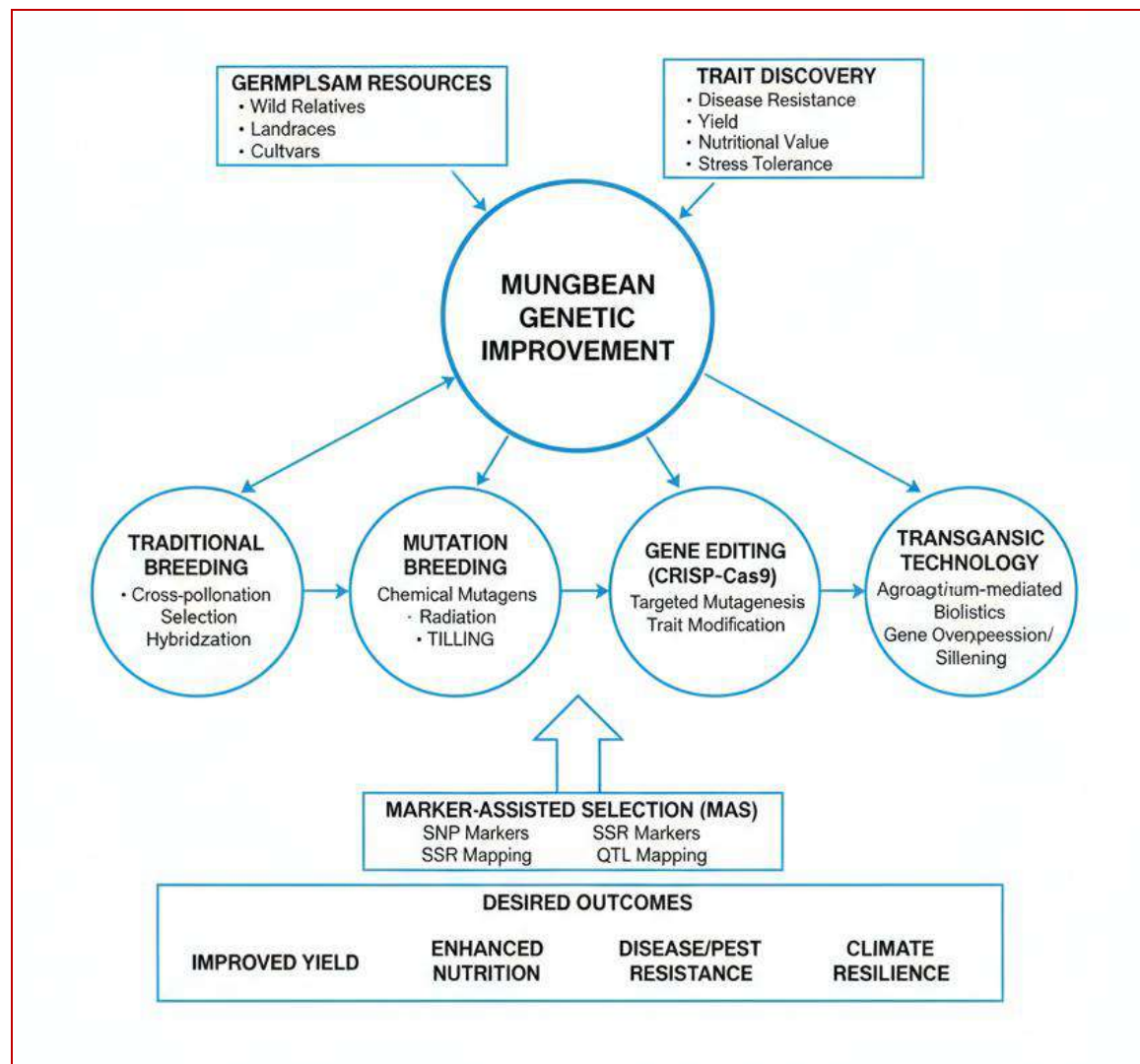


Fig. 1 : Use of different biotechnological approaches for mungbean improvement

2. Different Biotechnological Approaches for Mungbean improvement

The genetic enhancement of mungbean leverages a sophisticated continuum of molecular techniques, beginning with foundational genomic tools like whole-genome sequencing and transcriptomics to identify key genes and quantitative trait loci (QTLs) associated with desired traits. Molecular marker-assisted selection (MAS) is routinely employed to introgress major

genes, such as those conferring resistance to the Yellow Mosaic Virus, using tightly linked SSR and SNP markers, thereby accelerating breeding cycles with high precision. For more complex polygenic traits like drought tolerance, genomic selection (GS) utilizes genome-wide marker profiles to predict breeding values, enhancing selection efficiency. Meanwhile, genetic transformation via *Agrobacterium*-mediated methods enables the direct insertion of foreign genes, such as Bt toxins for insect resistance. Most transformative is the advent of CRISPR-Cas9 genome editing, which allows for precise, transgene-free knockout or modification of endogenous genes—for instance, editing negative regulators of stress response pathways to engineer resilience. The integration of these techniques, from marker-assisted backcrossing to cutting-edge editing, creates a powerful, multi-pronged strategy for developing next-generation mungbean cultivars with stacked traits for yield, nutrition, and climate resilience.

2.1 Omics Resources: The Foundational Framework

The development of genomic resources has been a prerequisite for advanced breeding. The landmark achievement was the sequencing of the mungbean genome (~579 Mb), identifying approximately 22,427 protein-coding genes (Kang et al., 2014). Subsequent initiatives have generated extensive transcriptomic, proteomic, and metabolomic datasets under stress conditions, providing candidate genes for manipulation. For instance, transcriptome profiling under drought stress identified upregulation of *VrDREB2A* and *VrLEA* genes, associated with osmotic adjustment (Chen et al., 2016; Singh et al., 2021).

2.2 Molecular Marker-Assisted Selection (MAS)

MAS has demonstrably expedited the breeding cycle for simply inherited traits. The most notable success is the development of MYMV-resistant varieties. The *MYMIV* resistance locus, mapped to chromosome 5, has been introgressed using linked SSR markers (CEDG180 and CEDG028) with over 95% selection efficiency (Kitsanachandee et al., 2013). Similarly, QTLs for drought tolerance (e.g., *qDTY-4.1*) and salinity tolerance (*qSal-7*) have been identified, paving the way for pyramiding multiple resistances (Table 1).

Table 1: List of key QTLs/Markers Deployed in Mungbean Improvement

Trait	QTL/Marker Name	Chromosome	Phenotypic Variance Explained (PVE %)	Reference
MYMV	<i>MYMIV</i>	5	85%	Kitsanachandee et

Trait	QTL/Marker Name	Chromosome	Phenotypic Variance Explained (PVE %)	Reference
Resistance				al. (2013)
Drought Tolerance	*qDTY-4.1*	4	18.2%	Chang et al. (2023)
Seed Size	*qSW-8.1*	8	31.5%	Liu et al. (2022)
Salinity Tolerance	*qSal-7*	7	15.7%	Iqbal et al. (2025)

2.3 Genetic Transformation and Transgenic Development

Mungbean has proven recalcitrant to *Agrobacterium*-mediated transformation, but standardized protocols using cotyledonary node explants have yielded success rates of 1.5-3.0% (Mahmood-ur-Rehman et al., 2020). Transgenic approaches have primarily targeted insect resistance and abiotic stress tolerance. For example, the introduction of the *cry1Ac* gene from *Bacillus thuringiensis* conferred near-complete resistance to the pod borer (*Maruca vitrata*), reducing larval survival by 98% in confined field trials (Addae et al., 2020). Similarly, overexpression of the *VrNHX1* vacuolar antiporter gene enhanced salinity tolerance, with transgenic lines showing a 40% higher shoot dry weight under 150 mM NaCl stress compared to wild-type plants (Mishra et al., 2014). Public acceptance and regulatory hurdles remain significant challenges for the commercialization of transgenic mungbean.

2.4 The CRISPR-Cas9 Revolution

Genome editing using CRISPR-Cas9 technology represents a paradigm shift, allowing for precise, *transgene-free* modifications. This is particularly advantageous for consumer-sensitive crops like mungbean. A seminal study successfully knocked out the *MYMV* gene, creating a visible albino phenotype as proof-of-concept (Talakalya et al., 2022). Current research focuses on editing negative regulators of stress pathways. For instance, knocking out the *VrPP2C* gene, a negative regulator of the ABA signaling pathway, is projected to enhance drought tolerance without yield penalty. The multiplexing capability of CRISPR allows

simultaneous editing of multiple genes, such as those in the GA (Gibberellic Acid) biosynthesis pathway to modulate plant architecture.

2.5 Data-Driven Breeding and Integration

The integration of high-throughput phenotyping, genomic selection (GS), and speed breeding is creating a new breeding pipeline. GS, which uses genome-wide markers to predict breeding values, shows promise for complex polygenic traits. A recent study reported a prediction accuracy of 0.61 for grain yield using GS models, significantly higher than phenotypic selection alone (Bohra et al., 2015). When combined with speed breeding protocols that reduce generation time to 65-70 days, this data-driven cycle can potentially deliver improved lines in 3-4 years instead of 7-10.

3. Challenges and Future Prospects

Despite remarkable progress, bottlenecks persist. These include genotype-dependent transformation efficiency, incomplete functional annotation of the genome, and the polygenic nature of key agronomic traits. Future research must prioritize:

- Developing robust, genotype-independent transformation and editing delivery systems.
- Functional validation of candidate genes via robust phenotyping platforms.
- Establishing clear regulatory pathways for genome-edited products to ensure timely release to farmers.
- Strengthening public-private partnerships to facilitate technology deployment.

4. Conclusion

Biotechnological interventions have irrevocably altered the landscape of mungbean improvement. From marker-assisted pyramiding of resistant genes to the precise surgery of CRISPR-Cas9, these tools provide an unprecedented opportunity to tailor the crop for future climates and nutritional demands. The synergistic application of genomics, transformation, and editing, anchored in robust phenotyping, is poised to unlock the latent genetic potential of mungbean, ensuring its role in global food and nutritional security.

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THE ROVE BEETLE: UNVEILING THE SECRETS OF NATURE'S TINY BUT MIGHTY PREDATOR.

Article ID: AG-VO6-I01-25**Dr. Devi, M.**

Associate Professor (Agricultural Entomology), MIT College of Agriculture and Technology,
Musiri. Trichy, Tamil Nadu, India

Introduction

In the vast and diverse world of insects, the Rove Beetle stands out as a fascinating and often misunderstood creature. With over 63,000 known species, these beetles can be found in a wide range of habitats, from the humid tropics to the freezing tundra.

The Importance of Rove Beetles

Rove Beetles play a crucial role in maintaining the balance of nature. As predators, they feed on other insects, many of which are considered pests in gardens and agricultural fields. By controlling these pest populations, Rove Beetles help to reduce the need for chemical pesticides, promoting a healthier environment for plants and animals alike. Some species of Rove Beetles are also known to prey on the larvae of flies and other insects that can spread disease, further highlighting their importance in public health. In addition to their role as predators, Rove Beetles are also important decomposers. They feed on decaying organic matter, breaking it down and recycling nutrients that would otherwise be locked away. This process is essential for maintaining soil health and promoting plant growth.



Rove beetle - *Paederus fuscipes*

The Unique Characteristics of Rove Beetles

One of the most distinctive features of Rove Beetles is their unique body shape. With their shortened elytra (wing covers) and exposed abdominal segments, they are easily recognizable. Many species of Rove Beetles are also known for their bright colors and distinctive markings, making them a popular subject for insect enthusiasts. But Rove Beetles are not just interesting to look at; they are also incredibly useful. Scientists have been studying these beetles to learn more about their behavior, ecology, and evolution. By understanding more about Rove Beetles, researchers hope to develop new methods for controlling pest populations and promoting sustainable agriculture.

Some common species of Rove Beetles:

1. ***Aleochara bilineata***: A parasitic species that preys on fly larvae, often used in biological control.
2. ***Paederus fuscipes***: Known for its painful bite, which can cause dermatitis in humans.
3. ***Staphylinus caesarius***: A medium-sized species with a metallic blue sheen, often found in gardens.
4. ***Ocypus olens***: Also known as the "devil's coach horse," this species has a distinctive habit of raising its abdomen when threatened.
5. ***Philonthus* spp.**: A genus of Rove Beetles that includes many species commonly found in gardens, forests, and near water.

Rove Beetles play a **significant role in decomposition** by breaking down organic matter and recycling nutrients. They are often found in decaying environments, such as:

1. **Carrion**: Feeding on dead animals.
2. **Decaying plant matter**: Breaking down plant material in compost, leaf litter, and soil.
3. **Fungal growth**: Some species feed on fungi.

By consuming decaying matter, Rove Beetles:

1. **Recycle nutrients**: Release nutrients back into the ecosystem.
2. **Improve soil health**: Contribute to nutrient-rich soil.
3. **Support ecosystem balance**: Help regulate decomposition processes.

Some Rove Beetle species are specialized to feed on specific types of decaying matter, such as:

1. ***Creophilus maxillosus***: Feeds on carrion.
2. ***Ontholestes cingulatus***: Found in decaying organic matter.

Rove Beetles play a significant role in nutrient cycling by:

1. **Breaking down organic matter:** Consuming decaying plant and animal material.
2. **Releasing nutrients:** Excreting nutrient-rich waste that acts as a natural fertilizer.
3. **Improving soil health:** Enhancing soil structure and fertility.

By cycling nutrients, Rove Beetles support:

1. **Plant growth:** Providing essential nutrients for plant development.
2. **Ecosystem balance:** Maintaining nutrient availability and soil health.
3. **Soil biota:** Supporting diverse soil organisms.

Role In Nutrient Cycling

1. **Decomposition:** Working with other decomposers to break down organic matter.
2. **Food webs:** Serving as a food source for other animals.

Rove Beetles' contributions to nutrient cycling promote ecosystem health and resilience.

Interactions with other decomposers:

1. **Complementary roles:** Rove Beetles work alongside other decomposers like bacteria, fungi, and insects to break down organic matter.
2. **Predator-prey relationships:** Some Rove Beetles prey on other insects, such as fly larvae, that are also decomposers.
3. **Competition for resources:** Rove Beetles may compete with other decomposers for food and resources.

Rove Beetles provide several ecosystem services:

Ecosystem Services:

1. **Pest control:** Preying on pest species, reducing crop damage.
2. **Decomposition:** Breaking down organic matter, recycling nutrients.
3. **Nutrient cycling:** Releasing nutrients, promoting soil fertility.
4. **Food source:** Serving as a food source for other animals.
5. **Ecosystem balance:** Contributing to ecosystem stability and resilience.

Benefits to humans:

1. **Agricultural benefits:** Reducing pest populations, promoting healthy crops.
2. **Environmental benefits:** Maintaining ecosystem balance, promoting biodiversity.
3. **Ecological resilience:** Helping ecosystems withstand disturbances.

Conservation implications:

1. **Habitat preservation:** Protecting natural habitats to maintain Rove Beetle populations.
2. **Sustainable agriculture:** Promoting practices that support beneficial insects.
3. **Biodiversity conservation:** Recognizing the importance of Rove Beetles in ecosystems.

By providing these ecosystem services, Rove Beetles play a vital role in maintaining healthy, balanced ecosystems.

Biodiversity Contributions:

1. **Species richness:** With over 63,000 known species, Rove Beetles are one of the most diverse beetle families.
2. **Ecological niches:** They occupy a wide range of ecological niches, from decaying matter to living plants and animals.
3. **Food web interactions:** Rove Beetles serve as both predators and prey, supporting complex food webs.
4. **Habitat diversity:** They inhabit diverse habitats, including forests, grasslands, wetlands, and more.

Importance of biodiversity:

1. **Ecosystem resilience:** Diverse ecosystems are more resilient to disturbances and changes.
2. **Ecosystem services:** Biodiverse ecosystems provide a range of essential services, including pest control and nutrient cycling.
3. **Adaptation to change:** Diverse species are more likely to adapt to changing environmental conditions.

Major Threats:

1. **Habitat destruction:** Loss of natural habitats due to deforestation, urbanization, and agricultural expansion.
2. **Climate change:** Changes in temperature and precipitation patterns can disrupt Rove Beetle populations and ecosystems.
3. **Pollution:** Chemical pollutants can harm Rove Beetles directly or alter their food sources.
4. **Invasive species:** Non-native species can compete with Rove Beetles for resources or prey on them.

5. **Overuse of pesticides:** Broad-spectrum insecticides can harm Rove Beetles and other beneficial insects.

Consequences:

1. **Population decline:** Loss of biodiversity and ecosystem disruption.
2. **Ecosystem instability:** Reduced ecosystem resilience and function.
3. **Loss of ecosystem services:** Impacts on pest control, decomposition, and nutrient cycling.

Conservation efforts:

1. **Habitat preservation:** Protecting natural habitats and restoring degraded areas.
2. **Sustainable land-use practices:** Promoting practices that minimize harm to Rove Beetles and their habitats.
3. **Integrated pest management:** Using targeted and environmentally friendly pest control methods.
4. **Climate change mitigation:** Reducing greenhouse gas emissions to minimize climate change impacts.

By addressing these threats and promoting conservation efforts, we can help protect Rove Beetle biodiversity and maintain ecosystem health.

Conclusion

The Rove Beetle may be small, but it plays a significant role in maintaining the health of our ecosystem. As we continue to learn more about these fascinating creatures, we are reminded of the importance of preserving biodiversity and promoting sustainable practices. By appreciating the importance of Rove Beetles and other insects, we can work towards creating a healthier, more balanced environment for all living things.

PROCEDURE FOR PATENT APPLICATION IN INDIA

Article ID: AG-VO6-I01-26**¹Ramesh, V.,^{1*}V. Krishnan, ¹N. Swaminathan, ²M. K. Sakthi Anand and ³J. Arathi**

¹Faculty, ²Ph. D. Scholar & ³PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

Corresponding Author: V. Krishnan

1. Introduction

A patent is a form of intellectual property right (IPR) granted for an invention. It provides the inventor or the assignee with an exclusive right, for a limited period, to prevent others from making, using, selling, or importing the patented product or process without authorisation. In return, the inventor is required to make a full public disclosure of the invention. The patent system functions as a key driver of technological advancement by protecting innovation, ensuring public availability of technical knowledge, and contributing to industrial and economic development.

2. Purpose of the Patent System

The Indian patent system aims to encourage inventions by protecting them and facilitating their utilisation. By safeguarding inventions, the system supports industrial growth, promotes technological progress, and enables the transfer and dissemination of knowledge.

A patent essentially represents a property right or legal title, which can become a valuable asset for an individual or an enterprise. However, because patent rights are territorial in nature, a patent granted in one country is enforceable only within that jurisdiction. For international protection, inventors must apply separately in multiple countries or use systems such as the Patent Cooperation Treaty (PCT).

3. Legislative Framework

The Indian patent regime is based on the Patents Act, 1970 (No. 39 of 1970), as amended by subsequent laws, most notably the Patents (Amendment) Act, 2005. The implementation is

governed by the Patents Rules, 2003, and their later amendments. These legal instruments bring India into compliance with international norms, particularly the WTO-TRIPS Agreement (Trade-Related Aspects of Intellectual Property Rights).

4. Patent Administration in India

The Patent Office operates under the Department for Promotion of Industry and Internal Trade (DPIIT), Ministry of Commerce and Industry. It has four regional branches: Kolkata (Head Office), Mumbai, Chennai, and New Delhi, each responsible for applications from their respective territories. In addition, the Patent Information System (PIS) at Nagpur maintains a global collection of patent documents and provides search and document supply services, while the Intellectual Property Training Institute (IPTI), also in Nagpur, conducts training programs for officials and stakeholders in intellectual property.

5. Eligibility to Apply

Patent applications may be filed by the true and first inventor, the inventor's assignee, or the legal representative of a deceased inventor. Such applications can be filed singly or jointly. As India follows the "first-to-file" principle, patent rights are awarded to the person who first files the application rather than the one who first conceived the invention. This makes timely filing a crucial step in securing protection.

6. Applicant Precautions

Inventors need to take certain precautions before filing a patent. Publication of an invention in a scientific journal, newspaper, or any other platform before filing can make the invention unpatentable.

Similarly, putting the invention to public or commercial use before filing can invalidate the patent claim. Confidential use, experimental trials, or disclosures made under confidentiality agreements are exceptions to this rule. Inventors should also avoid waiting until an invention is perfected for commercialisation; instead, applications can be filed at an early stage through provisional specifications, thereby securing a priority date.

7. Types of Patent Applications

Indian law recognises several categories of patent applications. These include the ordinary application, the application for a patent of addition (filed for modifications or improvements of an existing invention), the divisional application (arising from multiple inventions disclosed in one filing), the convention application (for claiming priority from

convention countries), and the national phase application under the PCT system.

An application may be filed with either a provisional or a complete specification. A provisional specification provides a preliminary description and establishes the priority date but must be followed by a complete specification within 12 months. A complete specification, on the other hand, is a comprehensive document that fully explains the invention.

8. Structure of a Complete Specification

A complete specification is the most critical document in the patent process. It must describe the invention in sufficient detail to enable a person skilled in the relevant field to replicate it. Generally, it consists of the title, field of invention, background of the invention, including drawbacks of existing solutions, objectives of the invention, a statement and summary of the invention, a brief description of the drawings, a detailed description with examples, and the claims, which define the scope of legal protection sought.

9. Patentability Criteria

For an invention to qualify for a patent in India, it must meet three essential criteria. It should be novel, meaning it has not been previously published or publicly known anywhere in the world. It should involve an inventive step, which means it is not obvious to a person skilled in the art with reference to existing knowledge. Finally, it must be industrially applicable, which implies that the invention can be manufactured or used in an industry.

10. Non-Patentable Inventions

Certain subjects are specifically excluded from patent protection under Section 3 of the Patents Act. These include inventions contrary to natural laws, morality, or public order; discoveries of natural substances, plants, or animals (other than microorganisms); new forms of known substances without significant efficacy enhancement; merely aggregated mixtures or arrangements of known devices; methods of agriculture or horticulture; diagnostic, therapeutic, or surgical treatments for humans and animals; business methods, mathematical methods, or algorithms; artistic, literary, or aesthetic creations; presentation of information; and traditional knowledge or duplication of known properties. Additionally, inventions relating to atomic energy or those that endanger national security are excluded from protection.

11. Examples for Better Understanding

The difference between patentable and non-patentable inventions can be illustrated with examples. A new drug molecule showing improved therapeutic efficacy may qualify for a patent,

whereas a novel crystalline form of an existing drug without significant improvement would not. A new type of automated seed sorter designed through technical innovation may be patentable, but a method for planting or growing crops would not. Similarly, a solar-powered irrigation pump involving an innovative mechanism is patentable, but a financial or business method for trading agricultural commodities is not.

The Indian patent system provides a robust mechanism for encouraging innovation while ensuring that unjustified monopolies are avoided. For students, researchers, and inventors, understanding the principles of patent law is vital to safeguard innovations, maximise their commercial potential, and contribute meaningfully to the advancement of science, technology, and society.

12. Appropriate office for applying & for other proceedings

An application is required to be filed according to the territorial limits where the applicant or the first-mentioned applicant, in case of joint applicants, for a patent normally resides or has domicile or has a place of business or the place from where the invention actually originated. If the applicant for the patent or party in a proceeding has no business place or domicile in India, the appropriate office will be according to the address for service in India given by the applicant or party in a proceeding. The appropriate office once decided in respect of any proceedings under the Act shall not ordinarily be changed. The four patent offices are located at Kolkata, Mumbai, Delhi and Chennai.

13. Documents required for filing an application

1. Application form in duplicate (Form 1).
2. Provisional or complete specification in duplicate. If the provisional specification is filed, it must be followed by the complete specification within 12 months. (Form 2).
Drawing in duplicate (if necessary).
3. Abstract of the invention in duplicate.
4. Information and undertaking listing the number, filing date and current status of each foreign patent application in duplicate (Form 3).
5. Priority document (if priority date is claimed) in a convention application, when directed by the Controller.
6. Declaration of inventor-ship where a provisional specification is followed by a complete specification or in case of a convention/PCT national phase application (Form 5).

7. Power of attorney (if filed through Patent Agent).

Fee (to be paid in cash or by cheque/by demand draft) (See: Schedule I).

(Note: The cheque or demand draft should be payable to the "Controller of Patents", drawn on any scheduled bank at a place where the appropriate office is situated

14. Publication and examination of patent applications

All the applications for patent, except the applications prejudicial to the defence of India or abandoned due to non-filing of a complete specification within 12 months after filing the provisional or withdrawn within 15 months of applying, are published in the Patent Office Journal just after 18 months from the date of filing of the application or the date of priority, whichever is earlier.

The publication includes the particulars of the date of the application, application number, name and address of the applicant, along with the abstract. The patent applications are not open for public inspection before publication. After the date of publication of the application, as stated above, the complete specification along with provisional and drawing, if any, abstract, application on any form or on plain paper and any correspondence between the office and applicant may be inspected at the appropriate office by making a written request to the Controller in the prescribed manner and on the payment of prescribed fee.

Early Request for Publication:

The applicant may also file a request for early publication in Form-9 with a prescribed fee of Rs 2500/- or Rs 10,000/- for natural person and other than natural person respectively. The above application is published ordinarily within one month from the date of the request on Form-9. The applicant shall have provisional Rights from the date of publication.

Request for examination

No application for patent will be examined if no request is made by the applicant or by any other interested person in Form-18 with prescribed fee of Rs.2, 500/- or Rs.10, 000/-for natural person and other than natural person respectively, within a period of 48 months from the date of priority of the application or from the date of filing of the application, whichever is earlier. Where no request for examination of the patent application has been filed within the prescribed period, the aforesaid application will be treated as withdrawn and, thereafter, the application cannot be revived.

Examination

Patent application, where a request has been made by the applicant or by any other interested person, will be taken up for examination, according to the serial number of the requests received on Form 18. A First Examination Report (FER) stating the objections/requirements is communicated to the applicant or his agent according to the address for service ordinarily within six (06) months from the date of request for examination or date of publication, whichever is later. The application or complete specification should be amended to meet the objections/requirements within a period of 12 months from the date of the First Examination Report (FER).

No further extension of time 5 is available in this regard. If all the objections are not complied with within the period of 12 months, the application shall be deemed to have been abandoned. When all the requirements are met, the patent is granted. After 6 months from the date of publication, the letter patent is issued, entry is made in the register of patents, and it is notified in the Patent Office Journal.

Withdrawal of patent application

The patent application can be withdrawn at least 3(Three) months before the first publication, which will be 18(Eighteen) months from the date of filing or date of priority, whichever is earlier. The application can also be withdrawn at any time before the grant of the patent. The application withdrawn after the date of publication cannot be refiled as it is already laid open for public inspection. However, an application withdrawn before the publication can be refiled, provided it is not opened to the public otherwise.

15. Opposition proceedings to the grant of patents, pre-grant opposition

Where an application for a patent has been published but a patent has not been granted, any person may, in writing, represent by way of opposition to the Controller against the grant of any Patent. The representation shall be filed at the appropriate office and shall include a statement and evidence, if any, in support of the representation and a request for a hearing if so desired. The above representation may be made on the following grounds

- (a) That the applicant for the patent or the person under or through whom he claims, wrongfully obtained the invention or any part thereof from him or from a person under or through whom he claims;

- (b) That the invention, so far as claimed in any claim of the complete specification, has been published before the priority date of the claim
- (c) That the invention so far as claimed in any claim of the complete specification, is claimed in a claim of a complete specification published on or after the priority date of the applicant's claim and filed in pursuance of an application for a patent in India, being a claim of which the priority date is earlier than that of the applicant's claim;
- (d) That the invention, so far as claimed in any claim of the complete specification, was publicly known or publicly used in India before the priority date of that claim. Explanation—For this clause, an invention relating to a process for which a patent is claimed shall be deemed to have been publicly known or publicly used in India before the priority date of the claim if a product made by that process had already been imported into India before that date except where such importation has been for the purpose of reasonable trial or experiment only;
- (e) That the invention so far as claimed in any claim of the complete specification is obvious and clearly does not involve any inventive step, having regard to the matter published as mentioned in clause (b) or having regard to what was used in India before the priority date of the applicant's claim; 6
- (f) That the subject of any claim of the complete specification is not an invention within the meaning of this Act, or is not patentable under this Act;
- (g) That the complete specification does not sufficiently and clearly describe the invention or the method by which it is to be performed;
- (h) That the applicant has failed to disclose to the Controller the information required by section 8 or has furnished the information which in any material particular was false to his knowledge;
- (i) That in the case of a convention application, the application was not made within twelve months from the date of the first application for protection for the invention made in a convention country by the applicant or a person from whom he derives title;
- (j) That the complete specification does not disclose or wrongly mentions the source or geographical origin of biological material used for the invention;
- (k) That the invention so far as claimed in any claim of the complete specification, is anticipated having regard to the knowledge, oral or otherwise, available within any local or

indigenous community in India or elsewhere, but on no other ground.

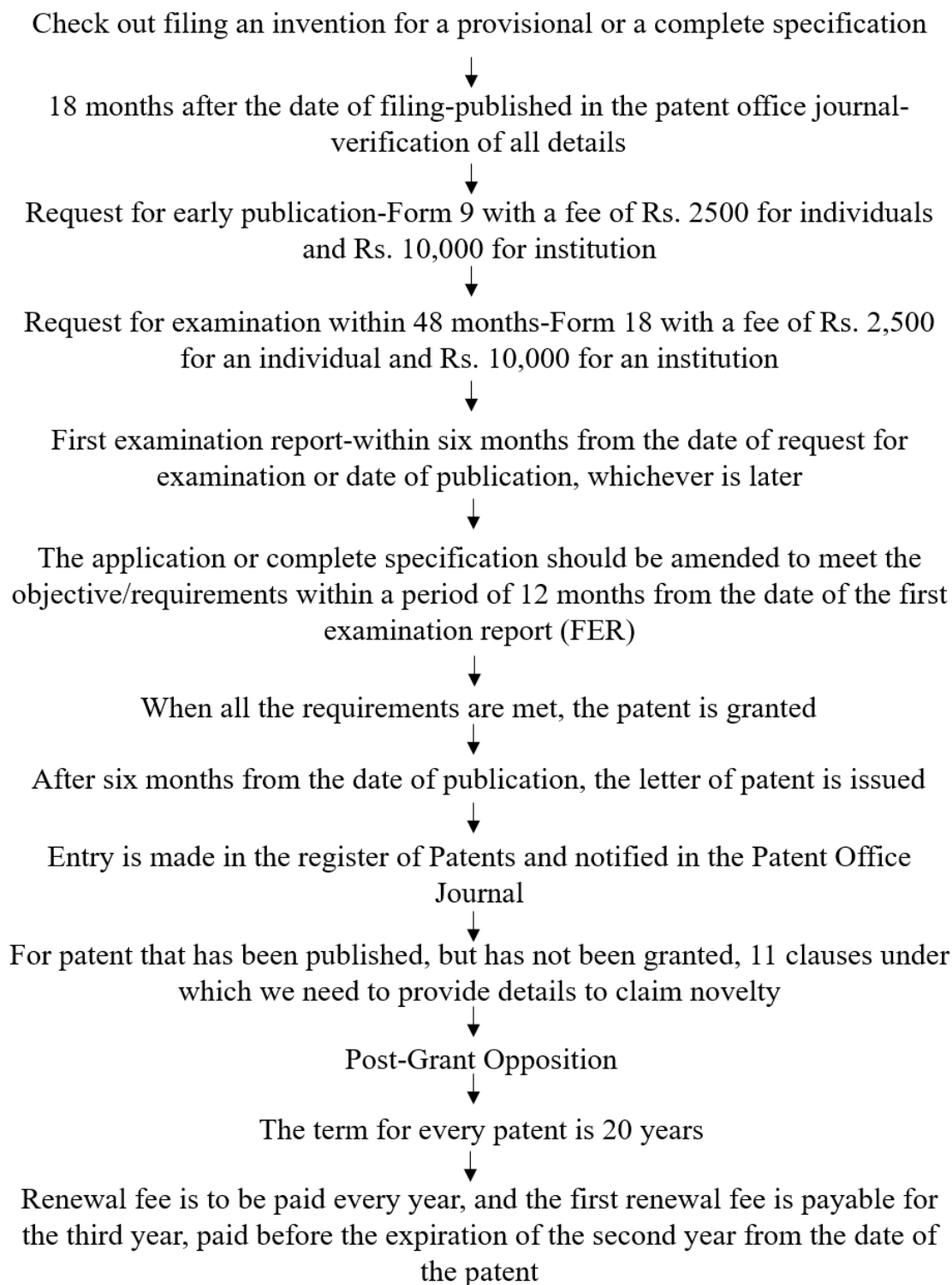


Fig. 1. Key points to be remembered to obtain a patent for an invention

The Controller shall, if requested by such person to be heard, hear him and dispose of such representation. If the opposition is decided in favour of the applicant, the patent is granted and the grant of patent is published in the Patent Office Journal, thereby opening the application, specification and other related documents for public inspection on payment of the prescribed fee.

16. Grant of patent

When all the requirements of the FER are met or in case of opposition under section 25(1), if the opposition is decided in favour of the applicant, the patent is granted, after 6 months from the date of publication under section 11 A, the letter patent is issued, entry is made in the register of patents and it is notified in the Patent Office, Journal, thereafter opening the application, specification and other related documents for public inspection on payment of prescribed fee.

17. Term and date of patent

The term of every patent will be 20 years from the date of filing of the patent application, irrespective of whether it is filed with a provisional or complete specification. Date of patent is the date on which the patent application is filed.

18. Post-grant opposition:

Any interested person can file a notice of opposition (along with a written statement and evidence, if any) any time after the grant of a Patent but before the expiry of a period of one year from the date of publication of the grant of a Patent in the Patent Office Journal. The above notice under Section 25(2) shall be filed on Form-7 along with a fee of Rs. 1500/- or Rs. 6000/- for a natural person and other than a natural person, respectively, in duplicate at the appropriate office. The grounds of opposition under section 25 (2) are the same as given before in the case of pre-grant opposition. The post-grant opposition is decided by an *Opposition Board*, followed by a hearing and a reasoned decision by the Controller.

19. Rights of the patentee

Where a patent covers a product, the grant of a patent gives the patentee the exclusive right to prevent others from performing, without authorisation, the act of making, using, offering for sale, selling or importing that product for the above purpose.

Where a patent covers a process, the patentee has the exclusive right to exclude others from performing, without his authorisation, the act of using that process, using and offering for sale, selling or importing for those purposes, the product obtained directly by that process in

India. These rights created by statute are circumscribed by various conditions and limitations as provided in the Patents Act, 1970, as amended by the Patents (Amendment) Act, 2002.

20. Register of patents

The Register of Patents is kept in the Patent Offices and can be inspected, or an extract from it can be obtained on payment of the prescribed fee. Register of Patents contains the name and address of the patentee, notification of assignment, *etc.*, particulars in respect of validity or proprietorship of patent and payment of renewal fee.

Table.1. Statutory fee for patent application

Particulars	Natural person (INR)	Other than Natural person (INR)
For filling patent application	1,000	4,000
For each sheet of application in addition to 30 sheets	100	400
For each claim in addition to 10 claims	200	800
Notice of opposition	1,500	6,000
Request for early publication	2,500	10,000
Request for Examination	2,500	10,000

21. Renewal fee

To keep the patent in force, a Renewal fee is to be paid every year. The first renewal fee is payable for the third year and must be paid before the expiration of the second year from the date of patent. If the patent has not been granted within two years the renewal fees may be accumulated and paid immediately after the patent is granted, or within three months of its recorded in Register of Patents or within extended period of nine months, by paying extension fees of six month on Form 4, from the date of recorded. If the renewal fees are not paid within the prescribed time, the patent will cease to have effect. However, provision to restore the patent is possible, provided an application is made within eighteen months from the date of cessation.

The renewal fee is counted from the date of filing of the Patent application. Six months' grace time is available with an extension fee for payment of the renewal fee. No renewal fees are payable on Patents of Addition, unless the original patent is revoked and if the Patent of

Addition is converted into an independent patent; the renewal fee, then, becomes payable for the remainder of the term of the main patent.

Table 2. Renewal fee for patent application

Particulars	Natural person (INR)	Other than Natural person (INR)
Before the expiration of 2 nd year from the date of patent in respect of 3 rd year	500	2,000
Before the expiration of 6 th year from the date of patent in respect of 7 th year	1,500	6,000
Before the expiration of 10 th year from the date of patent in respect of 11 th year	3,000	12,000
Before the expiration of 15 th year from the date of patent in respect of 16 th year	5,000	20,000

22. Restoration

An application for restoration of a patent that lapses due to non-payment of renewal fees must be made within 18 months of lapse. The application is to be filed in the appropriate office according to the jurisdiction. Documents can be filed through online or in the patent office having jurisdiction: Kolkata (head office), Delhi, Mumbai, and Chennai

COPYRIGHT POLICY IN INDIA

Article ID: AG-VO6-I01-26

¹Arathi, J., ^{2*}V. Krishnan, ²N. Swaminathan, ²V. Ramesh, ³M. K. Sakthi Anand

¹ PG Scholar, ²Faculty & ²Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

Corresponding Author: V. Krishnan

1. Introduction

Copyright is a bundle of exclusive rights granted by statute to the author of the works to exploit or authorise the exploitation of the copyright work, based on international norms like Berne Convention, Trade Related Aspects of Intellectual Property Rights (TRIPs) Agreement and WIPO Copyright Treaty (WCT). The copyright works in which rights subsist are 'original' literary, dramatic, musical and artistic works, and cinematograph films and sound recording. This page gives information as to Indian Law on Copyright and has full texts of Legislations, Cases and International Conventions.

2. What is Copyright?

Copyright is one of the chief forms of intellectual property that is afforded protection by the law, the other three being patents, trademarks, and industrial designs. In its most simplistic formulation, **copyright implies protection against copying of one's work by another**. Its chief object is to encourage people to create original works in different fields like literature, art and music by rewarding them with the exclusive right for a limited period of exploit the work for monetary gain. Theoretically, it acts as an incentive for people to come out with newer and newer copyrightable works, which add to the knowledge stock of mankind.

3. Historical development of Copyright laws

Copyright is a set of exclusive rights granted to the author or creator of an original work, including the right to copy, distribute and adapt the work. Copyright does not protect ideas, only their expression or fixation in most. Jurisdictions copyright arises upon fixation and does not

need to be registered.

Table 1. Historical development of Copyright laws

Period / Year	Event / Legislation	Significance
Medieval England	Emergence of copyright as a control mechanism	Not initially to protect authors → but to prevent unauthorised publications <i>against the Church & the King</i> . The printing press increased copying capacity → authors realised the commercial value of their works.
1662	Licensing Act (Charles II)	First recognition of authors' rights; controlled printing in a major way.
1710	Statute of Anne (8 Anne c.19)	First true copyright law: granted authors exclusive rights to copy/publish books for a limited period; introduced criminal penalties for infringement.
18–19th Century	Expansion of copyright scope	Inclusion of sculpture, art, engravings, and other creative works
1911	Imperial Copyright Act	Consolidated earlier laws; declared copyright a statutory right (not common law). Expanded to new subject matters like cinematograph film
1956 (UK)	Copyright Act, 1956	Replaced the 1911 Act; modernised copyright law in line with emerging media.

4. International Framework for Copyright

Table 2 International Framework for Copyright

Treaty / Convention	Year	Focus / Significance
Berne Convention	1886	Protection of literary and artistic works internationally.
Rome Convention	1961	Protection of performers, producers of phonograms, and broadcasting organizations.

Universal Copyright Convention	1952	Alternative to Berne; facilitated wider participation by countries.
TRIPS Agreement	1994 (WTO)	Linked copyright with trade; enforced minimum IP standards globally.
WIPO Copyright Treaty	1996	Addressed digital works and online dissemination.
WIPO Performance and Phonograms Treaty	1996	Focused on rights of performers and producers of sound recordings.

. Copyright owners have the exclusive statutory right to exercise control over copying and other exploitation of the works for a specific period of time, after which the work is said to enter the public domain. Uses which are covered under limitations and exceptions to copyright, such as fair use, do not require permission from the copyright owner. All other uses require permission and copyright owners can license or permanently transfer or assign their exclusive rights to others.

Initially copyright law only applied to the copying of books. Over time other uses such as translations and derivative works were made subject to copyright and copyright now covers a wide range of works, including maps, dramatic works, paintings, photographs, sound recordings, motion pictures and computer programs. The British Statute of Anne 1709, full title "An Act for the Encouragement of Learning, by vesting the Copies of Printed Books in the Authors or purchasers of such Copies, during the Times therein mentioned", was the first copyright statute.

Today copyright laws have been standardized to some extent through international and regional agreements such as the Berne Convention and the European copyright directives. Although there are consistencies among nations' copyright laws, each jurisdiction has separate and distinct laws and regulations about copyright. National copyright laws on licensing, transfer and assignment of copyright still vary greatly between countries and copyrighted works are licensed on a territorial basis. Some jurisdictions also recognise moral rights of creators, such as the right to be credited for the work.

5. Indian Law on Copyright

In India, the first legislation on Copyright was the Indian Copyright Act, 1847. This Act continued to be in force till it was replaced by the Indian Copyright Act, 1914. The Copyright Act, 1957, as amended in the years 1984, 1994 and 1999, to accommodate the obligations under

international treaties, governs the present law relating to copyright.

Copyrights subsist in:

- Original literary, musical, dramatic and artistic works.
- Cinematograph films
- Sound recordings

A computer programme is considered to be literary work and protected as such. Copyright also subsists in translations, abridgements or compilations of other works, provided that the consent of the original Copyright holder has been obtained. The author will then have separate copyright in respect of the translated or abridged work. All these are considered to be literary works.

The general rule of copyright is that the author is the first owner of the copyright. However, this rule is subject to exceptions in the case of employment work, commissioned work and government work. The author is the person who put intellectual labour into creating the copyrighted work. But in the case of sound recording and cinematograph film author is the producer is the author.

Table 3. Copyright Laws in India

Year	Legislation	Basis / Influence
1847	Indian Copyright Act	Based on England's Copyright Act, 1842.
1914	Indian Copyright Act	Extension of the Imperial Copyright Act, 1911, with modifications.
1957	Copyright Act, 1957	Modelled on the UK Copyright Act, 1956, it remains the foundation of Indian copyright law (with later amendments).

The Copyright Act makes it very clear that copyright is *only* a statutory right, and common law copyright is not recognised. It is a very exhaustive piece of legislation that seeks to encompass the entire spectrum of rights and liberation, even minutely related to copyright. Section 14 of the Act lists various rights of a copyright owner of literary, dramatic, musical or artistic work, cinematograph film, sound recording and computer programme.

Along with the copyright for the author, various neighbouring rights to protect the

interests of performances, broadcasters etc. have also developed to safeguard their interests. The 1994 Amendment Act has incorporated these into the Copyright Law in India. “Performers’ rights” was introduced as Section 38 by the 1994 amendment to the Copyright Act. Under Section 37 right known as “Broadcasting Reproducing Right” is given to every broadcasting organisation in respect of its broadcasts for a period of 25 years. Performer’s rights, protection is given to various types of performers like actors, dancers, musicians, jugglers, acrobats, etc. These rights are also available for a period of 25 years and guarantee rights such as reproduction of sound or visual recording of the performances and their broadcast or other communication to the public, etc.

6. Term of Protection

The duration for which copyright subsists in India varies depending on the nature of the work and whether the author is a natural person or a legal entity. Generally, for literary, dramatic, musical, or artistic works created by natural persons, copyright protection lasts for the lifetime of the author plus an additional 60 years. In cases of joint authorship, this term is calculated from the death of the last surviving author to pass away. For works published posthumously, copyright subsists for a fixed period of 60 years from the date of publication. However, if the author's name is revealed before the expiry of this period, the protection continues for 60 years following the author's death.

For cinematograph films and sound recordings, copyright protection is guaranteed for 60 years from the date of publication. In situations where the copyright owner is the Government or an organisation, copyright similarly lasts for 60 years from publication. Here, “publication” refers to making the work available to the public either by issuing copies or by communicating the work publicly.

7. Enforcing Copyright

The owner of a copyrighted work enjoys exclusive rights as enumerated under Section 14 of the Copyright Act. Unauthorised production, reproduction, or use of the work or any substantial part thereof constitutes infringement. Section 51 specifically addresses infringement, labelling any violation of the copyright owner's exclusive rights or any unauthorized communication to the public as infringement. This includes acts such as selling, advertising for sale, distributing, or importing infringing copies of the work.

8. Transactions Involving Copyright

While copyright protects the author's rights against unauthorized copying, authors often authorize others to exploit their copyrighted works in exchange for compensation. This is primarily facilitated through two mechanisms: assignment and licensing.

An assignment transfers ownership of the copyright from the author to another party. Unless otherwise stipulated, the term of an assignment is considered to be five years. The assignee must exercise the assigned rights within one year from the date of assignment for it to continue, unless the contract specifies otherwise. Assignments may also cover future works, taking effect as new creations come into existence. An author can assign rights territorially, for example granting rights in one country only while retaining others. It is important to note that registration of assignments is not mandatory, and copyrights can be transferred via bequest.

9. Licenses

Licenses provide authority to use the copyrighted work without transferring ownership and are regulated under Chapter VI of the Copyright Act. Licenses are broadly categorized as voluntary licenses, granted by copyright owners, and compulsory licenses, which are legislated under specific circumstances to protect public interest.

Distinguishing between an assignment and a license depends largely on contractual terms, with the key difference being that the licensee does not acquire ownership rights. License terms generally last five years, similar to assignments, with rights to use needing to be exercised within a year from the grant of the license unless otherwise agreed. Licenses may also be granted for works not yet created, activating when such works come into existence. The Act's provisions for compulsory licenses, especially under Section 31- aim to safeguard public access to knowledge. International conventions such as the Berne Convention and the Universal Copyright Convention recognise the legitimacy of compulsory licenses in developing countries, especially for uses such as translation and broadcasting of works under certain conditions.

In India, compulsory licenses can be granted for "Indian works" whose authors reside or publish first in India, particularly if the author refuses further publication, performance, or broadcasting. Compulsory licenses also facilitate the production and publication of translations of copyrighted materials in the public interest. The Copyright Board has the authority to issue such licenses.

10. The Indian Music Industry

The Indian Music Industry (IMI) is a non-commercial, non-profit organization affiliated with the International Federation of Phonographic Industry (IFPI). Registered under the West Bengal Societies Registration Act, the IMI aims to defend, preserve, and develop the rights of phonogram producers, promote musical culture, encourage fair trade policies, and conduct anti-piracy operations. The IMI plays a significant role in shaping copyright enforcement and policy within India's musical landscape.

11. International Framework: The TRIPS Agreement

The 1994 Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) marks a significant international development governing copyright protection. TRIPS was negotiated within the Uruguay Round of GATT and contains specific provisions concerning copyrights. Membership in the World Trade Organization (WTO) requires states to comply with TRIPS standards, which include adhering to the Berne Convention (except for moral rights Article 9(1)), extending copyright to computer programs and databases, and providing rental rights for computer programs and films.

Under TRIPS, where copyright duration differs from the life of a natural person (e.g., corporate works), the minimum term is set at 50 years from the date of authorized publication or creation.

12. Obtaining Copyright

Unlike patent rights, copyright protection does not require mandatory registration in most jurisdictions, including India, which adheres to the Berne Convention. Copyright arises automatically when a creative work is fixed in a tangible medium such as a manuscript, recording, or digital file. While registration is not needed to enforce copyright, it serves as prima facie evidence of ownership and can facilitate legal disputes. The original copyright owner can sometimes be different from the author, especially in "work for hire" agreements where employers hold copyrights.

13. Exclusive Rights Granted by Copyright

Copyright legally grants the exclusive right to reproduce, distribute, and publicly perform or display the work. Initially, copyright protection centred on copying rights related to print media such as books, but over time it has expanded to include dramatizations, adaptations, translations, and derivative works. The rights are generally territorial, confined by national laws,

but harmonised by international treaties like the Berne Convention to ensure a baseline of protection globally. Technological advances have transformed copyright enforcement. The separation of content from its medium, such as the shift from paper to digital formats, allows widespread reproduction, distribution, and adaptation. This evolution challenges copyright law to balance the rights of creators with accessibility.

14. First-Sale Doctrine and Exhaustion of Rights

The first-sale doctrine permits the lawful purchaser of a copyrighted work, such as a book or a CD, to resell or lend it without infringing copyright, known as exhaustion of rights internationally. This rule clarifies that copyright controls the distribution of copies but not the resale of legitimately obtained copies.

Some countries impose restrictions on parallel imports, allowing copyright holders to control resale and distribution across borders, which may affect pricing and market availability.

PROTECTION OF INDUSTRIAL DESIGN, LAYOUTS, TRADE SECRETS AND TRADITIONAL KNOWLEDGE IN INDIA

Article ID: AG-VO6-I01-28***¹Krishnan, V., ¹N. Swaminathan, ¹V. Ramesh, ²J. Arathi and ³M. K. Sakthi Anand**

¹Faculty, ²PG Scholar & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and
Research Institute, Karaikal 609603, U. T. of Puducherry, India

***Corresponding Author: V.Krishnan**

1. Introduction

Intellectual Property Rights (IPR) are essential legal tools that protect the creations of the mind, encourage innovation, and promote economic growth. By granting exclusive rights to inventors, creators, and businesses, IPR ensures that investments in developing new products, technologies, and brands are rewarded while also stimulating further research and creativity. India's intellectual property framework, aligned with international conventions such as TRIPS, the Paris Convention, and the Madrid Protocol, offers comprehensive coverage of various types of intellectual property. This essay discusses the protection of designs and layouts, trade secrets and traditional knowledge, trademarks, and the ownership and duration of protection in the IPR regime, providing detailed examples and procedural guidelines relevant to both Indian and international contexts.

2. Industrial Designs and Layouts

Designs under intellectual property law refer to the unique visual and aesthetic features of products, such as the shape, pattern, colour, or configuration, that give a distinctive appearance and appeal to the consumer. These elements are crucial for product differentiation in the market and add substantial value to goods, fostering competition and innovation.

In India, design protection is administered under the Designs Act, 2000, which provides legal safeguards for original, new, and non-obvious designs applied to an article manufactured or imported in India. To be eligible for protection, a design must not have been published anywhere in the world before application and must not be dictated purely by the product's technical

function. The registration process begins with filing a detailed application, including clear representations of the design and a statement identifying the article. Following a formal examination by the Patent Office, the design is published in the official journal for public viewing. Provided no objections are raised, registration is granted and confers exclusive rights for a period of ten years, which can be extended by a further five years upon renewal.

In addition to industrial designs, India separately protects the layout designs (topographies) of semiconductor integrated circuits under the Semiconductor Integrated Circuits Layout-Design Act, 2000. This legislation is vital for protecting the creative graphical representations embedded in microchips, granting the right holder exclusive use for ten years from the date of registration.

India's design statute is harmonised with international obligations under the Paris Convention and the TRIPS Agreement, which set minimum standards for design protection. However, India has not yet acceded to the Hague Agreement for international design registration, meaning applicants must file design applications individually in each country where protection is sought. In practice, industries such as automotive, electronics, and fashion in India actively leverage design rights to protect innovations—for example, Tata Motors holds registered design rights for proprietary car body shapes that distinguish its vehicles from rivals.

The Designs Act, 2000 is the principal statute governing protection of industrial designs in India. It applies to features that are new or original and not previously published anywhere worldwide. Protection excludes technical functions or processes.

1. Eligibility: The design must be original and novel and applied to an article capable of industry use.

2. Registration Procedure:

- Application is filed with the Controller General of Patents, Designs, and Trademarks detailing the design representation and article specification.
- Formality check and examination occur, typically completed within 2-6 months.
- Upon meeting requirements, the design is registered and published in the Official Journal.

3. Duration: Initially 10 years of exclusive rights from the date of registration, extendable by 5 additional years.

Table 1. Protection duration for Design and Layouts

Aspect	India	International Standards	Protection Duration
Industrial Designs	Designs Act, 2000	Paris Convention, TRIPS	10 years + 5 years extension
Semiconductor Layouts	Semiconductor Layout-Design Act	Agreement on Trade-Related Aspects of IP Rights (TRIPS)	10 years

3. The Creative and Analytical Process of Industrial Design

Although industrial design is often considered a creative discipline, it also involves multiple analytical processes. Designers employ methodologies such as user research, sketching, comparative product research, model making, prototyping, and testing. These processes may be applied chronologically or adapted flexibly by the designers and their teams. Industrial designers frequently utilise 3D software, computer-aided industrial design (CAID), and CAD programs to transform concepts into production-ready models.

They are also responsible for defining product characteristics such as overall form and structure, the placement of details, colour, texture, sound, and ergonomic considerations. In addition, they may influence the production process, the choice of materials, and the way the product is presented to consumers at the point of sale. The involvement of industrial designers in product development often results in enhanced usability, reduced production costs, and greater consumer appeal. Some classic examples of industrial design that are celebrated both as works of art and as engineering achievements include the iPod, the Jeep, the Fender Stratocaster, the Coca-Cola bottle, and the Volkswagen Beetle.

4. Broader Scope and Values in Industrial Design

Industrial design extends beyond aesthetics to encompass technical concepts, usability, engineering, and market positioning. It also considers psychological and emotional dimensions, such as user desire, seduction, and attachment to the product. These broader values and aspects vary across different schools of thought and among practicing designers. While some approaches emphasise artistic styling, others belong to the functionalist school, where usability and ergonomic efficiency are prioritised over appearance.

5. Overlaps with Related Design Fields

Industrial design and product design frequently overlap with related areas, including user interface design, information design, and interaction design. Educational programs also reflect this diversity: some art colleges focus heavily on product styling, while mixed programs integrate engineering with design. In contrast, other schools treat aesthetics as secondary to functionality and ergonomics, aligning more with functionalist principles. Related disciplines such as exhibit design and interior design are also closely connected with industrial design practices.

6. Industrial Design Engineer

The term *Industrial Design Engineer* describes professionals who combine creative design ability with strong technical competence. These designers bridge the gap between artistry and engineering in the development of products. James Dyson, the inventor of the Cyclone vacuum cleaner, is a well-known example of such a designer, embodying the integration of innovative design and technical precision.

7. Trade Secrets

A trade secret means information, which is kept confidential as a secret. This is generally not known in the relevant industry, offering an advantage to its owner over other competitors. Unlike other types of Intellectual property, this trade secret is fundamentally a "do-it-yourself" type of protection. For engineers, inventors, and designers, the trade secrets are to be maintained secretly. Such trade secrets include some formulae, programmes, methods, progresses or data collections etc. If there is any improper disclosure or use of the trade secret by another person, the inventor may claim and recover damages resulting from illegal use.

TRIPS agreements offer the protection for trade secrets under the heading 'protection of undisclosed information'. The engineer in competitive field should feel their responsibility and status when they make use of such trade secrets till its disclosure. If the information of a trade secret is available through any legitimate means and if any inventor is responsible illegally for such leaking, then the trade secret may become ineligible for protection. Enforcement of Intellectual Property Rights is definitely private rights. If anybody uses the material without the inventors' permission, the Intellectual Property right owners can use any remedies available under the civil law.

Trade secrets pertain to confidential business information or technical know-how that provides a commercial advantage due to its secrecy. Unlike patents, trade secrets do not require formal registration and can be protected indefinitely as long as the information remains undisclosed. Indian law protects trade secrets principally through contract law and common law doctrines related to breach of confidence and fiduciary duties. Companies often use non-disclosure agreements (NDAs) and strict internal protocols to safeguard proprietary formulas, manufacturing processes, business strategies, and source code. Internationally, protection of undisclosed information is mandated by Article 39 of the TRIPS Agreement, obligating members to prevent its unauthorised use and disclosure.

8. Protection of Undisclosed Information (Trade Secrets)

Trade secrets or undisclosed information refer to confidential business information that provides a competitive advantage because it is not generally known or readily accessible.

Characteristics of Trade Secrets

- The information is secret, meaning it is not publicly known within the relevant business circles. It has commercial value precisely because it remains secret.
- The owner has taken reasonable measures to maintain its secrecy.

Examples include formulas, methods, processes, patterns, compilations, and techniques.

9. Legal Status and Protection in India

- India does not currently have a dedicated statute exclusively for trade secrets.
- Protection is primarily provided under contract law (for example, confidentiality agreements) and common law principles.
- The Indian Contract Act, 1872, and certain provisions of the Indian Penal Code (Nyaya Sanhita), as well as the Information Technology Act, 2000, provide indirect protection.
- Recent developments include the proposed Protection of Trade Secrets Bill, 2024, which aims to establish a comprehensive legal framework addressing trade secret misappropriation, enforcement, and remedies.
- The Bill defines trade secrets precisely and introduces strong mechanisms for legal recourse in commercial courts, including injunctions and damages.

Protection of undisclosed information is critical for industries, research institutions, and businesses relying heavily on innovation and confidential know-how. Despite being less

discussed than patents or copyrights, trade secret protection is often the most vital and practical form of intellectual property protection for many sectors.

10. Traditional Knowledge

Traditional Knowledge (TK) comprises community-held knowledge systems concerning medicinal plants, agricultural methods, artisanal crafts, and cultural practices. Such knowledge often predates modern scientific documentation but holds immense value to indigenous and local communities. The need to protect TK arises primarily to prevent biopiracy—where external entities seek unauthorised patents or commercial exploitation of indigenous knowledge without appropriate consent or benefit-sharing.

Traditional knowledge (TK) encompasses indigenous knowledge systems and practices related to agriculture, healthcare, and biodiversity.

- Legal Safeguards in India: The Traditional Knowledge Digital Library (TKDL) systematically documents traditional medicinal formulations to prevent wrongful patenting (biopiracy).
- The Biological Diversity Act, 2002 requires prior approval from the National Biodiversity Authority for accessing biological resources or associated knowledge.
- Protection involves defensive disclosure and use of existing IPR to prevent misappropriation, as TK itself generally is not patentable.

18.4. Procedure for Protection of TK

- Documentation through projects such as TKDL.
- Registering related innovations under relevant IPRs (*e.g.*, patents for improved formulations).
- Legal recourse through biodiversity regulations and anti-piracy actions.

Example

India successfully defended traditional medicinal knowledge of turmeric and neem against unauthorised patent claims using TKDL evidence in the US and Europe. The protection mechanisms for TK align defensive documentation with trade secret strategies, allowing communities to maintain control over the dissemination and commercialisation of their knowledge. India has successfully contested several foreign patents regarding turmeric, neem, and other traditional remedies through evidence supplied *via* TKDL, demonstrating the efficacy of this approach.

TRADEMARK POLICY IN INDIA

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¹Swaminathan, N., ^{1*}V. Krishnan, ¹V. Ramesh, ²M. K. Sakthi Anand and ³J. Arathi¹Faculty, ²Ph. D. Scholar & ³PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V. Krishnan

1. Introduction

A trademark is a distinctive sign, symbol, or indicator utilised by an individual, business, or legal entity to identify its goods or services as originating from a unique source. This identification allows consumers to distinguish these goods or services from those of competitors. A word, phrase, symbol, logo, or design used to identify and distinguish goods or services in commerce. The primary purpose of trademarks is to protect the goodwill of a business, ensure product differentiation, and prevent consumer confusion. The scope of a trademark is broad and may include a name, word, phrase, logo, symbol, design, image, shape, packaging, sound, colour combination, or any combination thereof. There are also non-conventional trademarks that include unusual marks such as smell marks, sound marks, or colour marks that do not fit into traditional categories. Famous examples of trademarks include the word mark “NIIT,” the fanciful word mark “Kodak,” and device/logo marks like the “Apple logo.”

2. Concepts of Trademarks

Purpose of Trademarks: To protect brand identity by preventing confusingly similar marks that could mislead consumers.

Scope of Protection: Covers commercial identifiers like brand names, logos, slogans, and service marks. Exclusive rights to use the mark on covered goods/services and prevent infringement.

Exclusivity rights: Right to use the mark exclusively for goods/ services and to stop others from using confusingly similar marks.

Ownership is with the registrant; can be assigned or licensed subject to legal requirements.

Duration: Valid for 10 years from the date of application, renewable indefinitely every 10 years on payment of renewal fees.

Table 1. Protection period of Trademarks

Trademark Feature	Indian Regulation	International Treaty	Protection Duration
Registration Law	Trade Marks Act, 1999	Madrid Protocol (WIPO)	10 years, renewable indefinitely

International coverage: Territorial, though treaties (Madrid Protocol) help in international protection.

Overlap with others: A slogan may be trademarked, while the same ad's text/design may be copyrighted.

Registration process: Moderate to high cost, lengthy, involves examination for similarity with existing marks.

Infringement test: Whether consumers are likely to be confused between marks.

Licensing: No concept of compulsory licensing; protection tied to commercial use.

3. Symbols Used for Trademarks

Certain symbols indicate the status of trademarks. The symbol TM denotes an unregistered trademark used to promote or brand goods without formal registration. The symbol SM indicates an unregistered service mark used specifically for services. The symbol ® indicates a registered trademark, signifying legal protection granted for that trademark under the law.

Table 2. Symbols for different types of Trademarks

Symbol	Meaning	Usage
TM	Unregistered trademark	Used to promote or brand goods without registration
SM	Unregistered service mark	Used to promote or brand services
®	Registered trademark	Indicates legal protection for a registered trademark

4. Importance of Trademarks

Trademarks perform several critical functions: they enable consumers to identify the

source and quality of goods or services, prevent unauthorised use or counterfeiting, provide legal remedies when infringements occur, and enhance brand reputation while fostering consumer loyalty.

5. Types of Trademarks

There are different categories of trademarks, each with varying degrees of protectability:

1. **Generic Marks:** These are common terms that identify the goods themselves, like the word “Milk” for dairy products, and generally cannot be protected as trademarks.
2. **Descriptive Marks:** These directly describe a product’s purpose, function, or quality, such as “Cold & Creamy” for an ice cream brand. These marks have weak protection unless they acquire secondary meaning from extensive use.
3. **Suggestive Marks:** They hint at certain characteristics of a product but require imagination by the consumer to connect to the product, for example, “Netflix” for internet films. These are inherently distinctive and generally protectable.
4. **Arbitrary Marks:** These are common words used in a context unrelated to their literal meaning, such as “Apple” for electronics, and enjoy strong protection.
5. **Fanciful Marks:** These are invented or created terms with no prior meaning, exemplified by “Kodak” or “Xerox,” and receive the highest level of trademark protection.

6. Trademark Registration

Trademarks are considered a form of property, and rights may be established either through actual use in the marketplace or formal registration with the trademarks office. Some jurisdictions operate on a first-to-use principle, recognizing rights from actual usage, while others follow first-to-file, where the first to register obtains rights.

The registration process, illustrated here with the U.S. example, begins with application filing at the United States Patent and Trademark Office (USPTO). The application undergoes examination for classification and compliance with distinctiveness and prior conflicts. If objections arise, an office action is issued for the applicant’s response. After passing this review, the mark is published for opposition over 30 days, during which third parties may oppose the registration. If unopposed or if opposition is overcome, the trademark is registered. In many countries outside the U.S., trademark registration typically occurs before opposition proceedings, and the opposition period may last approximately six months after registration.

Registration Process involves

1. Filing an application in the prescribed form with detailed description and representation.
2. Examination by the Trademark Office for distinctiveness and conflicts.
3. Advertisement in the Trademark Journal to invite objections
4. Registration granted if no opposition or after successful opposition proceedings.

7. Rights of Trademark Owners

Owning a registered trademark grants exclusive rights to use the mark relative to the goods or services registered. The owner can prevent unauthorised or confusingly similar use by others, including extending protection against use on dissimilar goods or services if such use is likely to cause consumer confusion. Trademark rights are territorial, valid only within the jurisdiction of registration.

8. International Protection of Trademarks

Despite their territorial nature, trademarks can receive wider protection through international agreements. The TRIPS Agreement (1994, WTO) sets minimum standards for IPR protection globally. The Madrid Protocol (1989) facilitates international registration through a single application process, and the Paris Convention (1883) guarantees trademark protection among member countries based on priority filing dates.

9. Trademark Laws in India

Historically, India's trademark protection began with the Trade and Merchandise Marks Act of 1958. The comprehensive Trade Marks Act, 1999 marked a significant reform to align India's trademark laws with globalization trends, the TRIPS Agreement, and modern commercial practices. Under the Trade Marks Act, 1999, a trademark is defined as a mark capable of graphical representation and able to distinguish the goods or services of one person from those of another. The term "mark" includes devices, brands, logos, signatures, numerals, shapes of goods or packaging, and colour combinations. The Act also recognizes collective and certification marks.

10. Trademarks: Ownership and Period of Protection

Trademarks are signifiers such as logos, brand names, slogans, or symbols used to distinguish the goods or services of one entity from others. They play a critical role in building brand identity, fostering consumer trust, and facilitating market competition. India's trademark system is governed by the Trade Marks Act, 1999, enforced by the Office of the Controller

General of Patents, Designs, and Trademarks. The rigorous registration process includes filing a detailed application, substantive examination for distinctiveness and conflicts, public advertisement in the Trademark Journal for opposition, and final registration. Upon registration, the owner receives exclusive rights to use the mark on designated goods/services and to prevent unauthorised use or infringement.

11. Nature and Function of Trademarks

Trademarks protect signs, logos, and symbols that uniquely identify goods or services, playing a crucial role in brand building and consumer trust.

18.5.2. Indian Legal Framework

The Trade Marks Act, 1999 is the governing law for trademark registration and enforcement in India. India's accession to the Madrid Protocol has streamlined the trademark registration process for Indian and foreign businesses, enabling protection in multiple countries through a single international application. Famous international brands such as Apple, Nike, and McDonald's have successfully used trademark protection in India to prevent unauthorised use and counterfeit products, thereby securing their market position.

18.5.3. International Protection

India is a signatory to the Madrid Protocol, facilitating trademark protection across multiple countries from a single application, reducing costs and administrative burdens for applicants.

Example

Multinational corporations like Coca-Cola, Samsung, and Google hold trademark registrations in India, leveraging protections to combat counterfeit products and unauthorized use. Registered trademarks in India remain valid for ten years from the filing date and can be renewed indefinitely in successive ten-year phases by paying renewal fees and demonstrating continued use. India's membership in the Madrid Protocol facilitates international trademark protection, enabling applicants to seek trademark registrations in multiple countries through a single streamlined filing. Global corporations such as McDonald's, Coca-Cola, and Samsung effectively utilize India's trademark system to protect their brands, combat counterfeits, and maintain consumer confidence.

10. Remedies under the Act

The Act provides broad protections. Both registered and unregistered marks receive

protection; registered marks are covered under civil remedies, while unregistered marks may receive protection against unfair use under criminal law. Thus, Indian law offers robust safeguards to trademark owners. Trademarks are indispensable tools in trade and commerce, shaping brand identity and consumer loyalty. While registration strengthens these rights, unregistered trademarks may also be protected in specific circumstances. The distinctiveness of a mark largely determines its strength and scope of legal protection. The Trade Marks Act, 1999, has modernised India's trademark framework, harmonising it with international standards under TRIPS, thereby providing a firm legal foundation for protecting brand equity in India's dynamic market environment.



CLASSIFICATION OF CULTIVATED CAPSICUM ANNUUM CHILI PEPPERS

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¹*Krishnan, V., ¹V. Kanthaswamy, ¹M. S. Marichamy, ²N. Bavya and ³B. Bavithra,

¹Faculty, ²PG Scholar & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V.Krishnan

1. Introduction

Chili is grown throughout the country and is used in almost all dishes. Chillies are of numerous and their degree of pungency varies. Dry and fresh Chillies 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. Chillies 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.

Capsicum annum: This species is cultivated worldwide and it produces fruits of many colours including red, green, and yellow, often with pungent taste. *Capsicum annum* is the primary species in its genus, as it has been widely cultivated for human consumption for a substantial amount of time and has spread across the world. This species has many uses in culinary, medicine, self-defense, and ornamental applications. This species is further grouped into the following botanical varieties and forms as detailed below.

a. Cayenne peppers or long chili peppers (*Capsicum annum* var. *longum*): Cayenne types are long, slender, and curved fruits with high pungency. They are often sun-dried and ground into powder, commonly used in spice blends and chilli flakes. These are called red hot chillies or cow horn pepper and are the most common chili pepper that are largely used in various curry

preparation by use of the ground chili powder. Cayenne peppers are a group of tapering, 10 to 25 cm long, generally skinny, mostly red-coloured peppers, often with a curved tip and somewhat rippled skin, which hang from the bush as opposed to growing upright. Most varieties are generally rated at 30,000 to 50,000 Scoville units (SHU). This long chili pepper includes the following varietal forms.

- i. Kashmir chili pepper:** Native of Kashmir valley, India. The fruits are deep red in colour, but not hot to taste. They are used to add colour to any dishes. It has 200 SHU.
- ii. Jwala chili pepper:** This is native of Gujarat, India. These have spicy taste and are served sparingly with evening snacks such as samosa, batata and vadas as an accompaniment. It is green when young and turns red at maturity. It has 20,000 to 30,000 SHU.
- iii. Guntur chili pepper:** This is native of Guntur region of Andhra Pradesh. These are India's hottest chillies and are used in cuisine of Andhra Pradesh, which are lot spicier than any other Indian cuisines. It has 3,00,000 to 3,50,000 SHU.
- iv. Byadgi chili pepper:** This is native of Byadgi region, Haveri district of Karnataka. It is known for its colour and spice. They add dark red colour to the curries and especially used in Udupi cuisine. It has 50,00 to 1,00,000 SHU.
- v. Long Cayenne peppers:** These are 8-12 inches long, spicier chillies, also called super long cayennes. It has 50,000 SHU.
- vi. Dragon Cayenne pepper:** These are 7-10 inches long, hot chillies, dark red in colour and used to prepare red hot sauce. It has 30,000 to 50,000 SHU.
- vii. Red Ember peppers:** These are 6-8 inches long, pretty spicy with thick fruit wall. They have 30,000 to 50,000 SHU.
- viii. Red Rocket peppers:** These are 4-6 inches long and are bright red in colour. They are moderately spicy and can be used fresh as well as dried form. It is used to make red pepper flakes and hot sauce. It has 30,000 to 50,000 SHU.
- ix. Purple Cayenne peppers:** These are 3-5 inches long. They change from green to purple instead of red at maturity.
- x. Golden Cayenne peppers:** These grow up to 12 inches long and produce yellow-coloured fruits. They are moderately hot and have 30,000 to 50,000 SHU.

xi. Orange Cayenne peppers: These are elongated, slender straight to curved conical shaped, thin-walled chillies with tapering end. Fruits that are dark green at start and they turn to bright orange and contain flat, round cream-coloured seeds. They have mild flavour and have 30,000 to 50,000 SHU.

xii. Sweet Cayenne peppers: These are sweet in taste and have up to 12 inches long, with crunchy, thin-walled fruits. They start with green fruits and turn to red at maturity. They are excellent for stir fries, salsa. They are less hot and have 1000 SHU.



Fig. 1. Different cultivated types of Cayenne Peppers. A. Kashmir Chili, B. Jwala Chili, C. Guntur Chili, D. Byadgi Chili, E. Long Cayenne Pepper, F. Dragon Cayenne Pepper, G. Red Ember Pepper, H. Red Rocket Pepper, I. Purple Cayenne Pepper, J. Golden Cayenne Pepper, K. Orange Cayenne Pepper and L. Sweet Cayenne Pepper

b. Jalapeño peppers (*Capsicum annuum* var. *annuum*): Jalapeños are medium sized chili peppers that have thick skin, blunt-ended fruits with moderate pungency. Milder Jalapenos are smooth and white streak mark on them indicate their age and hotness. They are rich in Vitamin A and C. They are consumed fresh, pickled, or smoked (in which case they are called chipotle) or fried or wrapped or stuffed and are a staple in Mexican and Tex-Mex cuisine. This variety have the following types.

i. Mucho Nucho Jalapenos: These are larger Jalapenos growing up to 4 inches length. It starts off green and turn red. These are extremely hot.

ii. Goliath Jalapenos: These are the largest Jalapenos reaching up to four and half inches. They are thick walled with broad shoulders having shiny medium green to start and turns bright red at ripening. Highly suited for grilling, slicing and stuffing.

iii. Striped Jalapenos: The plant has a pattern of white and green variegated foliage and the unripe fruit has white stripes on green background.

iv. Lemon spice Jalapenos: They have yellow ripening fruits that notably small, but delicious in taste having 7500 SHUs.

v. Purple Jalapenos: They produce purple to deep black coloured fruits that contains plenty of antioxidants, but are less flavourful.

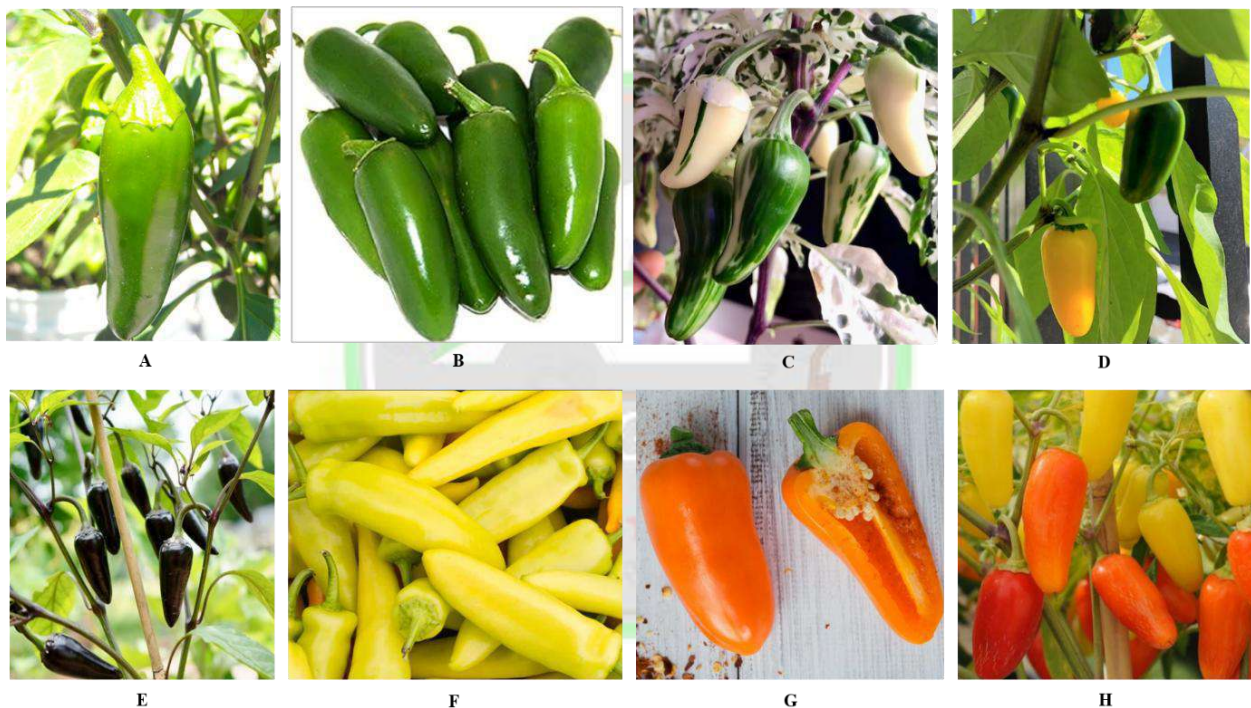


Fig. 2. Different cultivated types of Jalapeno Peppers. A. Mucho Nucho Pepper, B. Goliath Jalapeno Pepper, C. Striped Jalapeno Pepper, D. Lemon Spice Jalapeno Pepper, E. Purple Jalapeno Pepper, F. Golden or Yellow Jalapeno Pepper, G. Orange Jalapeno Pepper and H. NuMex Pinata Jalapeno Pepper

vi. Golden or yellow Jalapenos: The fruits are golden yellow to orange and end up red. It is having slight fruity taste and mild in hotness. It is bit larger than regular green jalapenos and mostly used for pickling.

vii. Orange Jalapenos: These produce juicy, sweet, thick-walled fruits of 3.5 inches long with citrus flavour. It starts off green and eventually turn vibrant orange before ripening to red. It has medium hotness.

viii. NuMex Pinata Jalapenos: They produce multicoloured fruits that are green to bright yellow to orange and finally red. It has 50,000 SHUs. It is an aromatic variety ideal for making colourful salas.

c. Paprika: Paprika is a large cone-shaped chili pepper, growing up to 8 inches and are generally non-pungent or mildly pungent, with bright red, thin-walled fruits. They are sun-dried and ground into paprika powder, widely used for its vibrant colour and mild flavour (250 TO 1000 SHUs) in cuisines globally. Paprika peppers are basically classified into two main subgroups viz.,

i. Hungarian paprika: These paprika are known for gold standard high quality paprika that are available in various flavours from sweet to hot. The sweet Hungarian paprikas are used for bajji making in India, which is nothing but Bengal gram flour dipped deep fried crispy snacks very popular in India. Hungarian paprika is further classified into five groups based on sweet to hotness viz.,

a. Kulonleges: Exquisite delicate sweet

b. Edesnemes: Delicate noble sweet

c. Feledes: Semi-sweet

d. Roza: Rose in colour and mildly hot

e. Eros: Hot

ii. Spanish paprika or Pimenton: These paprika are only secondary to Hungarian paprika. These are used to produce smoky paprika powder that are rich in smoky flavour. Spanish paprika are very popular Spanish dishes like Chorizo and Paella. The Spanish paprikas, based on sweet to spicy are classified into three subgroups viz.,



A



B

Fig. 3. Two major types of Paprika Peppers. A. Hungarian Parika and B. Spanish Paprika

a. **Pimenton dulce:** Mild flavour

b. **Pimenton agridulce:** Mildly spicy

c. **Pimenton picante:** More Spicy

d. **Serrano peppers: (*Capsicum annuum* var. *serrano*):** The word ‘Serrano’ was derived from *Sierrras* meaning mountain, due to the reason that Serrano peppers have originated in the mountainous regions of Mexican state. They have a hot and biting flavour with SHU value of 10,000 to 25,000. These are nine times hotter than Jalapenos pepper and are used to make hot sauce. The Serrano peppers are classified into five main groups viz.,

i. **Regular Serrano:** These are the most common Serranos found in gardens and supermarkets. The fruit is 2-4 inches long, bright green colour when unripe, turning to orange or yellow as it ripens. The SHU value is 8,000 to 23,000. They are quite spicy.

ii. **Tampiqueno Serrano:** These are similar to regular Serrano in heat level and size, but Tampiqueno starts off green but eventually turns a deep red colour as it matures.

iii. **Tipico Serrano:** These are slightly larger than Regular Serrano, growing up to 5 inches long. It starts off green and changes colour as it ripens to red or yellow. It has a fruity flavour that compliments its spiciness.

iv. **Chiapas Serrano:** These are native to Southern Mexico and named after the State of Chiapa. These are similar to Regular Serrano, but has smoky flavour and are mostly used for pickling.

v. **Poblano Serrano:** These are milder in heat, but still have a bit of spiciness. They are 4-6 inches long. They start off green and eventually turn a dark red or brown colour when fully ripe.

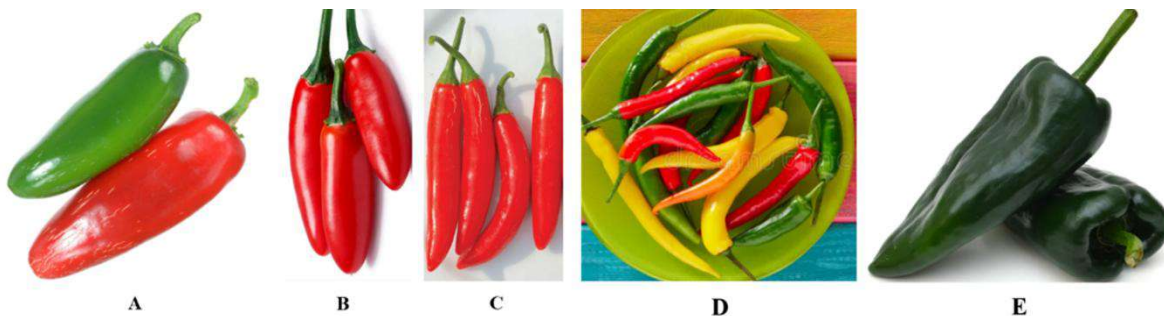


Fig. 4. Different types of Serrano Peppers. A. Regular Serrano, B. Tampiqueno Serrano, C. Tipico Serrano, D. Chialpas Serrano and E. Poblano Serrano

e. **Chiltepin peppers or Bird’s peppers or Bird’s eye peppers (*Capsicum annuum* var. *glabriusculum*):** Considered one of the wild ancestors of cultivated *Capsicum annuum*, Chiltepin

produces tiny, round, very pungent, upright fruits native to North America. The fruits of Chiltepin peppers are often red or orange-red in colour, measuring less than half an inch in diameter, but having powerful punch in terms of heat between 50,000 to 1,00,000 SHU. These chillies are often used in traditional medicines and local dishes in the Americas.

f. Friggittello or Golden Greek pepper", "Sweet Italian pepperoncini", or "Tuscan pepper: (*Capsicum annuum* var. *friggittello*): These peppers are mild with a slight heat and a hint of bitterness, and is sometimes pickled and sold in jars. It has a complex flavour which is appreciated most when it is eaten fresh. It lends itself very well to sautéing, stuffing, and popping. It combines nicely with fruits and is a suitable ingredient to use in salads and compotes or on sandwiches.

g. Mundu Chili or Ramnad Gudu Chili or Cherry Peppers (*Capsicum annuum* var. *conoides*): These are round-shaped chilli, grown in the Ramnad district in Tamil Nadu, India, It is also called Ramnad red mundu chilli. Especially, Mundu red chilli is very popular in south Indian cuisine, It has a dark shiny & thick skin. Available with or without the stem. This Ramnad red mundu chilli has a good flavour and aroma, exported worldwide. Also, Used for food colouring.

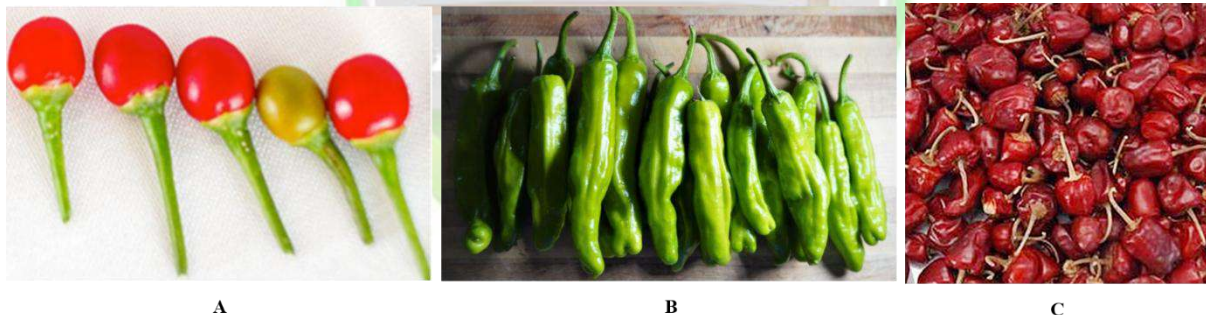


Fig. 5. A. Chiltepin Peppers, B. Friggittello Peppers and C. Ramanad Mundu chili peppers of *Capsicum annuum* species

h. Bell peppers or Capsicum (*Capsicum annuum* var. *grossum*): Bell peppers are native to Mexico, commonly called Capsicum in India. Cultivars of the plant produce fruits in different colors, including red, yellow, orange, green, white, chocolate, candy cane striped, and purple. Bell peppers are sometimes grouped with less pungent chili varieties as "sweet peppers" and mostly have an SHU value ranging from 0 to 500. They have mild flavour, non-pungent, deeply lobed fruits with thick crisp walls. Their vibrant colours, crisp and juicy texture and mildly-spicy taste add to the visual and culinary appeal of any dish. These are rich in Vitamins A, B₆, C, E,

fibre as well as rich in antioxidants that can prevent heart diseases and cancer. There are 12 major cultivated types of Bell peppers viz.,

i. *Etiuda* or Squash Bell Peppers: These are large, orange bell peppers, reminiscent of Pumpkins with extremely thick walls, weighing half a pound with sweet flavour of citrus profile.

ii. *Cholate Beauty* Bell peppers: These are chocolate brown coloured with orange or brown flesh, 3-4 lobed fruit that matures in 70 days.

iii. *Purple Beauty* Bell Peppers: These have contrasting purple skin and green flesh that are medium in size.

iv. *California Wonder* Bell pepper or *Classic Green* Bell peppers: These are the most popular Bell peppers that starts off green and ripen to red. They are good to pickle at early stage, mildly bitter with crisp texture and rich in Vitamin C.

v. *Quadroto D'asti Giallo* Bell peppers: These are native of Italy that start out green and turns yellow. They have thick walls. Some mature fruits keep a little bit of its green, sweeter than Classic green, milder in taste and high in antioxidants and Vitamin C.

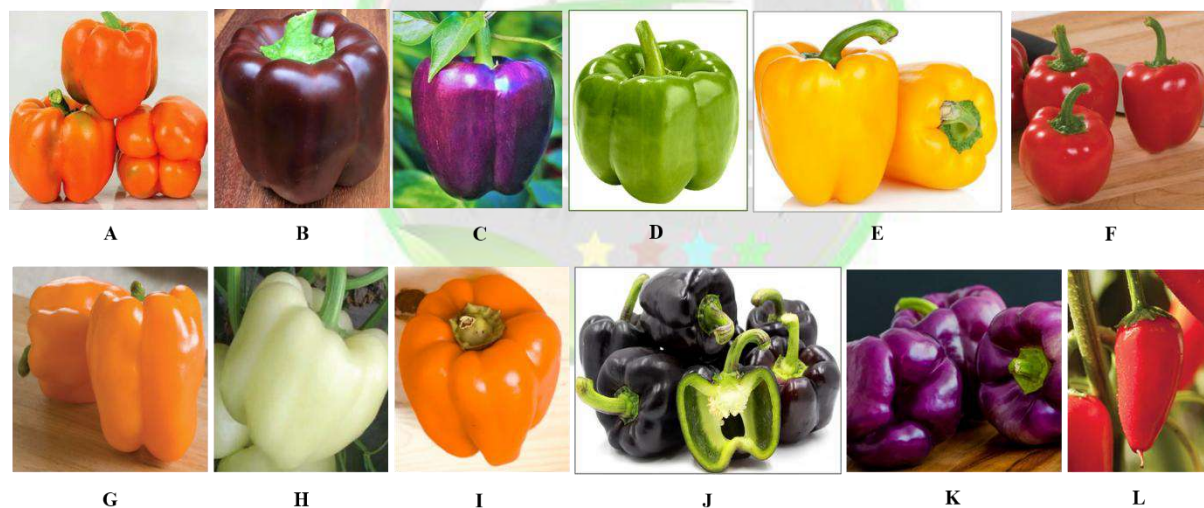


Fig. 6. Different cultivated types of Bell Peppers. A. *Etiuda* Bell pepper, B. *Chocolate Beauty* Bell pepper, C. *Purple Beauty* Bell pepper, D. *Californian Wonder* or *Classic Green* Bell pepper, E. *Quadroto D'asti Giallo* Bell pepper, F. *Cupid* Bell Pepper, G. *Gourmet* Bell pepper, H. *White* Bell pepper, I. *Sweet Sunrise* Bell Pepper, J. *Black* Bell pepper, K. *Island Sweet* Bell pepper and L. *Pimiento* Bell Pepper

vi. *Cupid* Bell peppers: These are small sized bell peppers with 2 inches diameter. These mature from green to red and are quite sweet and flavourful when fully ripe. They are rich in antioxidants.

vii. *Gourmet* Bell Peppers: These are bright orange coloured, medium sized and medium thick-walled fruits that have a fruity and sweet flavour and rich in Vitamin A & C.

viii. White Bell peppers: These are medium to large sized bell peppers that grow as a translucent white coloured and ripen into a pale-yellow colour.

ix. Sweet Sunrise Bell Pepper: These start with dark green fruits and turns into a yellow or orange colour when fully ripened. It has a fruity sweet flavour.

x. Black Bell peppers: These have a dark fruit colour, thick skin and sweet taste, creating a smoky flavour in the mouth when eaten.

xi. Islander Sweet Bell peppers: These are medium sized peppers that has thick flesh and give a mild sweet flavour. The fruit ripens from green to violet, yellow and orange pattern.

xii. Pimiento Bell peppers: These are sweet, succulent and more aromatic than red bell peppers. These are large red, heart shaped and is used for stuffing olives, cheese, loaf and other dishes.



BOTANICA OF CHILI AND CAPSICUM

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¹Marichamy, M. S., ¹V. Kanthaswamy, ¹*V. Krishnan, ²N. Bavya and ³B. Bavithra¹Faculty, ²PG Scholar & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V. Krishnan

1. Introduction

The chilli (*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 chillies in the international markets and exports dry chilli, chilli 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 Andhra Pradesh, followed by Karnataka, Himachal Pradesh, Maharashtra Odisha and Tamil Nadu, especially under protected environments. Indian chillies 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 chilli.

2. TAXONOMY OF CHILI AND CAPSICUM

Kingdom	Plantae
Sub kingdom	Trachobionta
Division	Magnoliophyta

Class	Equisetopsida
Sub class	Magnolidae
Order	Solanales
Family	Solanaceae
Genus	<i>Capsicum</i>
Species	<i>annuum</i>

Table 1. Taxonomic characters of five cultivated species of *Capsicum*

Species	Corolla colour	Corolla throat spot	Corolla shape	Calyx teeth	Anther colour	Seed colour
<i>Capsicum annum</i>	White	None	Rotate	Present	Blue purple	Tan
<i>Capsicum frutescens</i>	Greenish white	None	Rotate	None	Blue	Tan
<i>Capsicum chinense</i>	White greenish	None	Rotate	Present	Blue	Tan
<i>Capsicum baccatum</i>	White	Green yellow	Rotate	Present	Yellow	Tan
<i>Capsicum pubescence</i>	Purple	None	Rotate	Present	Purple	Black

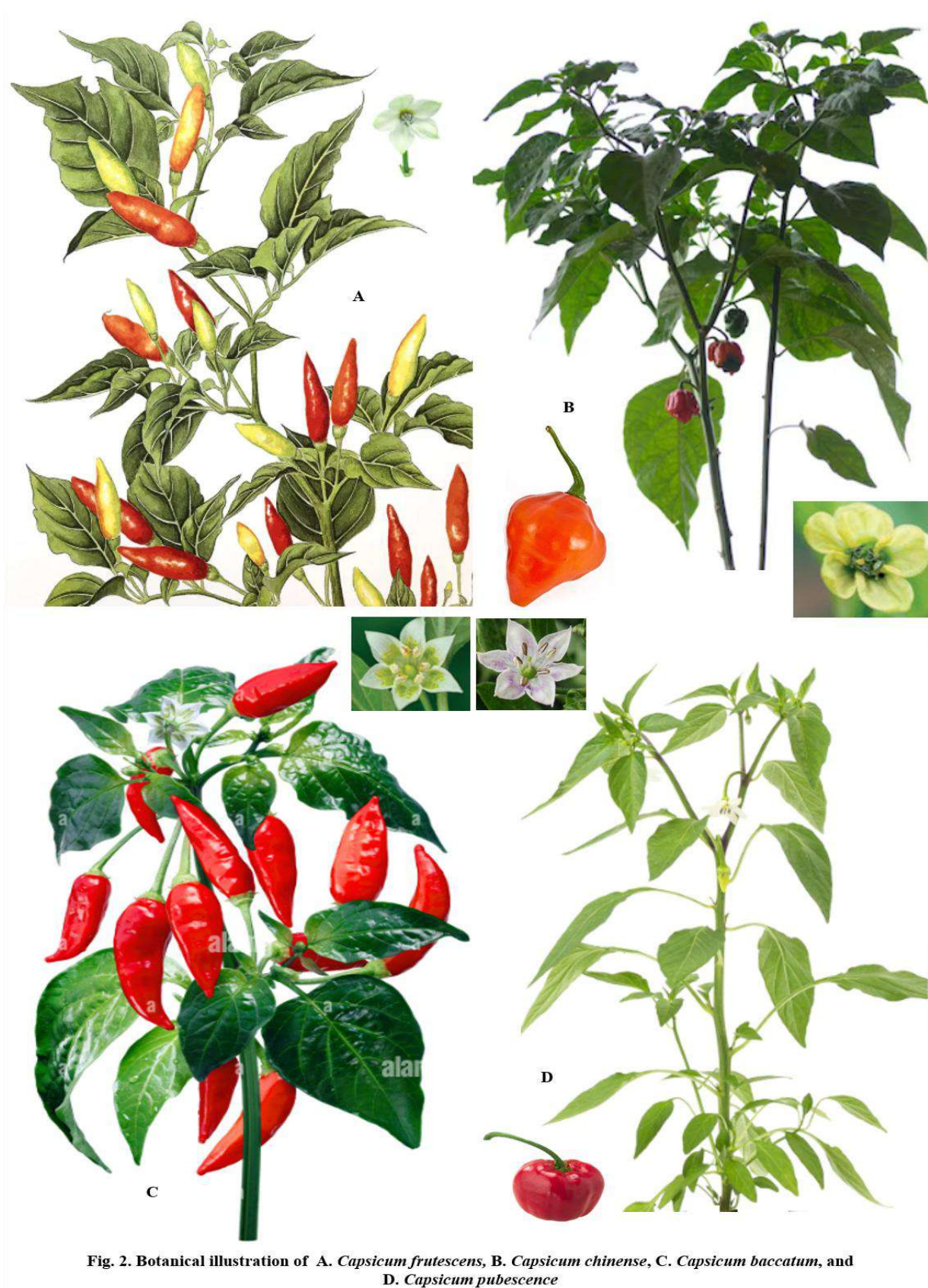
3. PLANT MORPHOLOGY

The botanical description of the four important species is described hereunder.

1. ***Capsicum annum***: Typically has erect plants that grow 1-1.5 meters tall. The leaves are simple and similar in size and shape. The leaf blade is ovate to elliptic, with a margin that ends in an acuminate or long-acuminate apex. The inflorescences are axillary, with one flower per axil, rarely more. The corolla is usually entirely white, occasionally entirely purple or pale yellow, with white or cream filaments, sometimes purple, and pale blue to purplish anthers. The berries are highly variable in size, shape (elongated, round, triangular, campanulate, or blocky), and colour (white, yellow, green, orange, purple, and deep purple when immature; lemon-yellow, pale yellow-orange, pale orange, orange, light red, red, dark red, purple, and purple-black at maturity). The seeds are pale yellow, with more than 50 seeds per fruit.



Fig. 1. Botanical illustration of *Capsicum annuum* species. A. Plant, B. Flower, C. Flower in vertical section, D. Carpel, E. Carpel in cross section, F. Stigma, G. Epipetalous stamens, H. Anthers (Dorsal and ventral view), I. Fruit, J. Fruit in cross section, K. Different shapes of fruit, L. Seeds, M. Enlarged view of seed and N. Cross section of seed



2. *Capsicum frutescens*: The plant's height ranges between 0.3 to 1.5 meters, branching from near the base. The leaf pairs are more or less similar in size and shape, with membranous, concoloured or slightly discoloured leaves that are glabrescent or glabrous on both surfaces. The blades of the leaves are ovate or narrowly elliptic, with entire margins and an acuminate to long-acuminate apex. Inflorescences are axillary, typically hosting 2-5 flowers per axil, with solitary flowers being a rare occurrence. The corolla is usually dull white or greenish-white both outside and within, stellate with an interpetalar membrane. Filaments come in cream or purple, and anthers are ellipsoid, bluish-grey, purplish, or, rarely, dark green or yellow, connivant at anthesis. The berry is typically green and yellowish-green when immature, transitioning to yellow, orange red as it matures. Seeds are C-shaped to sub globose, pale yellow, numbering from 10 to 52 per fruit.

3. *Capsicum chinense*: Erect plant, standing 0.5-2.5 meters tall, with few to many branches originating near the base. The leaf pairs are unequal in size but share a similar shape, with membranous, either concoloured or slightly discoloured leaves - dark green above and pale green below. The leaf blades are ovate to elliptic, featuring entire margins and a short acuminate, acuminate, or acute apex. Inflorescences are axillary, typically hosting 2-4 flowers per axil, occasionally with solitary flowers. The corolla is 5 or 6-merous, dull white or greenish-white, occasionally adorned with purple spots both outside and within. The corolla is stellate with an interpetalar membrane, and the filaments come in white, cream, or purple, inserted on the corolla. Anthers are usually blue or bluish-grey, with rare instances of yellow or greenish-white, broadly ellipsoid or ellipsoid, and connivant or not connivant at anthesis. The berry, measuring less than 10 mm in diameter, is sub globose and orange to red in wild populations. Highly variable in size, shape, and colour, it can be sub globose, triangular, long triangular, campanulate, or even blocky. The apex may be pointed, blunt, or long-acuminate and upcurved, while the base is obtuse or truncate. When immature, the colour ranges from green, yellow, brown, to purple, transitioning to pale yellow, yellow, dark brown, orange, red, or vermilion-scarlet at maturity. The fruits may be deciduous or persistent and are known for their intense pungency, though occasional non-pungent varieties exist. Seeds are C-shaped or sub globose, pale yellow, or nearly white, numbering from 14 to 35 per fruit.

4. *Capsicum baccatum*: Erect plants that can exceed a height of 2 meters. The leaf pairs are unequal in size but similar in shape, with membranous leaves that are slightly discoloured. The leaf blades are ovate, with entire margins and an acute apex. The inflorescences are axillary, with 2-3 flowers per axil, and occasionally solitary flowers. The flowers are campanulate, with a white corolla featuring greenish-yellow spots. The filaments are white, inserted on the corolla, and the ellipsoid anthers are white or pale yellow, occasionally greyish, and not connivent at anthesis. The berry is globose or sub globose, less frequently ellipsoid with a truncate or flattened apex. It is green when immature, turning to greenish-black and then bright red at maturity. The berry is deciduous, pungent, with a thick, opaque pericarp containing giant cells. Seeds are ovoid, sub globose, or C-shaped, pale yellow to yellow, with 12-15 seeds per fruit.

5. *Capsicum pubescence*: The plant habit is erect, reaching a height of 1 to 4 meters. The leaf pairs are markedly unequal in size, with similar or dissimilar shapes. The leaves are membranous, concolored or discolored, glabrescent to densely pubescent on both surfaces and margins, with trichomes similar to those on stems. The leaf blades are ovate or, more rarely, elliptic, with an asymmetric and attenuate or cuneate base, entire margins, and an acuminate apex. Inflorescences are axillary, typically hosting 1-2 flowers per axil, rarely up to four flowers. The corolla is dark purple or violet with a white center outside and within (sometimes with a weak yellowish-green center within). It is rotate to stellate, with a thin interpetalar membrane, pubescent adaxially with short glandular trichomes, and glabrous abaxially. Filaments are purple or lilac, inserted on the corolla, and anthers are ellipsoid or ovoid, purple with a wide cream connective, not connivent at anthesis. The berry is 20-40 mm long, round, blocky, or elongate-curved, with the base obtuse, lobate or truncate, sometimes narrowed forming a neck like structure, and the apex blunt or sunken, rarely pointed. It is green when immature and brightly coloured at maturity, ranging from red to light yellow or blackish. The berry is persistent, very pungent, with a thick pericarp. Seeds are brownish-black to black, C-shaped, sub globose, or irregular, numbering from 15 to 45 per fruit.

4. FLORAL BIOLOGY OF CHILI PEPPERS

Chilli flowers are solitary, borne in the axils of leaves, and may be white, greenish-white, or purplish depending on the variety. The plant is mostly self-pollinated, but a small degree of cross-pollination (up to 10–20%) may occur through insect activity. Each flower is pentamerous, complete, and actinomorphic. The calyx consists of five green sepals that remain attached even

after fruit formation. The corolla is composed of five fused petals that are often white or tinged with purple. There are five stamens attached to the corolla (epipetalous), and the filaments vary in length. The ovary is superior, bicarpellary, syncarpous, and has numerous ovules with a long, slender style and bifid stigma.

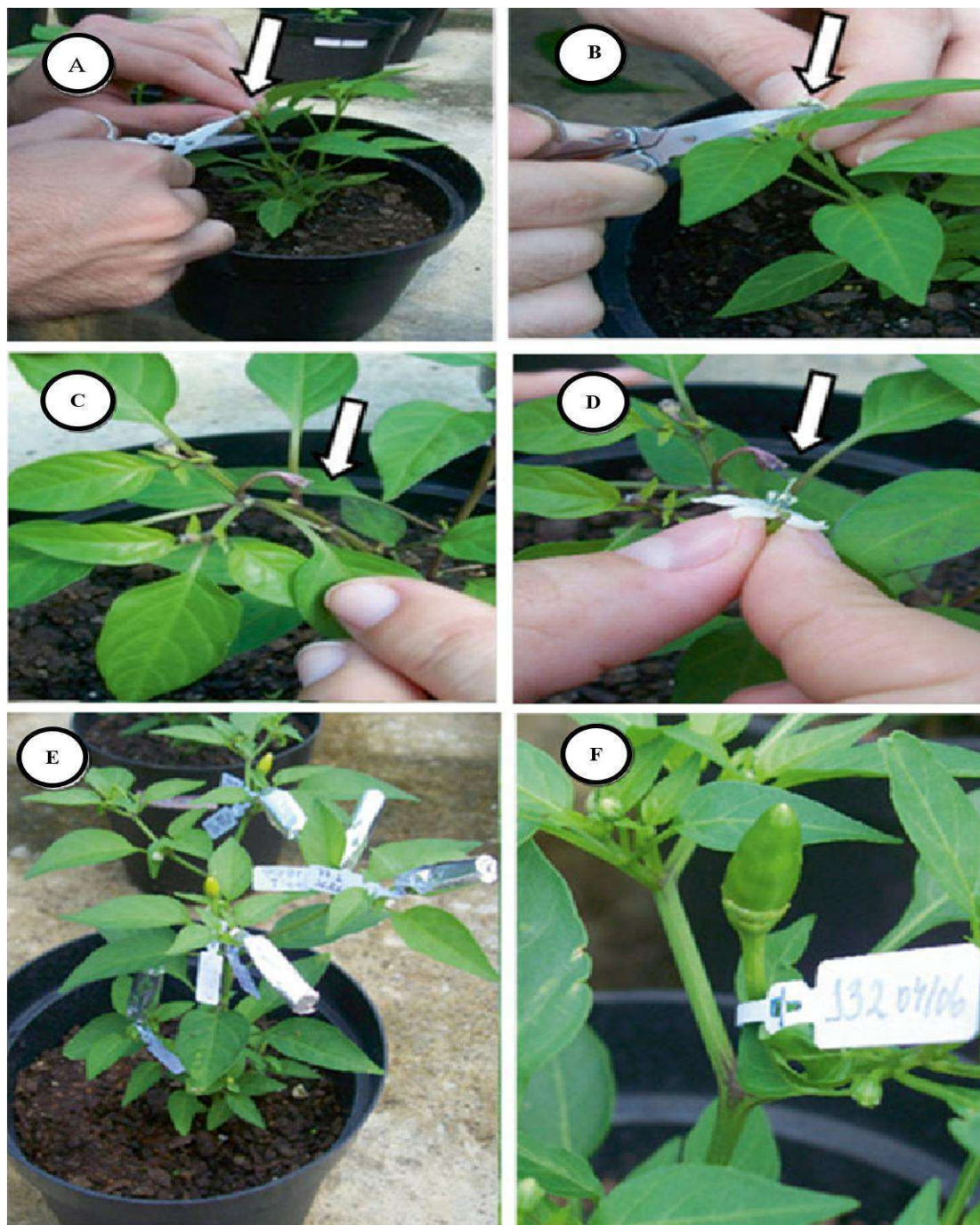


Fig. 3. Emasculation and crossing techniques in Chili Pepper. A. Selection of unopened flower bud. B. Removal of epipetalous corolla along with stamens, C. Emasculated flower, D. Dusting anther on emasculated flower using flower from male parent, E. Covering the dusted flower with butter paper cover and F. Labelling the cross.

5. Anthesis: Flowering beings 1-2 months after planting and it takes another month for flowering. Flowers opening and anther dehiscence depend on the weather condition to a large extent. During cool as well as cloudy days, the flower opening is delayed. Anthesis generally occurs in the morning (6:00 to 10:00 AM), and dehiscence of anthers is usually synchronous with anthesis. Anthers normally dehisce between 8.00 am to 11.00 am. The stigma becomes receptive slightly before anthesis and remains so for up to 48 hours, making it suitable for controlled hybridization. Fruit setting occurs 5–7 days after fertilization, and full fruit development may take 30–40 days depending on the variety and growing conditions.

6. Selfing and Crossing Techniques

Selfing: Select a panicle before anthesis, cover it with a paper cover for 10 days or till anthesis is over in all the spikelet.

Crossing Techniques: The selection of appropriate size and kind of buds for emasculation is important for success of crossing and to get maximum hybrid seed yield. Only few healthy first formed flower bud from each flower cluster (inflorescence) should be selected for emasculation, which are expected to open (anthesis) next day. The remaining buds in the cluster should be removed because abortion rate of this kind of buds are high. The time to develop experimental crosses, emasculation is usually done in the evening hours, but for commercial hybrids seed production it is practiced in the morning also. From the selected flower bud, all the five anthers should be carefully removed with the help of forceps. Utmost care should be taken to remove: anthers intact (without having any puncture from forceps) so that no pollen should adhere on the stigma should not get mechanical injury. The emasculated buds should be covered with light cotton layering in order to protect stigma from foreign pollen. During commercial hybrid seed production, protection of emasculated buds from cotton is also necessary to protect stigma from self-pollens. However, during male sterile based hybrid seed production, such protection is not required.

The best time for pollen collection is in the morning (before pollen has shed from anthers). For developing experimental crosses, anthers of selected line are collected and pollens are collected on the tip of forceps. During commercial hybrid seed production, abundant quantities of fully open flower before pollen defeasance are collected and kept in petri plates under sunlight for few minutes which facilitate in bursting of pollens from anthers and the anthers are removed and crushed, so that pollen dehisce form the anthers. Pollen grains along

with crushed anthers are collected preferable in pollinating ring. For developing experimental crosses, cotton layers of emasculated buds are removed and pollination is performed using brush/forceps contain desired pollen. Alternatively, the flower of male parent can directly be utilized for pollination. During commercial hybrid seed production, at the time of pollination, stigma of emasculated bus is inserted in pollinating ring or into the glass tube, so that abundant pollen adheres to the stigma. After pollination, pollinated buds are tagged from thread and again protected with the help of thin cotton layers.



SUPERANTIGENS – THE IMMUNE SYSTEM’S DANGEROUS SHORTCUT

Article ID: AG-VO6-I01-32**T.Varsha Chythanya***

Department of Fish Pathology and Health Management, Tamil Nadu Dr.J.Jayalalitha Fisheries
University-Fisheries College and Research Institute, Thoothukudi, Tamil Nadu, India.

Abstract

Superantigens are special proteins produced by some microbes that cause an excessive immune response. Unlike normal antigens, superantigens do not need to be processed by antigen-presenting cells. Instead, they directly connect T-cell receptors (TCRs) with MHC class II molecules on antigen-presenting cells. This abnormal binding activates a large number of T cells at once, leading to the release of huge amounts of cytokines (cytokine storm). As a result, the immune response becomes uncontrolled and may finally cause cell death (apoptosis). B-cell superantigens work differently. They bind directly to immunoglobulins (antibodies) present on the surface of B cells, leading to abnormal B-cell activation.

Keywords: T-Lymphocytes, B-Lymphocytes, Antigen Presenting Cells, Enterotoxin, Apoptosis.

Introduction

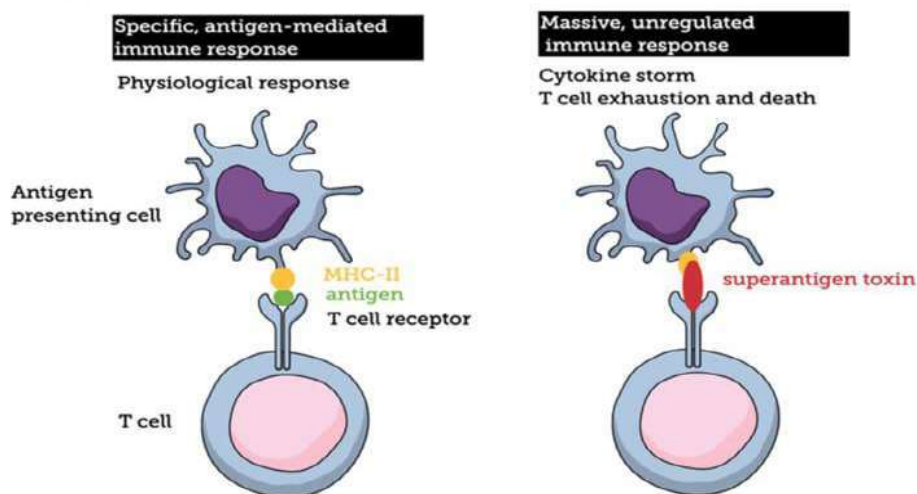
Superantigens are microbial proteins that trigger an extremely strong, non-specific immune response. First described in 1989, they were shown to cause massive T-cell activation by directly linking T-cell receptors (TCRs) with MHC class II molecules. In contrast, B-cell superantigens activate many B cells through a different mechanism, without involving TCR–MHC interactions. The term superantigen now broadly refers to any molecule that activates more than 5% of total lymphocytes, highlighting their ability to cause abnormal immune hyper-activation. This article focuses on how superantigens interact with T- and B-cell receptors and the diseases they cause.

T-Cell Superantigens:

T-cell superantigens are microbial proteins that cause excessive T-cell activation, first identified with staphylococcal enterotoxin B (SEB). They act by directly linking T-cell receptors

(TCRs) with MHC class II molecules on antigen-presenting cells, bypassing normal antigen processing. As a result, very small amounts can activate up to 30% of T cells, compared to only 0.0001% during normal immune responses, leading to severe immune damage. Common T-cell superantigens are enterotoxins produced by *Staphylococcus aureus* and *Streptococcus pyogenes*. These enterotoxins are relatively small proteins, ranging from 20 to 28 kDa, and consist of two domains. Although they show considerable sequence variability, enterotoxins and enterotoxin-like proteins from both bacterial species share a highly conserved three-dimensional structure. This structural conservation has led to the suggestion that these toxins originated from a common evolutionary precursor. Notably, staphylococcal enterotoxins are heat-stable, and some retain their biological activity even after cooking and digestion, making them a major cause of foodborne illness. About 25% of food-poisoning cases in the United States are caused by staphylococcal enterotoxins. In addition to food poisoning, T-cell superantigens are involved in severe inflammatory diseases such as toxic shock syndrome, systemic inflammatory response syndrome, scarlet fever, and atopic dermatitis.

Superantigens



SOURCE: ResearchGate

Pictorial Representation of normal Antigen and Superantigen;

Cellular Response and their Binding:

T-cell superantigens cause strong immune effects by acting differently on immature and mature T cells. Immature CD4⁺ and CD8⁺ T cells are depleted, while mature T cells are

massively activated, leading to rapid proliferation and a cytokine storm. Cytokines such as IFN- γ , IL-17, and IL-12 recruit neutrophils and other immune cells. Paradoxically, this intense response helps *Staphylococcus aureus* survive, as it can persist inside neutrophils and macrophages, especially in abscesses. Superantigens first bind to MHC class II molecules on antigen-presenting cells, then interact with T-cell receptors (TCRs). They bind MHC class II at two sites: a high-affinity, zinc-dependent site on the β chain and a lower-affinity site on the α chain, with most superantigens preferring the β -chain site, forming very stable complexes. Superantigens mainly bind the TCR β chain, though some (e.g., SEH) bind the α chain. Even though superantigen–TCR binding is low-affinity, it is sufficient to trigger extensive T-cell activation and cytokine storm.

B-Cell Superantigens:

B-cell superantigens are antigens that bind directly to B-cell receptors (BCRs) outside the usual antigen-binding site. By cross-linking BCRs, they cause hyper-activation and drive B cells toward apoptosis. They can also bind the Fc region of immunoglobulins. Key examples include Staphylococcal Protein A (SpA), Streptococcal Protein G (SpG), and Peptostreptococcal Protein L (PpL)—all bacterial cell wall proteins. These proteins share a stable, multidomain “beads on a string” structure. Binding of B-cell superantigens triggers BCR signaling, leading to receptor capping, pro-apoptotic pathway activation (caspase-3, mitochondrial changes), and programmed cell death. They also impair antibody functions such as opsonization, phagocytosis, and complement-mediated killing, resulting in B-cell depletion and immune evasion, making them important bacterial virulence factors.

Diseases associated with superantigen production in Humans:

• Toxic shock syndrome
• Eczema
• Diabetes mellitus
• Kawasaki disease
• Guttate psoriasis
• Rheumatic fever

• Nasal polyps
• Scarlet fever
• Infective endocarditis

Superantigens in Fish:

Staphylococcus aureus is a leading cause of foodborne illness worldwide, mainly due to staphylococcal enterotoxins (SEs), which act as powerful superantigens. Studies show that fresh and frozen fish from retail markets often carry *S. aureus* and its enterotoxin genes, usually due to poor hygiene during handling, processing, and storage, which promotes bacterial growth and toxin production. *Streptococcus dysgalactiae* is also an emerging pathogen in aquaculture, with superantigen genes contributing to bacterial virulence, spread, and pathogenicity in aquatic hosts and potentially in mammals, underscoring the zoonotic and cross-environmental risks of superantigen related infections.

Superantigens as Tool in Research and Therapy

While superantigens are often harmful, they have valuable applications in medicine and research. Their ability to activate large numbers of T cells makes them useful in cancer immunotherapy, where T cells can be redirected to target tumor cells. In immunology research, superantigens help study T- and B-cell activation, TCR–MHC interactions, cytokine signaling, immune tolerance, and apoptosis. Proteins like Protein A, Protein G, and Protein L are widely used in antibody purification and immunoassays. Engineered or detoxified superantigens are also being tested as vaccine adjuvants, immune modulators in autoimmune diseases, and in transplantation research.

Conclusion

Superantigens are a unique group of molecules that strongly modulate the immune system. While naturally linked to severe inflammatory diseases, they also have valuable uses in research, diagnostics, and therapy. They are applied in cancer immunotherapy, vaccine development, and studies of host–pathogen interactions. With careful engineering and better understanding, superantigens could be safely used to create new immunotherapies, improve

disease management, and enhance food and aquatic safety, making them important targets for future biomedical research.

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AGRI -TECH STARTUPS: BRIDGING THE GAP BETWEEN RURAL YOUTH AND SUSTAINABLE AGRICULTURE

Article ID: AG-VO6-I01-33**Dr. P. Malini¹, Dr. B. Kranthi Kumari², Dr. T. Gopi Krishna³ and Dr. Krishna Reddy⁴**^{1, 2}-Teaching Associates, Department of Agricultural Extension, ³-Professor & UHOD,⁴-Associate Dean, Department of Agricultural Extension, SMGR Agriculture College,

Udayagiri, India

**Corresponding Author: Dr. P. Malini*

Abstract

The agricultural sector in India is undergoing a significant transformation, which includes AgriTech startups that leverage advanced technologies such as artificial intelligence (AI), machine learning, robotics, and IoT to address key challenges faced by farmers and rural communities. The traditional farming model characterized by low profitability, unpredictable outcomes, and labor-intensive practices has led many young people to migrate to urban centers in search of better opportunities. AgriTech startups present a compelling solution, offering career pathways in technology, innovation, and entrepreneurship while transforming agriculture into a more efficient, sustainable, and profitable sector. This article explores the factors contributing to the growth of AgriTech startups in India, with a focus on the role of youth-led ventures in driving innovation, highlights key areas where AgriTech startups can thrive and government initiatives which provide critical support to AgriTech startups. However, young entrepreneurs face challenges such as financial constraints, infrastructure gaps, and slow adoption of technology among farmers. Despite these hurdles, the rise of AgriTech startups offers immense potential to create sustainable change in Indian agriculture, benefiting both rural youth and the broader agricultural ecosystem.

Keywords: Agri-Tech, Startups, Youth, Agriculture, Technology

Introduction

With rapid climatic changes, advancements in technology and shifting socio-economic

factors there is need to rethink and reshape our approach to agriculture. Over time, there has been a significant decline in the interest of rural people towards agriculture, driven by urbanization, low profitability, limited access to resources, unpredictable outcomes, and the labor-intensive nature of traditional farming. As a result, many young people have moved away from farming in search of more stable and lucrative career options. However, the rise of AgriTech startups has opened up a wide array of career opportunities beyond traditional farming, offering pathways in tech, entrepreneurship, and innovation. By leveraging cutting-edge technologies like artificial intelligence (AI), machine learning, robotics, IoT (Internet of Things), biotechnology and data analytics, the agricultural sector can become more efficient, profitable, attracting rural populations back to farming. Moreover, AgriTech offers exciting career opportunities for farmers and rural youth, transforming agriculture from a traditional, labor-intensive occupation into a tech-driven, innovative field that promises higher profitability, sustainability and growth.

Encouraging Rural Youth to Stay in Agriculture

One of the most pressing challenges facing rural areas today is the mass migration of youth to urban centers in search of better job opportunities. However, this migration can be reduced by introducing **technology-based innovations** that make agriculture more attractive and sustainable. To keep youth in agriculture, it's crucial to show them that farming can be **profitable, modern, and respectable**. Youth returning to agriculture are often equipped with **innovative skills** gained through exposure to vocational training, **AgriTech programs**, or **entrepreneurship boot camps**. These young agri-entrepreneurs use their knowledge of technology, marketing, and business development to build **agriculture-based startups**, creating value-added products, or improving the efficiency of farming practices. This is where AgriTech Startups come into the play.

What is AgriTech Startup?

AgriTech is the fusion of agriculture and technology, aimed at creating innovative tools, platforms, and systems to transform the production, management, distribution, and marketing of food. By applying cutting-edge technology, AgriTech addresses key problems in agriculture, leading to improvements in farming practices, efficiency, and sustainability. A young company that emerges in this space is referred to as an AgriTech startup-a new venture that leverages technology to solve challenges in the agricultural sector.

Rise of AgriTech Startups in India

In India, several factors contribute to the growth of AgriTech startups. These include the country's large agricultural base, which provides a vast market for innovative solutions, and the rural and young population, many of whom are increasingly turning to technology-driven solutions in agriculture. The Indian government has also been supportive of this growth through initiatives like Startup India, which provides funding, mentorship, and policy support for emerging businesses. They are not only developing solutions to modernize traditional farming practices but also act as key players in shifting perceptions about agriculture, positioning it as a modern, tech-driven industry. Presently there are 2,800 DPIIT recognized Agri-Tech start-ups in India.

Youth-Led AgriTech Ventures

India's large and youthful population can be a key factor in the success of AgriTech startups. With over 50% of India's population under the age of 25, there is an immense pool of talent ready to innovate in agriculture. Young people are more open to adopting new technologies and experimenting with novel ideas. If this vibrant demographic are equipped with the latest knowledge and tech skills, it will propel the growth of AgriTech, creating new opportunities for both rural and urban areas. As India's agricultural sector faces pressing challenges such as climate change, water scarcity, and low productivity, the youth are bringing forward innovative solutions that are not only sustainable but also scalable.

Key Areas for Youth to Explore in Agri-Tech Startups

AgriTech start-ups have wide range of opportunities within the agriculture sector. Choosing the right opportunity according to the local need and condition leads to better chances of success. The key areas in which Agri Tech start-ups can boom are Precision farming, organic farming, farm mechanization, Supply chain and market access, agri fin tech, agri biotechnology, smart irrigation, climate resilient farming, vertical farming, agricultural robotics, Waste management and Upcycling, Agri logistics and Cold chain, online market places etc.

Opportunities supporting AgriTech Startups

- Rashtriya Krishi Vikas Yojana is providing support to startups in organic farming, food processing, farm mechanization, precision farming, natural resource management, renewable energy etc sector under the Innovation and Agri-entrepreneurship Development Programme in the form of grants.

- Prime Minister's Wi-Fi Access Network Interface (PM WANI) boosting wifi access in rural areas through public Wi-Fi Hotspot providers.
- NABARDs AgriSURE Fund provides blended finance to high impact technology such as Farm machinery and IT based solutions.
- Under the Startup India Initiative, Government of India is providing numerous benefits such as tax exemption for 3 years, financial aid and simplified regulatory procedures.
- Direct financial assistance, grants, access to government platforms, infrastructure and incubation support were provided through Digital Agriculture Mission.
- Financial assistance and subsidies were provided for purchase of Drones to farmers and Agri graduates.
- Under Atal Innovation Mission (AIM), assistance and grants was given to incubators, workshops etc.

Challenges faced by Youth in starting AgriTech Start-ups

While several government initiatives provide financial support, infrastructure, and policy incentives to promote AgriTech startups, young entrepreneurs still face significant barriers in utilizing these opportunities effectively. Therefore, addressing these challenges is essential to fully harness the opportunities available for sustainable growth of AgriTech start-ups. The major challenges faced by them are:

Financial burden: It is the major problem faced by many young entrepreneurs. Due to the seasonal dependence, agriculture is more prone to risk, so majority of venture capitalists were not interested to invest in such activities. High initial capital requirement for purchase of technical equipment and land are another major problem.

Adoption Gap: Convincing farmers to use new technology is the biggest task to any entrepreneur as farmers are resistant to new tools and technology.

Poor infrastructure facilities: Lack of proper internet connections makes it difficult to adopt technological advancements in rural areas.

Lack of technical and business skills: Many young entrepreneurs have limited exposure to advanced agricultural technologies, data analytics, marketing, and business management.

Regulatory and compliance issues: Complex government regulations, licensing procedures, and policy uncertainty can delay startup operations.

Limited access to markets: Difficulty in connecting with farmers, buyers, and supply chains reduces scalability and profitability.

Low awareness among farmers: Farmers may not fully understand the benefits of Agri Tech solutions, leading to slow adoption.

Risk and uncertainty: Climate change, price fluctuations, and crop failures increase operational risks.

Inadequate mentorship and incubation support in rural areas: Lack of guidance from experienced professionals affects innovation and sustainability.

Conclusion

AgriTech startups are revolutionizing agriculture by offering innovative solutions that tackle key challenges faced by farmers and rural communities. Using cutting-edge technologies like AI, IoT, and robotics, these startups are improving farming efficiency and sustainability, while creating new job opportunities for young people in rural areas. Despite challenges such as financial constraints, slow adoption, and poor infrastructure, government initiatives like Startup India and the Digital Agriculture Mission are laying the groundwork for growth. The emergence of AgriTech ventures is more than just a passing trend; it represents a shift towards modern, profitable, and technology-driven agriculture, drawing young talent back to the sector and empowering them to drive sustainable change. By overcoming these challenges and capitalizing on the opportunities, India's AgriTech industry can reach its full potential, benefiting both rural youth and the agriculture sector as a whole.

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AGRO-TERRORISM: THE SILENT THREAT TO FOOD SECURITY, FARMERS LIVELIHOODS AND NATIONAL STABILITY

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***Harish B P, Thirumal A and Hanumanthappa R**

^{1&2}Ph.D. Scholar, Department of Agricultural Extension Education, University of Agricultural Sciences, Bengaluru, Karnataka, India.

³Ph.D. Scholar, Department of Agricultural Economics, University of Agricultural Sciences, Bengaluru, Karnataka, India.

*Corresponding Author: Harish B P

Introduction

Agriculture has always been the backbone of human civilization. From the earliest settlements to modern nations, it has ensured food availability, supported livelihoods and shaped social and economic development. Even today, agriculture remains central to global survival by providing food, raw materials for industries, employment and income for a large segment of the population. In a country like India, where a significant proportion of people depend directly or indirectly on farming, agriculture is not merely an economic activity but a foundation of national food security, rural stability and socio-economic resilience.

Despite its importance, modern agriculture is increasingly exposed to a wide range of challenges. Climate change has intensified extreme weather events such as droughts, floods, heat waves and cyclones, while the spread of pests, diseases and invasive species continues to threaten crop and livestock productivity. Rapid urbanization, environmental degradation and resource depletion have further compounded these problems. Alongside these natural and structural challenges, agriculture is now facing emerging man-made threats that receive far less attention but pose equally serious risks.

One such critical yet often overlooked threat is **agro-terrorism**. **Agro-terrorism** refers to the deliberate introduction of biological, chemical or other harmful agents into agricultural systems, including crops, livestock, and food supply chains, with the intent to cause widespread

fear, economic disruption, and social instability. Unlike conventional forms of terrorism that rely on visible violence and immediate impact, agro-terrorism operates silently and strategically. The damage it causes may remain unnoticed for weeks or even months, by which time the affected crops or animals may have already spread the contamination across regions.

This covert nature makes agro-terrorism particularly dangerous. A single, well-planned attack can result in massive crop failures, livestock mortality, trade restrictions, loss of farmer livelihoods and erosion of public confidence in food safety systems. In an agrarian economy like India's, such attacks have the potential to destabilize rural communities, strain national food reserves and disrupt both domestic and international markets. Therefore, understanding agro-terrorism as a real and emerging threat is essential for safeguarding agriculture, ensuring food security and protecting national stability in an increasingly interconnected and vulnerable world.

Agriculture is a soft target

Agriculture is widely regarded as a soft target because of its open and decentralized structure. Farming activities are spread over vast geographical areas, making it impossible to secure them in the same way as industrial plants, laboratories or military installations. Fields, orchards and livestock units remain largely exposed with little physical surveillance or controlled access, which increases their vulnerability to intentional or accidental threats.

Another major concern is the generally low level of biosecurity practiced at the farm level. Most farms operate with minimal preventive measures and routine activities such as the movement of people, animals, equipment and vehicles occur with limited oversight. Unauthorized or unnoticed access to farms is common, creating opportunities for the introduction of harmful biological agents through contaminated seeds, infected animals or polluted water sources.

Delayed diagnosis further amplifies this vulnerability. Many exotic pests and diseases closely resemble locally occurring problems, leading farmers and field workers to underestimate their seriousness and delay reporting. In an era of expanding global trade, climate change and increased movement of planting materials and agricultural commodities, the risk of both accidental and deliberate introduction of harmful organisms has increased significantly, posing a serious challenge to agricultural security.

Forms of Agro-Terrorism

Agro-terrorism can manifest in several forms, depending on the targeted component of

the agricultural system and the methods employed. These attacks may focus on crops, livestock, food supply chains or essential agricultural inputs, each posing serious risks to food security and economic stability.

Crop-based agro-terrorism involves the deliberate introduction of plant pathogens, insect pests or invasive weed species into agricultural fields. Such actions can significantly reduce crop yield and quality, disrupt production cycles and lead to long-term ecological imbalances. The spread of these agents may remain undetected until substantial damage has already occurred.

Livestock-based agro-terrorism targets animals through the intentional spread of highly contagious diseases such as foot-and-mouth disease, avian influenza or African swine fever. These diseases can spread rapidly across regions, causing mass mortality, forcing culling operations, and severely affecting the livelihoods of farmers dependent on animal husbandry.

Attacks on the food supply chain, where contamination occurs during harvesting, storage, processing or transportation of agricultural produce. Such incidents not only result in economic losses but also erode consumer confidence and may trigger trade restrictions and public health emergencies.

Water and agricultural input contamination represent an additional threat, involving the deliberate pollution of irrigation water, fertilizers, animal feed or other inputs. Even limited contamination can affect large areas, making this form particularly dangerous due to its potential for widespread and prolonged impact.

Impacts of Agro-Terrorism

Economic Impact: Causes heavy financial losses due to crop destruction, livestock deaths, increased control costs and trade restrictions, leading to reduced farmer income and economic instability.

Food Security Impact: Disrupts food production and supply chains, resulting in shortages and price hikes that mainly affect poor and vulnerable populations.

Social Impact: Increases farmer distress, unemployment, migration and may trigger social unrest in rural and agrarian communities.

Psychological Impact: Creates fear and uncertainty about food safety, eroding consumer confidence and trust in agricultural and food systems.

Environmental Impact: Emergency responses such as excessive pesticide use and disposal of infected materials can degrade soil, water and ecosystems, affecting long-term sustainability.

India's Vulnerability to Agro-Terrorism

Food security is built on four key pillars availability, accessibility, utilization and stability of food. Agro-terrorism poses a direct threat to all these pillars simultaneously. Deliberate damage to crops or livestock reduces overall food production, thereby affecting availability. Economic losses and supply disruptions often lead to rising food prices, limiting accessibility, especially for low-income and vulnerable populations. Contamination of food products compromises safe consumption and proper utilization, while repeated or prolonged attacks disturb the stability of food systems by creating uncertainty in production, supply chains, and markets.

In a country like India, where a large share of the population depends on agriculture for both livelihood and nutrition, the implications are particularly severe. Agro-terrorism extends beyond farm-level damage to become a matter of national concern, with the potential to weaken food security, disrupt rural economies, and undermine public confidence in food safety. Therefore, addressing agro-terrorism is not merely an agricultural challenge but a critical national security priority that demands coordinated policy, surveillance, and preparedness efforts.

Role of Farmers in Prevention

Farmers serve as the **first line of defense** against agro-terrorism because they are in direct and continuous contact with crops, livestock and farm environments. Regular field inspections and close observation help in the early identification of unusual symptoms such as sudden wilting, unexplained pest outbreaks, abnormal animal behavior or unexpected crop losses. Prompt reporting of such observations to agricultural extension officials, veterinarians or local authorities is crucial for early diagnosis and rapid response. Preventive practices such as using certified seeds and planting materials, maintaining farm hygiene, proper disposal of crop residues and limiting unauthorized access to farms can significantly reduce vulnerability to intentional or accidental introductions of harmful agents.

Role of Government and Institutions

Governments and agricultural institutions play a central role in preventing, detecting and responding to agro-terrorism threats. Strengthening quarantine and border inspection systems is essential to prevent the entry of exotic pests, diseases and contaminated inputs. Investments in surveillance networks, diagnostic laboratories and research on plant and animal health enhance

national preparedness. Training agricultural extension workers, veterinarians and frontline staff improves early detection and awareness at the grassroots level, while well-equipped rapid response teams enable quick containment of outbreaks. Effective coordination among agricultural departments, public health agencies, disaster management authorities, and security forces ensures a comprehensive and timely response, making agro-terrorism prevention a shared responsibility across sectors.

Importance of Awareness and Education

Awareness and education are among the most effective tools for preventing agro-terrorism. Educating farmers, extension workers, and agricultural professionals about biosecurity risks, early warning signs and reporting mechanisms can significantly enhance preparedness. Integrating biosecurity and agricultural security concepts into formal agricultural curricula, along with regular farmer trainings and capacity-building programs, helps build long-term vigilance. Mass media platforms such as radio, television, social media and popular agricultural magazines can further amplify awareness. Village-level campaigns, demonstrations and community meetings play a crucial role in translating technical information into practical action. When farmers and citizens recognize that safeguarding agriculture is directly linked to national food security and economic stability, a sense of collective responsibility and cooperation naturally increases.

Way Forward: Building Resilient Agriculture

Strengthening resilience against agro-terrorism requires a comprehensive and multi-layered approach. Promoting diversified cropping systems reduces dependency on single crops and limits large-scale losses. Establishing strong local seed systems and encouraging the use of certified planting materials enhance biological security. The adoption of digital tools for pest and disease surveillance, along with real-time reporting systems, can improve early detection and response. Community participation and farmer-led monitoring networks further reinforce local resilience. In addition, public-private partnerships can accelerate innovation and resource sharing, while international cooperation is essential to manage transboundary pests and diseases, recognizing that agro-terrorism threats do not respect national borders

Conclusion

Agro-terrorism may operate quietly and often remain invisible in its early stages, but its consequences can be severe, widespread and long-lasting. Damage to crops, livestock and food

systems goes beyond agricultural losses, directly threatening food security, farmer livelihoods, public confidence, and economic stability. In agrarian economies, even a single incident can trigger cascading effects across rural communities, markets, and national food supply chains.

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ARC IN POTATO CULTIVATION-A NEW INNOVATION FOR FARMERS OF INDIA

Article ID: AG-VO6-I01-35**Subham Chakraborty**

Ph.D. Research Scholar, Department of Agronomy, Institute of Agricultural Science, University of Calcutta, 51/2, Hazra Road, Kolkata, Pin-700019, West Bengal, India

Introduction

Potato known as king of vegetable crop introduced in India during the early 17th century by Portuguese with its origin in South America. From history it can be found that potato flourished as a garden crop in Karnataka and Surat in the early years of 1675, later introduced to Shimla hills in 1828 with Nilgiri hills in 1830. It certainly spread in the hills and plains of India by 18th and 19th century and it took its place as a popular vegetable crop of India (Singh and Rana, 2014). In the past few decades due to technological advancement in agriculture, potato cultivation had grown enormously with couples of varieties being introduced according to the farmers' requirement. It is being exclusively used in different culinary preparations. According to CPRI, it was estimated that by 2050 India would produce 122 million metric tons (MT) (CPRI, 2015).

As per record, India is the second-largest producer of potatoes accounting 11.3% of the area and 16.0% of production. In 2.3 mha area, India produced 60.14 million of potato in 2022-2023 (Singh and Dutt, 2024). It was estimated that 5.4 million ton certified/quality seed approximately are essential which is not possible to produce through traditional breeding methods. It is evident that potato seed alone accounts for 40–50% of the total cost for potato production (Buckseth *et al.*, 2024). However, the main drawback which still remains in potato production with tubers are high seed cost, water scarcity, effect of bacterial or viral diseases are observed and weight of seed tuber causes problem in transportation, post-harvest loss etc. for which apical root cutting method of propagation have been innovated by researchers (Kaushik *et al.*, 2013, Biradar *et al.*, 2025, Gopal and Chauhan, 2010). This method can essentially reduce

time required for reaching the produced varieties in the hand of farmers' and can benefit small farmers' in India. The method of ARC involves tissue cultured plantlets from apical stem cuttings. The lateral buds are initiated by eliminating apical bud, advancing lateral growth and stimulating the multiply process that provides disease free propagation of plant-lets of high quality in a controlled environment (Dawson, 2005; Naik and Kairhaloo, 2007, Mbiyu *et al.*, 2012; Sumarni *et al.*, 2014; Alam *et al.*, 2015). It began its journey in India from 2010 for which initiatives were taken in states of Karnataka, Odisha and West Bengal. This innovation has been fully adopted in Africa, India and South-East Asia for the benefits of small farmers'.

Production Procedure involved in ARC:

The rooting media essential for production of ARCs' are Cocopeat:perlite in 2:1, aeroponics or fogponics, cocopeat mixture and coconut coir and rockwool cubes. The hormones required are IBA, NAA and GA₃ while NPK in balanced ratio along with zinc and boron are essential for root development and better shoot growth. ARC is a low-cost innovation of potato production where micro-plants that are tissue cultured planted in the nursery to form a mother bed. The apical cutting having (2-3 cm) two leaves are collected in 12-15 days on a regular basis from the mother plants to replant in the mother bed for re-cutting or to plant in pot-trays containing coco peat-perlite blend and vermiculite:perlite mixture (1:1) that enable rooting. 8 rooted cuttings are produced from 1 microplant in 45 days. Root cuttings of 15-20 days old are planted in preliminary net houses or in open fields for production of 1st generation seed production. In controlled condition, the juvenile condition of the mother plant can be prolonged and can create ARCs' (Kumari, 2024 and NAAS, 2021).

Benefits of ARC:

Compared to conventional method, ARCs' in potato has several benefits:

- Higher multiplication rates are obtained with ARCs' that is 20x-50x times per production cycle
- Planting can be done in 2-4 weeks of rooting due to lack of dormancy.
- As the plantlets are made from meristem-culture so they are free from any disease.
- Lesser requirement of labour with uniform spacing.
- Cost-effective nature of this technique also enables in bringing new varieties from other parts of the world in the chain of production.

- Involvement of mechanization for ridge formation ensuring good aeration in soil and healthy tuber growth.
 - Time of production of new plantlets is reduced due to integration of conventional and new innovative technology in ARC's enabling farmers to undertake seed production within a short period.
 - Wider adaptability as it can be introduced from laboratory to green houses or field without any sort of stress more easily for which it benefits the farmers for potato production without any problem.
 - It can prove profitable business for small farmers' due to production of good seed quality at low cost with quick multiplication rates and farmers can use both seed potato and ware potato.
 - Helpful for areas where seed production is negligible.
- (Buckseth *et al.*, 2022, Wauters *et al.*, 2022, Sadawarti *et al.*, 2024).

Constraints

- Mortality rate is high in planting material along with disease and pest susceptibility
 - Inadequate storage and facility of warehousing
 - Labour shortage in peak season
 - Lack of quality planting material
 - Lack of transport facility
 - Lower price of potato produced through ARCs
 - Lack of adequate technical information transfer to farmers'
- (Madhu and Basavaraj, 2025 and Moolimane *et al.*, 2025).

Adoption

As per information available till to-date, this new method has started to spread in different states of India. International Potato Center (CIP) in collaboration with Central Potato Research Institute (CPRI), University of Horticultural Sciences, Bagalkot and Directorate of Horticulture, Govt. of Odisha has enquired the performance and economic standards regarding this new method in parts of India such as Karnataka, Assam, Haryana and Odisha. The farmers in Kanchanpur region of Tripura also started adopting ARCs of potato and obtained good increase in yield. The regions of Hasan, Kolar, Chikkaballapur, Chikmagalur, Belagavi and

Dharwad districts of Karnataka adopted this technology. In Meghalaya, women are doing their potato cultivation through ARC method under the collaboration with IFAD's Megha LAMP project. In Haryana the trials are undergoing rapidly along with development of a digital tracking system. Basically, varieties like K-Jyoti, K-Himalini, K-Chipsona 4 are at present being used.

Conclusion

It can be concluded that in order to combat continuous change in climate along with ever growing population such innovative techniques are essential for better and faster production of potato yielding much higher than conventional methods. Diseases related to potato for which farmers require to rely on pesticides can be reduced through introduction of such advance method of potato production. Large scale awareness programme is required for dissemination of this technology to other parts of India to minimize dependency of seed potato from northern Indian states of Punjab and Haryana. Government policies regarding technological advancements in agriculture requires to be re-constructed so that in coming days more and more cost-effective disease-free crops seed can be produced that are having advantage in yielding at a higher rate in climate-change and other environmental stress also newer varieties from other countries can be established at a much shorter period of time.

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DRONE TECHNOLOGY IN AGRICULTURE: BENEFITS AND CHALLENGES FOR RURAL INDIA

Article ID: AG-VO6-I01-36**Tarun Kshatriya T**

Department of Soil Science & Agricultural Chemistry, Tamil Nadu Agricultural University,
Coimbatore – 641003, Tamil Nadu, India

Introduction

Indian agriculture is at a critical crossroads. With nearly half of the country's population dependent on farming for livelihood, the sector faces persistent challenges such as fragmented landholdings, labour shortages, declining soil health, erratic rainfall patterns, and increasing production costs. At the same time, the pressure to ensure food security for a growing population is intensifying. In this context, the integration of advanced technologies into agriculture is no longer optional it is essential. Among emerging technologies, **drone technology**, also known as Unmanned Aerial Vehicles (UAVs), has gained considerable attention for its transformative potential in farming systems.

Drones are capable of collecting high-resolution spatial and temporal data, performing precise input application, and enabling rapid decision-making. In agriculture, they are used for crop monitoring, field mapping, pesticide and fertilizer spraying, irrigation assessment, yield estimation, and disaster management. For a country like India where agriculture is dominated by small and marginal farmers drone technology presents both immense opportunities and complex challenges.

Rural India, in particular, stands to benefit from drones due to limited access to extension services, delayed input delivery, and inadequate monitoring of crops. Drones can bridge the gap between scientific knowledge and on-field practices by offering real-time insights and precision interventions. However, despite government initiatives and pilot projects, the adoption of agricultural drones in rural India remains uneven. Issues such as high initial costs, lack of technical skills, regulatory barriers, digital infrastructure gaps, and social acceptance continue to restrict widespread use.

This article critically examines the **benefits and challenges of drone technology in agriculture**, with a special focus on rural India. It explores how drones can enhance productivity, sustainability, and resilience in farming, while also addressing the economic, technical, institutional, and social barriers that must be overcome for inclusive and effective adoption.

Overview of Drone Technology in Agriculture

Agricultural drones are specialized UAVs equipped with sensors, cameras, GPS, and spraying systems designed to support farm management activities. Depending on their function, drones are broadly classified into **fixed-wing drones**, **rotary-wing drones**, and **hybrid drones**. Fixed-wing drones are suitable for large-area mapping due to their longer flight duration, while rotary-wing drones are preferred for **spraying and localized** monitoring because of their ability to hover and manoeuvre precisely.

Modern agricultural drones are integrated with advanced sensors such as RGB cameras, multispectral sensors, hyperspectral sensors, and thermal cameras. These sensors enable the detection of crop stress, nutrient deficiencies, pest infestations, and water stress well before they become visible to the human eye. When combined with Geographic Information Systems (GIS) and artificial intelligence (AI), drone data can be transformed into actionable insights for farmers.

In India, the use of drones in agriculture is still at a developing stage but is gaining momentum through policy support, startup innovation, and government-led demonstrations. Drones are increasingly viewed not just as **tools** for large commercial farms but as shared services that can benefit smallholder farmers through cooperatives, Farmer Producer Organizations (FPOs), and custom hiring centres.

Applications of Drones in Indian Agriculture

Crop Monitoring and Health Assessment

One of the most impactful applications of drones is real-time crop monitoring. Drones can fly over fields at regular intervals and capture high-resolution images that provide detailed information on crop growth patterns, plant vigour, and spatial variability within fields. Vegetation indices derived from multispectral images help identify stress caused by nutrient deficiency, pest attacks, or disease outbreaks.

For rural farmers, early detection of crop stress is crucial, as delays often result in irreversible yield losses. Drone-based monitoring allows timely corrective measures, reducing dependence on blanket input application and minimizing losses.

Precision Spraying of Pesticides and Fertilizers

Drone-based spraying systems enable precise and uniform application of pesticides, herbicides, and foliar fertilizers. Unlike conventional spraying methods, drones reduce chemical wastage, prevent over-application, and minimize human exposure to toxic agrochemicals.

In rural India, where manual spraying is labor-intensive and often unsafe, drones significantly improve operational efficiency. They are especially useful in difficult terrains, waterlogged fields, and tall crops where manual access is limited.

Soil and Field Mapping

Drones can generate detailed topographic maps and soil variability maps, helping farmers understand field characteristics such as slope, drainage patterns, and moisture distribution. These maps support better land preparation, crop planning, and irrigation design.

For regions with uneven terrain or degraded soils, drone-based mapping plays a vital role in improving land and water resource management.

Irrigation Management

Thermal sensors mounted on drones can detect variations in canopy temperature, which are closely linked to water stress. By identifying under-irrigated or over-irrigated zones, drones help optimize water use an extremely critical factor in water-scarce rural regions of India.

Yield Estimation and Crop Insurance

Accurate yield estimation using drone data supports better market planning and transparent crop insurance assessments. Drones can objectively assess crop damage caused by floods, droughts, or pests, reducing disputes and delays in insurance claim settlements.

Benefits of Drone Technology for Rural India

Enhanced Agricultural Productivity

By enabling precise input application and timely interventions, drones directly contribute to improved crop yields. Farmers can focus resources on affected areas rather than treating entire fields uniformly, resulting in better crop performance and cost efficiency.

Cost and Labour Efficiency

Rural India faces acute labour shortages due to migration and demographic changes.

Drones reduce dependency on manual labour for monitoring and spraying operations. Although initial investment is high, shared service models significantly lower per-acre operational costs.

Environmental Sustainability

Drone-assisted precision agriculture reduces excessive use of fertilizers and pesticides, minimizing soil and water pollution. Reduced chemical runoff and optimized water usage contribute to environmentally sustainable farming practices.

Risk Reduction and Climate Resilience

With increasing climate variability, drones help farmers adapt by providing timely information on crop stress, moisture deficits, and weather-related damage. Early warnings and rapid assessments enhance resilience to climate-induced risks.

Empowerment through Data-Driven Decision Making

Drones democratize access to advanced agricultural information. When supported by extension services, drone data empowers rural farmers to make informed decisions, improving confidence and reducing dependency on guesswork.

Government Initiatives and Policy Support in India

The Government of India has recognized the strategic importance of drones in agriculture and introduced supportive policies such as simplified drone regulations, promotion of domestic drone manufacturing, and financial assistance for drone deployment. Programs encouraging the use of drones through agricultural institutions, rural youth training, and women-led self-help groups aim to create local employment and technical capacity.

Subsidies for drone purchase and service-based models through cooperatives are particularly relevant for rural India, where individual ownership may not be economically viable.

Challenges of Drone Adoption in Rural India

High Initial Investment

The cost of agricultural drones, sensors, maintenance, and skilled operators remains a major barrier. Small and marginal farmers often lack access to credit and are hesitant to invest in unfamiliar technologies.

Technical Skills and Training Gaps

Operating drones and interpreting data requires technical expertise. In many rural areas, lack of training facilities and digital literacy restrict effective utilization of drone technology.

Infrastructure and Connectivity Issues

Drone operations rely on GPS, internet connectivity, and power supply. Poor digital infrastructure in remote rural regions limits real-time data processing and decision-making.

Regulatory and Legal Constraints

Despite policy reforms, regulatory compliance related to drone registration, flight permissions, and safety protocols can be complex for rural users. Awareness of legal procedures remains limited.

Social Acceptance and Trust

Farmers may initially distrust drone technology due to lack of awareness or fear of crop damage and surveillance concerns. Building trust through demonstrations and success stories is essential.

Data Management and Privacy Concerns

Handling large volumes of drone-generated data raises concerns about data ownership, privacy, and misuse. Clear guidelines are needed to protect farmers' interests.

Role of Startups, Cooperatives, and Extension Services

Agri-tech startups play a crucial role in bridging the gap between technology and farmers by offering drone services on a pay-per-use basis. Farmer Producer Organizations (FPOs) and cooperatives enable collective access to drones, making the technology affordable and scalable.

Extension services must evolve to integrate drone-based advisories, ensuring that data insights are translated into practical recommendations suited to local conditions.

Future Prospects of Agricultural Drones in Rural India

The future of drone technology in Indian agriculture lies in integration with artificial intelligence, machine learning, and satellite data. Autonomous drones, real-time analytics, and mobile-based advisory platforms will further simplify usage for rural farmers.

With increasing policy support, declining hardware costs, and growing awareness, drones are expected to become an integral part of smart and climate-resilient agriculture in India. Capacity building, inclusive business models, and strong institutional support will determine the pace and scale of adoption.

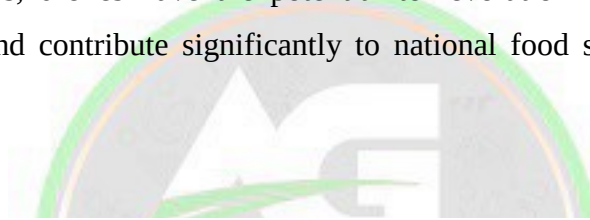
Conclusion

Drone technology represents a powerful tool for transforming agriculture in rural India by enhancing productivity, sustainability, and resilience. From crop monitoring and precision

spraying to irrigation management and disaster assessment, drones offer solutions to many longstanding challenges faced by Indian farmers. Their ability to provide timely, accurate, and field-specific information aligns well with the principles of precision and sustainable agriculture.

However, the successful integration of drones into rural farming systems is not without challenges. High costs, skill gaps, infrastructure limitations, regulatory complexities, and social acceptance issues must be systematically addressed. A farmer-centric approach—supported by government policies, cooperative models, startups, and extension services—is essential to ensure equitable access and effective utilization.

In conclusion, drone technology is not a replacement for traditional farming knowledge but a powerful complement to it. When combined with local expertise and supportive institutional frameworks, drones have the potential to revolutionize rural Indian agriculture, improve livelihoods, and contribute significantly to national food security and environmental sustainability.



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BUTTERFLY PEA PLANT: A FLOWERING ALLY FOR SUSTAINABLE GROWTH

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Dr. Rajeshwari Desai* and Miss. Ruby K.R**

* Senior Scientist, AICRP-WIA, University of Agricultural Sciences, Dharwad-5,

** MSc Scholar Dept. of Human Development and Family Studies, College of Community Science, University of Agricultural Sciences, Dharwad-5, Karnataka.

*Corresponding Author: Dr. Rajeshwari Desai

Introduction

In the global push toward sustainable agriculture, the butterfly pea (*Clitoria ternatea*) stands out as a highly versatile and eco-friendly plant. Native to Southeast Asia and widely grown across India, this hardy legume thrives in poor soils with minimal water, making it ideal for climate-resilient farming. Its nitrogen-fixing properties naturally enrich the soil, reducing the need for chemical fertilizers. Beyond its agronomic value, the plant is prized for its vivid blue flowers, which are used in herbal teas, natural dyes, cosmetics, and traditional medicine. As demand grows for low-input, high-value crops, butterfly pea is emerging as a symbol of sustainable innovation.

Introduction

The butterfly pea (*Clitoria ternatea*) is a vibrant flowering legume. Known for its striking deep blue petals shaped like butterflies, this hardy plant is much more than just a visual delight. It's drought-tolerant, requires minimal care, and naturally enriches soil by fixing nitrogen, making it an excellent choice for sustainable and organic farming.



butterfly pea plant

Why is it gaining attention now? With increasing challenges like climate change, water scarcity, and soil degradation, the butterfly pea's resilience and low resource needs make it a practical crop for drought-prone areas. Additionally, its flowers are used in herbal teas, natural dyes, and traditional medicine, meeting the growing demand for eco-friendly and health-conscious products. In today's push for sustainable agriculture and green living, the butterfly pea is proving to be an invaluable, multipurpose plant for the future.

A Natural Fit for Eco-Friendly Agriculture:

The butterfly pea plant is perfectly suited for eco-friendly and sustainable farming practices. As a legume, it naturally fixes nitrogen in the soil, reducing the need for synthetic fertilizers that can harm the environment. It thrives with minimal water and can grow in poor or degraded soils, making it ideal for regions facing drought and soil erosion. Its fast growth and ability to improve soil health make it an excellent cover crop or intercrop, promoting biodiversity and preventing soil degradation. With such low input requirements and multiple benefits, the butterfly pea is emerging as a valuable ally for farmers committed to greener agriculture.



butterfly pea plant farm

Zero-Waste, Multi-Use Crop

The butterfly pea plant exemplifies a zero-waste, multi-purpose crop, with nearly every part offering valuable applications. Its flowers, rich in anthocyanins, are widely used in the production of herbal teas, natural food colorants, cosmetics, and wellness products. Notably, butterfly pea tea has gained international recognition for its antioxidant properties. The plant's leaves and pods are edible and serve as nutritious fodder for livestock, providing a sustainable alternative to conventional animal feed. Additionally, the roots and seeds have long been utilized in traditional medicine, attributed with potential anti-inflammatory, diuretic, and cognitive-enhancing benefits. This comprehensive utilization reflects the principles of circular agriculture, maximizing resource efficiency by minimizing waste.

Growing Role in Green Industry

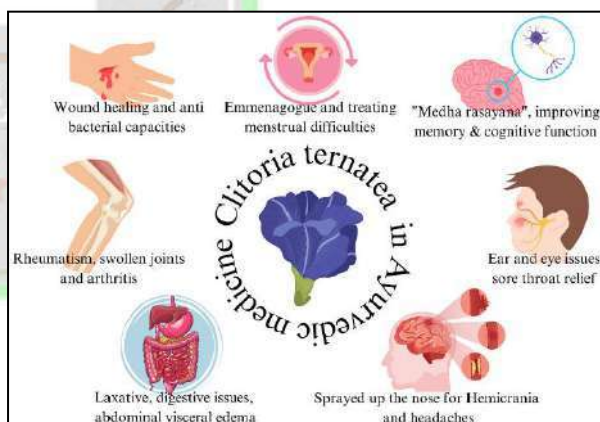
Butterfly pea flower extracts are emerging as a sustainable and eco-friendly alternative to synthetic dyes across the cosmetic, textile, and food industries.

These natural dyes are non-toxic, biodegradable, and packed with antioxidants, making them highly attractive to environmentally conscious consumers and businesses seeking greener solutions. In India, several startups and cooperatives have recognized this potential, actively cultivating butterfly pea to produce value-added products such as herbal wellness formulations, organic farming kits, and export-quality natural dyes. This growing industry not only supports sustainable production but also opens new avenues for rural entrepreneurship and economic development.



Medicinal and Nutraceutical Potential

The butterfly pea plant is abundant in bioactive compounds such as flavonoids, peptides, and anthocyanins, which contribute to its growing reputation in medicinal and nutraceutical fields. Ongoing research highlights its promising roles in stress reduction, cognitive enhancement, and blood sugar regulation. Additionally, its antioxidant-rich profile has made it a popular ingredient in anti-aging skincare formulations. These health benefits position butterfly pea as a sustainable and valuable resource for the expanding plant-based medicine and wellness industries, offering natural alternatives to synthetic products while supporting holistic health.



1. Wound healing and antibacterial activity Butterfly pea possesses strong antibacterial and healing properties. The bioactive compounds present in the plant help prevent infections and promote faster wound repair, making it useful in traditional skin and injury treatments.

2. Emmenagogue and menstrual health support The plant is traditionally used to regulate menstrual cycles and reduce menstrual discomfort. Its natural compounds support hormonal balance and reproductive health.

3. Medhya Rasayana – memory and cognitive enhancement Recognized in Ayurveda as a *Medhya Rasayana*, butterfly pea improves memory, learning ability, and overall cognitive function. It also helps reduce mental stress and supports brain health.

4. Relief from ear, eye, and throat problems Butterfly pea is used in traditional remedies to ease ear pain, eye irritation, and sore throat, reflecting its soothing and anti-inflammatory effects.

5. Relief from headaches and hemicrania (migraine) The plant is used for headache and migraine relief, sometimes through nasal application of its extract, helping calm the nervous system.

6. Digestive support and laxative action It acts as a mild laxative, improves digestion, and helps relieve abdominal discomfort and visceral edema, supporting overall gut health.

7. Treatment of rheumatism, swollen joints, and arthritis Due to its anti-inflammatory properties, butterfly pea is effective in reducing joint swelling, rheumatic pain, and symptoms of arthritis.

Supporting Rural Livelihoods

The butterfly pea plant (*Clitoria ternatea*) is emerging as a valuable crop for supporting rural livelihoods, particularly because of its low-input cultivation needs and wide range of usable plant parts. It can be grown successfully on small plots of land with minimal water, fertilizers, and capital investment, making it especially suitable for small and marginal farmers.

Community-based farming initiatives, including those led by women and self-help groups, are increasingly adopting butterfly pea



cultivation to create sustainable income opportunities. The flowers, available in vibrant natural colors, are harvested and processed into dried floral products, herbal teas, natural dyes, and cosmetic ingredients. Other parts of the plant, such as leaves, stems, roots, and seeds, are also utilized in traditional medicine, value-added herbal products, and seed production, ensuring complete use of the plant and reducing waste.

With its ability to generate multiple marketable products from a single crop, butterfly pea cultivation promotes inclusive rural entrepreneurship and diversification of farm income. The plant's eco-friendly nature supports environmentally sustainable agricultural practices, while strengthening local value chains and reducing dependence on synthetic inputs. Overall, butterfly pea represents a practical example of how plant-based innovations can empower rural communities while contributing to long-term economic and ecological sustainability.

Recipe for Butterfly Pea (Blue Tea)

Ingredients:

- Dried butterfly pea flowers – 5–7 flowers(*or 1 teaspoon dried flowers*)
- Water – 1 cup (250 ml)
- Lemon juice – ½ teaspoon (optional)
- Honey or jaggery – to taste (optional)
- Ginger or mint – optional

Procedure

1. Boil one cup of water to a gentle boil.
2. Add the dried butterfly pea flowers to the hot water.
3. and let it steep for 5–7 minutes until the water turns a deep blue color.
4. Strain the teaStrain out the flowers into a cup.
5. Enhance the flavor (optional)Add honey or jaggery for sweetness.Add a few drops of lemon juice to see the tea change from blue to purple, and for a refreshing taste.
6. ServeEnjoy the tea hot or cold.



Conclusion

The butterfly pea plant exemplifies sustainable development through its efficient use of resources, adaptability to changing climatic conditions, and potential to drive inclusive economic growth. Its multifunctional applications across agriculture, healthcare, and industry underscore its strategic importance for India's pursuit of a greener and more resilient future. As stakeholders increasingly prioritize crops that contribute to land restoration and environmental sustainability, the butterfly pea emerges as a valuable asset distinguished not only by its striking appearance but also by its significant potential to support sustainable agricultural practices and rural livelihoods.

CLIMATE CHANGE AND PLANT DISEASES: A NEW CHALLENGE FOR FARMERS

Article ID: AG-VO6-I01-38***¹S. Dugyala, ¹K. Mahendra and ²S. Bhavana**

¹Assistant Professor, Department of Plant Pathology, School of Agriculture, Kaveri University, Gowraram, Telangana.

²Assistant Professor, Department of Crop Physiology, School of Agriculture, Kaveri University, Gowraram, Telangana.

*Corresponding Author Email ID: S. Dugyala

1. Introduction

Agriculture has always been closely linked with climate. Temperature, rainfall, humidity, wind, and sunlight determine not only crop growth and yield but also the health of crops. For centuries, farmers planned their agricultural activities based on fairly predictable seasonal patterns. However, this long-standing balance between climate and agriculture is now being seriously disturbed. In recent years, farmers across India and many parts of the world are experiencing unusual and unpredictable weather conditions. Untimely and heavy rains, prolonged dry spells, frequent heat waves, sudden floods, rising average temperatures, and increased humidity have become common occurrences rather than rare events. These changes are clear indicators of climate change, a global phenomenon that is increasingly influencing agricultural systems. While the impact of climate change on crop yields and water availability is widely discussed, its effect on plant diseases often receives less attention, despite being equally serious.

Farmers are increasingly reporting that plant diseases are appearing earlier in the season, spreading more rapidly, and causing severe damage to crops. In some cases, diseases are being observed in new geographical areas where they were previously unknown. Crops that were once considered resistant are now becoming susceptible, and familiar disease management practices are failing to provide effective control. Climate change alters the complex interactions between

the host plant, the pathogen, and the environment, which together determine disease development. Rising temperatures can accelerate the growth and reproduction of pathogens, increased humidity and rainfall favour fungal and bacterial infections, and mild winters allow survival of insects and pathogens that would otherwise be killed by cold conditions. At the same time, climate stress weakens plants, reducing their natural defence mechanisms and making them more vulnerable to infections.

Plant diseases already account for substantial yield losses worldwide, threatening food security and farmers' livelihoods. Climate change is further aggravating this problem by creating conditions that favour disease outbreaks, increasing the frequency and intensity of epidemics, and complicating disease prediction and management. Traditional disease control strategies, developed under stable climatic conditions, are no longer sufficient in many situations. Therefore, understanding the relationship between climate change and plant diseases has become essential. Farmers need this knowledge to adapt their crop management practices, extension workers must provide climate-smart disease advisory services, and students of agriculture must be equipped with updated concepts to address future challenges. Addressing plant diseases in the era of climate change is not just a scientific necessity but a crucial step towards ensuring sustainable agriculture and food security.

2. What Is Climate Change?

Climate change refers to long-term and gradual alterations in the Earth's climate system, including changes in temperature, rainfall patterns, humidity, wind flow, and the frequency and intensity of extreme weather events. Unlike short-term weather variations, which may change from day to day or season to season, climate change results in persistent shifts in climatic conditions over several decades or longer. These long-term changes are primarily driven by increasing greenhouse gas emissions, especially carbon dioxide (CO₂), methane, and nitrous oxide, arising from industrial activities, deforestation, fossil fuel combustion, and intensive agricultural practices. As a result, the natural balance of the climate system is disturbed, leading to widespread effects on ecosystems, agriculture, and human livelihoods.

3. Major Features of Climate Change Affecting Agriculture

Climate change influences agriculture in multiple ways, both directly and indirectly. The major climatic changes that significantly affect crop production and plant health include:

a) Increase in average temperature:

Rising temperatures accelerate crop growth but often reduce crop duration, leading to lower yields. Higher temperatures also favour the rapid multiplication of many plant pathogens, insects, and vectors, increasing disease pressure in crops.

b) Irregular and erratic rainfall:

Unpredictable rainfall patterns cause uncertainty in sowing, irrigation, and harvesting. Excess rainfall creates favourable conditions for fungal and bacterial diseases, while reduced rainfall weakens plants and increases susceptibility to soil-borne and opportunistic pathogens.

c) Increased frequency of droughts and floods:

Prolonged droughts stress plants, impair root development, and reduce plant immunity, making crops more vulnerable to diseases. Floods and waterlogging damage roots and promote the spread of pathogens such as *Phytophthora*, *Pythium*, and bacterial wilt organisms.

d) Higher relative humidity:

Increased humidity, especially during critical crop growth stages, creates ideal conditions for many fungal diseases such as rusts, blights, mildews, and leaf spots. High humidity also enhances spore germination, infection, and disease spread.

e) Rising carbon dioxide (CO₂) levels:

Elevated CO₂ levels can increase plant biomass but often alter plant physiology, including changes in leaf thickness, nutrient composition, and defence responses. These changes may influence host–pathogen interactions, sometimes increasing disease severity or altering pathogen behaviour.

f) More frequent extreme weather events:

Heat waves, cyclones, hailstorms, and unseasonal rains cause physical injury to plants, creating entry points for pathogens. Extreme events can also disrupt pest and disease cycles, leading to sudden and severe outbreaks.

Overall Impact on Plant Diseases

These climatic changes directly influence crop growth and indirectly affect plant pathogens, insect vectors, and disease development. Changes in temperature and moisture conditions can modify pathogen survival, reproduction, virulence, and geographic distribution. Consequently, climate change is reshaping the epidemiology of many important plant diseases, posing new challenges for disease prediction and management (IPCC, 2021).

4. Understanding Plant Diseases in the Context of Climate

The development of plant diseases is not a random event. It depends on the simultaneous interaction of three essential factors, collectively known as the disease triangle. These three components are:

1. The host plant – a susceptible crop or variety
2. The pathogen – a disease-causing organism such as fungi, bacteria, viruses, nematodes, or phytoplasmas
3. The environment – climatic and soil conditions that favour disease development

Only when all three factors are present and favourable does a plant disease occur. Any change in one component of this triangle can significantly influence the occurrence, severity, and spread of plant diseases.

4.1. Role of Climate in the Disease Triangle

Among the three components of the disease triangle, the environment is the most dynamic and climate-sensitive factor. Climate change primarily alters environmental conditions such as temperature, rainfall, humidity, soil moisture, and wind patterns. These changes often create conditions that are highly favourable for pathogen survival, multiplication, and dispersal. Rising temperatures can accelerate pathogen life cycles, allowing multiple infection cycles within a single cropping season. Increased rainfall and humidity favour spore germination, infection, and rapid spread of fungal and bacterial pathogens. Changes in wind patterns help disseminate spores and insect vectors over long distances, introducing diseases into new areas.

4.2. Effect of Climate Change on the Host Plant

At the same time, climate change places physiological stress on the host plant. Heat stress, drought stress, flooding, and nutrient imbalances weaken plant defence mechanisms. Stressed plants have reduced ability to activate structural and biochemical defences, making them more susceptible to infection. Even crop varieties that were previously resistant may show breakdown of resistance under altered climatic conditions.

4.3. Effect of Climate Change on Pathogens

Climate change also directly affects the pathogen component of the disease triangle. Warmer temperatures and favourable moisture conditions enhance pathogen survival during off-seasons and increase their geographical range. Some pathogens may evolve increased aggressiveness or adaptability under changing environmental conditions. Mild winters allow

pathogens and insect vectors to survive year-round, leading to early disease onset in the next cropping season.

4.4. Resulting Disease Scenario

When a favourable environment coincides with a stressed host and an active pathogen population, the result is more frequent, severe, and unpredictable disease outbreaks. Diseases that were once considered minor may become major constraints, and new disease problems may emerge in previously unaffected regions. Thus, climate change disrupts the natural balance of the disease triangle by strengthening the pathogen and environment components while weakening the host, leading to increased disease incidence and intensity (Agrios, 2005). Understanding this altered disease triangle is essential for developing climate-resilient disease management strategies and ensuring sustainable crop production.

5. Effect of Rising Temperature on Plant Diseases

5.1. Faster Pathogen Growth

Higher temperatures accelerate the metabolism, reproduction, and infection cycles of many pathogens. Fungal spores germinate faster, bacterial populations multiply rapidly, and viruses spread more efficiently under warm conditions (Garrett et al., 2006).

5.2. Increased Survival of Pathogens

Milder winters allow pathogens and insect vectors to survive year-round. Diseases that were previously controlled by low winter temperatures are now persisting across seasons.

5.3. Shift in Disease Distribution

Many plant diseases are moving towards higher altitudes and latitudes. For example, rust diseases of wheat and blast disease of rice are now reported in newer areas due to rising temperatures (Chakraborty et al., 2000).



6. Impact of Rainfall Variability on Disease Development

6.1. Excess Rainfall and Flooding

Heavy rainfall creates ideal conditions for:

- Fungal diseases such as blights, leaf spots, and rots
- Soil-borne pathogens like *Pythium*, *Phytophthora*, and *Fusarium*
- Rapid disease spread through rain splash and runoff

Flooded soils reduce oxygen availability, weakening plant roots and increasing susceptibility to root diseases.

6.2. Drought Conditions

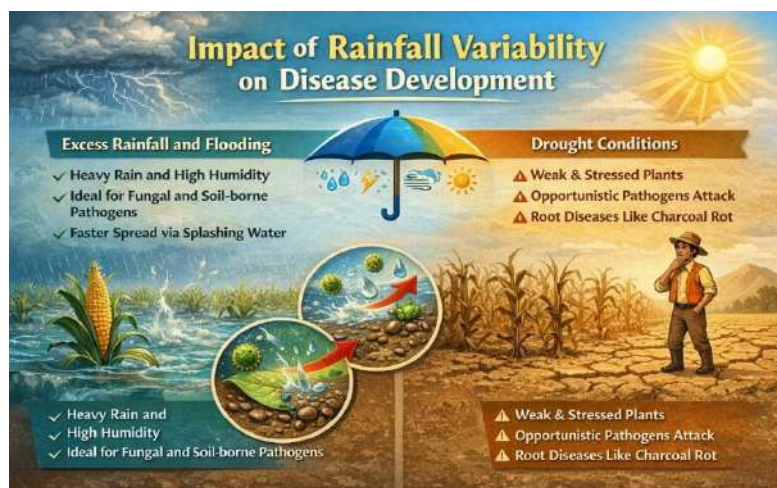
Drought-stressed plants have reduced physiological strength and weaker defence mechanisms. Such plants become easy targets for opportunistic pathogens. Drought also Favors diseases like charcoal rot and dry root rot in crops such as sorghum, maize, and pulses.

7. Role of Humidity and Leaf Wetness

High relative humidity and prolonged leaf wetness periods are critical for many foliar diseases. Climate change has increased night-time humidity and dew formation, which supports diseases such as:

- Downy mildew
- Late blight
- Sheath blight
- Powdery mildew

Extended wetness allows pathogens to penetrate plant tissues easily, leading to severe epidemics (Coakley et al., 1999).



8. Emergence and Re-emergence of Plant Diseases

Climate change is responsible for:

- Emergence of new diseases
- Reappearance of old diseases
- Increased virulence of existing pathogens

Pathogens evolve rapidly under changing environmental conditions, leading to the development of new races capable of breaking host resistance. Insect vectors such as aphids, whiteflies, and leafhoppers are also increasing in number and activity, enhancing the spread of viral diseases (Jones, 2009).



9. Increased Disease Pressure on Major Crops

Staple crops like rice, wheat, maize, and pulses are increasingly affected by climate-driven disease outbreaks. Vegetables and horticultural crops are particularly vulnerable due to their sensitivity to humidity and temperature changes.

This leads to:

- Higher yield losses
- Increased pesticide usage
- Rising cost of cultivation
- Environmental pollution
- Health risks to farmers

10. Why Traditional Disease Control Is Becoming Less Effective

- Chemicals degrade faster under high temperatures
- Repeated pesticide use leads to resistance in pathogens
- Climate-induced disease outbreaks occur suddenly, leaving little time for control
- Lack of timely disease forecasting

Thus, climate change demands new and adaptive disease management strategies.

10. Climate-Smart Plant Disease Management

Climate change has made plant disease occurrence more frequent, severe, and unpredictable. Under such conditions, conventional, calendar-based disease control practices are no longer sufficient. There is a growing need for climate-smart plant disease management, which focuses on anticipation, prevention, integration, and precision, rather than late and excessive chemical control. Climate-smart strategies aim to reduce yield losses, lower environmental impact, and enhance the resilience of cropping systems under variable climatic conditions.

10.1. Early Warning and Disease Forecasting

One of the most effective climate-smart approaches is early warning and disease forecasting. Weather-based disease forecasting models use real-time and historical data on temperature, relative humidity, rainfall, leaf wetness, and wind speed to predict the likelihood of disease outbreaks. Many important plant diseases such as rice blast, late blight of potato, downy mildews, and rusts are highly sensitive to weather conditions. When favourable conditions are predicted, farmers receive alerts through mobile apps, SMS services, or extension advisories.

Early warning systems enable farmers to:

- Take preventive measures rather than curative ones
- Apply fungicides or biocontrol agents at the right time
- Avoid unnecessary sprays, reducing cost and pesticide load
- Minimize yield losses through timely intervention

With climate change increasing weather variability, disease forecasting has become a critical tool for proactive disease management (Savary et al., 2019).

10.2. Use of Resistant and Climate-Resilient Varieties

The use of disease-resistant varieties remains one of the most economical and environmentally friendly strategies for plant disease management. Under climate change, breeding efforts are increasingly focusing on climate-resilient varieties that combine:

- Resistance to major diseases
- Tolerance to heat, drought, and flooding
- Stable performance under variable environments

Climate stress often weakens plant resistance, leading to resistance breakdown. Therefore, modern breeding programmes emphasize durable resistance and the use of multiple resistance genes. Resistant varieties reduce dependence on chemical pesticides, lower production costs, and perform more reliably under changing climatic conditions.

For farmers, adopting resistant and climate-resilient varieties means built-in protection against diseases, making them a cornerstone of climate-smart agriculture.

10.3. Integrated Disease Management (IDM)

Integrated Disease Management (IDM) is a **holistic** approach that combines multiple compatible disease control strategies to manage plant diseases in a sustainable manner. IDM is particularly effective under climate change because it does not rely on a single method that may fail under extreme or variable conditions.

Key components of IDM include:

- 1. Cultural practices:** Crop rotation breaks pathogen life cycles, proper spacing reduces humidity within the crop canopy, timely sowing avoids peak disease periods, and field sanitation removes sources of infection.
- 2. Biological control agents:** Beneficial microorganisms such as *Trichoderma*, *Pseudomonas*, and *Bacillus* suppress pathogens through competition, antibiosis, and induced resistance, especially under fluctuating climates.
- 3. Resistant varieties:** Using resistant cultivars forms the foundation of IDM and reduces disease pressure throughout the season.
- 4. Judicious chemical use:** Pesticides are applied only, when necessary, based on disease monitoring and thresholds, minimizing resistance development and environmental harm.

By integrating these components, IDM provides stable disease control, reduced chemical dependence, and long-term sustainability, making it highly suitable for climate-uncertain agricultural systems.

10.4. Role of Technology and Precision Agriculture

Advances in digital technology and precision agriculture are transforming plant disease management in the era of climate change. Modern tools help farmers detect diseases early,

monitor crop health continuously, and apply inputs efficiently.

Key technologies include:

- Remote sensing and satellite imagery to detect stress and disease hotspots
- Drones for rapid field scouting and targeted pesticide application
- Weather-based mobile apps providing disease alerts and spray advisories
- Digital decision-support systems integrating weather, crop stage, and disease data

These technologies allow site-specific and need-based disease management, reducing input wastage and disease spread. Precision agriculture not only improves management efficiency but also enhances climate resilience by optimizing resource use under uncertain weather conditions.

11. Role of Extension and Farmer Awareness

Extension services, Krishi Vigyan Kendras, and agricultural universities must:

- Educate farmers about climate–disease links
- Promote timely disease diagnosis
- Encourage adoption of climate-smart practices

Farmer awareness is the key to reducing losses caused by climate-induced diseases.

Conclusion

Climate change has become a major threat to plant health and crop productivity by altering temperature, rainfall, and humidity patterns, which in turn influence pathogen behaviour and increase disease risks for farmers. Although the challenge is complex, it can be addressed through climate-smart plant disease management, which focuses on prediction, prevention, integration, and precision. The combined use of early warning and disease forecasting systems, resistant and climate-resilient varieties, integrated disease management practices, and modern technologies enables farmers to manage plant diseases effectively under changing climatic conditions. Adopting these approaches is essential for sustainable crop production, environmental safety, and long-term food security in a climate-uncertain future.

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FLOODS IN INDIA: A SYSTEMATIC OVERVIEW AND MANAGEMENT PERSPECTIVES

Article ID: AG-VO6-I01-39***Harish B P and Thirumal A**

^{1&2}Ph.D. Scholar, Department of Agricultural Extension Education, University of Agricultural Sciences, Bengaluru, Karnataka, India.

*Corresponding Author: Harish B P

Introduction

Flooding is arguably the weather-related hazard that is most widespread around the globe. It can occur virtually anywhere. A flood is defined as water overflowing on to land that usually is dry. Flooding is often thought of as a result of heavy rainfall, but floods can arise in a number of ways that are not directly related to ongoing weather events. Out of the total geographical area of 329 million hectares, more than 40 million hectares is flood prone. An average every year, 75 lakh hectares of land is affected and damage caused to crops, houses and public utilities is Rs.1805 crores due to floods. The maximum number of lives (11,316) was lost in the year 1977. The frequency of major floods is more than once in five years.

Floods have a significant impact on agribusiness and agriculture, negatively affecting production and the rural economy in several ways. One of the most serious consequences is crop loss, as planting areas can be completely flooded, resulting in financial losses for farmers. In addition, the destruction of essential infrastructure, such as roads, bridges, warehouses, and silos, hinders the flow of production and causes delays in deliveries. Another important consequence is the contamination of soil and water used in agricultural production. Floods carry sediments, pollutants, and chemicals to crop areas, which can result in productivity losses and impact the quality of the produced food. Furthermore, the mortality of livestock, such as cattle, poultry, and pigs, can reduce the production of meat, milk, eggs and other livestock products.

The destruction of crops and the reduction in agricultural production caused by floods can also lead to food shortages in the market, resulting in price increases of agricultural products

and affecting food security of the population. To deal with these impacts, farmers need to be prepared, adopting prevention and planning measures to minimize the damage caused by extreme weather events. It is essential that public policies and investments in infrastructure be implemented to help mitigate the impacts of these climate disasters on agribusiness and agriculture. Prevention and adaptation are crucial to ensuring the resilience of the agricultural sector in the face of climate change and extreme weather events, thus protecting food security and the rural economy.

FLOOD

A flood is the overflow of water beyond the normal limits of a water body or the accumulation of water over areas that are not normally submerged. ((**UNDRR**)

Floods are natural events in which water temporarily covers land that is usually dry, causing damage to agriculture, infrastructure, and livelihoods. (**FAO**)

An analysis of accidental deaths and flood affected area in India

The data presented in Table 1, show that National, State & district level statistics on flood affected area in India. From the table we can observe that, there is flood affected areas in the country is around 15.75 million hectares spread over 435 districts. Flood affected area is 39.76 Lakh Ha in Bihar due to floods in Ganga, Kosi rivers affecting 38 districts which is highest in the country. Flood affected area is 26.62 Lakh Ha, in Uttar Pradesh spread over 72 districts due to floods in Ganga River system every year, Flood affected area is 24.56 Lakh Ha in Assam which spread over 35 districts due to the floods that occur in Brahmaputra, Barak rivers almost every year. Flood affected area in these 3 states amounts to 60% of total flooded area in the country.

Coastal states like Tamil Nadu, Andhra Pradesh, Odisha, West Bengal are more prone to floods. Flood inundation in all other states appears to be less frequent and seasonal due to unprecedented heavy rainfall with high intensities, standing water in low lying areas.

The data in the Table 2, shows that number of districts affected by flood and area wise categorization, more than 2 lakh flood affected area in hectares is 12 district are affected, followed by 1.5 -2 lakh hectares of area affected by flood is 11 district, where 1 – 1.5 lakh hectares of area affected by flood is 34 district, 50 thousand – 1 lakh hectares of area affected by flood is 50 district, 25 – 50 thousand hectares of area affected by flood is 48 district, 10,000 - 25,000 hectares of flood affected area is 66 district, 5 – 10 thousand hectares of flood affected

area is 52 district, 1-5 thousand hectares of flood affected area is 76 district and lastly 100 – 1,000 hectares of flood affected area is 86 district in India.

The data presented in Table 3, deficits the State-wise number of accidental deaths by flood in India in the year 2022, where in states like Bihar has maximum accidental death of 316 members, Maharashtra has 103 members and remaining states having a smaller number of deaths. Also, can observe that there is of more male deaths that is 409 and female are 138 deaths.

Table 1. Flood affected area (1998-2022) statistics at state level in India

Sl. No	State	No. of Districts Affected	Flood Affected Area (Ha)
1	Andhra Pradesh	24	738200
2	Arunachal Pradesh	5	3373
3	Assam	35	2464958
4	Bihar	38	3976851
5	Chhattisgarh	12	12029
6	Delhi	7	5848
7	Gujarat	16	517770
8	Haryana	9	67852
9	Jammu & Kashmir	10	43022
10	Jharkhand	2	2966
11	Karnataka	26	280156
12	Kerala	10	79377
13	Madhya Pradesh	30	210809
14	Maharashtra	20	233590
15	Manipur	9	88352
16	Meghalaya	2	8787
17	Odisha	23	1424313
18	Punjab	15	1424313
19	Rajasthan	10	155144
20	Tamil Nadu	24	552010
21	Telangana	14	10231

22	Uttar Pradesh	72	2662942
23	Uttarakhand	2	7604
24	West Bengal	20	1969750
	Total	435	15750723

Source: Flood Affected Area Atlas of India

Table 2. Flood affected area Severity categories-based district level (1998-2022) Statistics

Flood affected area (Ha)	No. of Districts Affected
>2,00,000	12
1,50,000 -2,00,000	11
50,000 - 1,00,000	34
50,000 - 1,00,000	50
25,000 - 50,000	48
10,000 - 25,000	66
5,000 – 10,000	52
1,000 – 5,000	76
00 – 1,000	86
Total	435

Source: Flood Affected Area Atlas of India

Types of floods

There are several types of floods that can occur, each with its own causes and characteristics. The most common types of floods are as follows:

Riverine floods: These floods occur when heavy rainfall or snowmelt causes rivers or streams to overflow their banks. River floods can be slow-moving and occur over a period of days or weeks, or they can be sudden flash floods, which occur rapidly and with little warning.

Coastal floods: These occur when high tides, storm surges, or large waves cause seawater to flood onto coastal areas. Coastal floods are often associated with cyclones or other severe weather events.

Flash floods: These floods occur when heavy rainfall occurs in a short period of time, overwhelming the capacity of drainage systems and causing water to rapidly accumulate in low-

lying areas. Flash floods can be particularly dangerous, as they can occur with little or no warning.

Urban floods: These occur in urban areas when the built environment and pavement prevent rainwater from being absorbed into the ground, causing it to accumulate in low-lying areas. Urban floods can also be caused by blocked drainage systems, overloaded sewage systems, or any other forms of infrastructure failure.

Pluvial floods: These occur when heavy rainfall exceeds the capacity of drainage systems, causing water to accumulate on the surface of the land. Pluvial floods can occur in both urban and rural areas and can be particularly damaging to infrastructure and property.

Dam or levee failures: These occur when dams or levees are unable to withstand the pressure of floodwaters, causing them to breach and release large volumes of water downstream.

Table 3. Selected state-wise number of accidental deaths by flood in India (2022)

Sl. No	States/UTs	Male	Female	Total
1.	Andhra Pradesh	5	1	6
2.	Arunachal Pradesh	2	1	3
3.	Assam	16	7	23
4.	Bihar	227	89	316
5.	Chhattisgarh	10	0	10
6.	Gujarat	14	2	16
7.	Himachal Pradesh	1	3	4
8.	Jammu & Kashmir	4	0	4
9.	Jharkhand	2	1	3
10.	Karnataka	16	8	24
11.	Kerala	3	0	3
12.	Madhya Pradesh	10	5	15
13.	Maharashtra	85	18	103
14.	Manipur	1	0	1
15.	Rajasthan	1	0	1
16.	Sikkim	1	0	1
17.	Tamil Nadu	0	1	1

18.	Tripura	1	0	1
19.	Uttar Pradesh	10	1	11
20.	Uttarakhand	0	1	1
21.	India	409	138	547

Source: Indiatat.com (2022)

Causes for flood

India is prone to floods due to its geography, heavy rainfall during the monsoon, changing weather patterns with rising temperatures leading to more frequent and intense rainfall events, snowmelt, river overflows-flooding, rapid snowmelt, dam or levee failure, coastal storms or storm surges, and tsunamis, as well as flash flooding and landslides. Coastal regions are also at risk of flooding due to tropical cyclones and storm surges.

Land-use / land cover changes such as deforestation, rapid urbanization & poor drainage conditions, and poor agricultural practices might have led to flood severity. During the last four decades, it has been observed that the frequency and severity of floods in India have been increasing. The Indian government has developed a National Disaster Management Plan to respond to floods and other natural disasters. The plan includes measures such as evacuation and rescue of people in flood-prone areas, provision of relief materials and medical aid, and the reconstruction of damaged infrastructure for flood mitigation.

Impact on farming community

Floods and landslides have a significant impact on agribusiness and agriculture, negatively affecting production and the rural economy in several ways. One of the most serious consequences is crop loss, as planting areas can be completely flooded, resulting in financial losses for farmers. In addition, the destruction of essential infrastructure, such as roads, bridges, warehouses, and silos, hinders the flow of production and causes delays in deliveries.

Another important consequence is the contamination of soil and water used in agricultural production. Floods carry sediments, pollutants, and chemicals to crop areas, which can result in productivity losses and impact the quality of the produced food. Furthermore, the mortality of livestock, such as cattle, poultry, and pigs, can reduce the production of meat, milk, eggs, and other livestock products.

The destruction of crops and the reduction in agricultural production caused by floods and landslides can also lead to food shortages in the market, resulting in price increases of

agricultural products and affecting food security of the population. To deal with these impacts, farmers need to be prepared, adopting prevention and planning measures to minimize the damage caused by extreme weather events.

It is essential that public policies and investments in infrastructure be implemented to help mitigate the impacts of these climate disasters on agribusiness and agriculture. Prevention and adaptation are crucial to ensuring the resilience of the agricultural sector in the face of climate change and extreme weather events, thus protecting food security and the rural economy.

MANAGING FLOODS

These measures can be classified into

1. Structural measures
2. Non-structural measures

Structural measures: Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structure system.

The main structural measures undertaken so far in India are as follows.

1. Embankments, Floodwalls, Flood levees
2. Dams and Reservoirs
3. Natural Detention Basin
4. Channel Improvement
5. Drainage Improvement
6. Diversion of flood water
7. Catchment area treatment/ afforestation
8. Anti-erosion works

Non-Structural Measures: Non-structural measures strive to keep the people away from floodwater. It contemplates use of floodplains judiciously.

Following are the main non-structural measures.

1. Flood forecasting and warning
2. Flood Hazard Zoning
3. Flood Proofing
4. Regulation of reservoirs
5. Flood Insurance

Flood Management Programmes in India

National Flood Management Programme (NFMP)

Implemented by the Government of India to assist states in the construction and maintenance of flood control infrastructure such as embankments, drainage channels and anti-erosion works in flood-prone areas.

Flood Management and Border Areas Programme (FMBAP)

This programme focuses on flood control, river management and anti-erosion works, especially in border states and riverine regions prone to frequent flooding.

National Disaster Management Plan (NDMP)

Prepared by the National Disaster Management Authority (NDMA), this plan provides guidelines for flood preparedness, response, relief and rehabilitation. It emphasizes early warning systems, evacuation planning and coordination among agencies.

Integrated Flood Management (IFM)

Promoted by national and international agencies, IFM advocates a holistic approach that combines land-use planning, watershed management, floodplain zoning and community participation rather than relying solely on structural measures.

Flood Forecasting Programme (Central Water Commission – CWC)

The CWC operates flood forecasting and warning systems across major river basins to provide advance information on rising water levels, enabling timely evacuation and preparedness.

Conclusion

Floods remain a persistent and severe threat to India's agriculture, infrastructure, and overall rural economy. The impact of floods extends beyond immediate physical damage, causing significant economic losses, disrupting food production, and compromising food security. To mitigate these impacts, a comprehensive measures to be taken to improve disaster management, early warning systems, and flood control infrastructure that include the construction of dams, embankments, and other flood control structures specifically to mitigate the impact of floods through different State & Central disaster management support organizations

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FLOWER DROP MANAGEMENT IN POMEGRANATE (PUNICA GRANATUM L.)

Article ID: AG-VO6-I01-40**A. Aathirai**

Post Graduate Student, Department of Fruit Science,
Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India.

Abstract

Pomegranate is an important commercial fruit crop cultivated extensively in arid and semi-arid regions of India. Despite its high export potential and profitability, pomegranate growers frequently face the problem of excessive flower drop, which directly affects fruit set and yield. Flower drop is a complex physiological disorder influenced by environmental, nutritional, hormonal, and management factors. Effective flower drop management requires an integrated approach involving balanced nutrition, proper irrigation, canopy management, growth regulator application, and pest–disease control. This article discusses the types of flowers in pomegranate, causes of flower drop, and practical management strategies to minimize losses and improve productivity.

Key words: Pomegranate, flower drop, fruit set, growth regulators, nutrient management

1. Introduction

Pomegranate (*Punica granatum* L.) is one of the most ancient fruit crops, valued for its nutritional richness, medicinal properties, and high market demand. India is the largest producer of pomegranate in the world, with major cultivation in Maharashtra, Karnataka, Gujarat, Andhra Pradesh, and Tamil Nadu. However, productivity is often limited due to poor fruit set caused by heavy flower drop.

In pomegranate, only a small percentage of flowers develop into fruits, while the remaining flowers drop at different stages. Flower drop is a natural phenomenon, but excessive drop becomes a serious constraint under unfavorable growing conditions. Understanding the physiological behavior of pomegranate flowers and adopting appropriate management practices

is essential to achieve higher yield and better fruit quality.



2. Types of Flowers in Pomegranate

Pomegranate bears three types of flowers:

2.1 Male (Staminate) Flowers

Bell-shaped

Short style and rudimentary ovary

Shed naturally after anthesis

Do not contribute to fruit formation

2.2 Hermaphrodite (Bisexual) Flowers

Vase-shaped

Well-developed ovary and long style

Capable of fruit set

Most important for yield

2.3 Intermediate Flowers

Characteristics between male and hermaphrodite flowers

Low fruit-setting ability

A higher proportion of hermaphrodite flowers is essential for improved fruit set and yield.

3. Causes of Flower Drop in Pomegranate

3.1 Physiological Causes

Natural shedding of excess flowers

Competition for carbohydrates

Poor flower differentiation

Hormonal imbalance (low auxin and cytokinin levels)

3.2 Climatic Factors

High temperature (>38–40°C)

Low relative humidity

Hot and dry winds

Sudden temperature fluctuations

Heavy rains during flowering

These conditions lead to pollen sterility, poor fertilization, and flower abscission.

3.3 Nutritional Imbalance

Nitrogen deficiency → weak flowering

Excess nitrogen → more male flowers

Deficiency of boron and zinc → poor pollen viability

Calcium deficiency → weak flower retention

3.4 Water Stress

Moisture stress during flowering

Irregular irrigation

Waterlogging conditions

Both drought and excess water can trigger flower drop by disturbing nutrient uptake and hormonal balance.

3.5 Pest and Disease Incidence

Thrips, aphids, and mites damage floral parts

Bacterial blight affects flower retention

Fungal infections under humid conditions

3.6 Improper Cultural Practices

Dense canopy and poor light penetration

Untimely pruning

Lack of crop regulation practices

Poor orchard sanitation

4. Flower Drop Management Strategies

4.1 Crop Regulation (Bahar Management)

Selection of appropriate bahar (Ambe, Mrig, or Hasta) based on water availability and climate

Proper rest period before bahar treatment

Synchronization of flowering improves fruit set

4.2 Nutrient Management

Balanced nutrition plays a crucial role in reducing flower drop.

Recommended practices:

Apply well-decomposed FYM (10–15 kg/tree/year)

Nitrogen, phosphorus, and potassium as per age of tree

Foliar sprays during flowering:

Boron: 0.2% borax

Zinc: 0.5% zinc sulphate

Calcium: 0.5% calcium nitrate

Avoid excess nitrogen during flowering stage

4.3 Irrigation Management

Light and frequent irrigation during flowering

Avoid moisture stress

Drip irrigation preferred for uniform moisture

Proper drainage to prevent water stagnation

4.4 Canopy Management

Annual pruning to remove dead, diseased, and overcrowded branches

Maintain open canopy for better light penetration

Improves photosynthesis and flower retention

4.5 Use of Plant Growth Regulators (PGRs)

Application of growth regulators helps in improving fruit set and reducing flower drop.

Effective PGRs:

NAA: 20–40 ppm at flowering

GA₃: 25–50 ppm

Brassinosteroids: Improve stress tolerance

Cytokinins: Promote hermaphrodite flowers

Sprays should be done during early flowering and repeated if necessary.

4.6 Pest and Disease Management

Regular monitoring of thrips and aphids

Use of neem-based formulations

Integrated pest management (IPM)

Timely control of bacterial blight through sanitation and copper fungicides

4.7 Environmental Stress Management

Use of shade nets in extreme heat conditions

Mulching to conserve soil moisture

Windbreaks to reduce hot wind damage

5. Integrated Approach for Better Flower Retention

No single practice can completely prevent flower drop. An integrated approach combining proper bahar treatment, balanced nutrition, regulated irrigation, timely pruning, PGR application, and pest management is essential. Adoption of modern orchard management practices significantly improves flower retention, fruit set, and overall productivity.

Conclusion

Flower drop in pomegranate is a major yield-limiting factor influenced by physiological, environmental, nutritional, and management-related causes. Understanding the flowering behavior and adopting scientifically proven management practices can significantly reduce flower drop. Integrated crop management, particularly balanced nutrition, irrigation scheduling, and growth regulator application, plays a vital role in improving fruit set and ensuring sustainable pomegranate production.

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HYDROGEL USES IN NURSERY MANAGEMENT OF FRUIT CROPS

Article ID: AG-VO6-I01-41**M. Shifana**

Post Graduate Student, Department of Fruit Science,
Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India.

Abstract

Efficient nursery management is crucial for producing healthy and vigorous planting material in fruit crops, as the early growth stage largely determines field establishment and long-term productivity. Water stress, nutrient leaching, and poor root development are common constraints faced in fruit crop nurseries, particularly under limited water availability. Hydrogels, also known as superabsorbent polymers, have gained attention as an effective soil amendment due to their remarkable ability to absorb and retain large quantities of water and release it gradually to plant roots. When incorporated into nursery media, hydrogels improve soil moisture retention, enhance aeration, and create a favorable microenvironment for root growth. Their use reduces irrigation frequency, minimizes moisture fluctuations, and indirectly improves fertilizer use efficiency by reducing nutrient losses through leaching. In fruit crop nurseries, hydrogel application has been shown to enhance seedling establishment, increase root and shoot biomass, and reduce transplant shock during field establishment. Although hydrogels do not act as nutrient sources, their role in sustaining moisture availability contributes significantly to stress tolerance and overall seedling quality. This article highlights the working mechanism of hydrogels, their practical applications in fruit crop nurseries, and the benefits and limitations associated with their use. The integration of hydrogels with sound nursery management practices offers a promising approach for improving water-use efficiency and producing resilient, high-quality fruit crop planting material, especially in water-scarce regions.

Introduction

In the cultivation of nursery plants, particularly for fruit crops, establishing strong and

vigorous seedlings is fundamental to achieving high productivity and sustainable yields. Young plants are especially vulnerable to water stress, nutrient deficiencies, and poor root development. Among the various agricultural tools developed to enhance nursery production, hydrogels — superabsorbent polymers capable of retaining large quantities of water — have emerged as a noteworthy soil amendment. By improving water retention, nutrient availability, and root microenvironment, hydrogels offer a range of benefits that can significantly enhance the quality and survival of fruit crop nursery plants.

This article explores the characteristics of hydrogels, mechanisms of action, and their specific roles in fruit crop nurseries. Emphasis is placed on effective application methods, physiological benefits to plants, and practical considerations for growers.

What Are Hydrogels?

Hydrogels are polymeric materials with an exceptional ability to absorb and retain water many times their own weight. Their three-dimensional network structure traps water molecules, which can then be released slowly back to the surrounding soil through capillary action or plant uptake. The most commonly used hydrogels in agriculture are polyacrylamide-based polymers, though biodegradable and natural variations (e.g., starch-based or cellulose-based hydrogels) are increasingly available.



Hydrogels are used as soil conditioners — not fertilizers — and do not supply nutrients by themselves. Their primary function lies in modifying the soil's physical properties to create a more favorable environment for root growth and plant establishment.

How Hydrogels Work in the Soil

Hydrogels work through three main mechanisms:

Water Retention:

When added to soil or potting media, hydrogels absorb irrigation water or rainfall and swell.

During periods of dry soil, they slowly release this stored water back to the roots, effectively reducing water stress experienced by plants.

Improved Soil Structure:

Hydrogels increase the soil's porosity and aeration. A looser soil structure improves root penetration and enhances microbial activity — both crucial for healthy seedlings.

Enhanced Nutrient Use Efficiency:

While hydrogels do not supply nutrients, they help retain soluble nutrients in the root zone by reducing leaching. This indirectly increases the efficiency of applied fertilizers.

Benefits of Hydrogels in Fruit Crop Nurseries

1. Reduction in Irrigation Frequency

One of the biggest challenges in nurseries is maintaining consistent moisture levels, especially in raised beds or containers where soil dries rapidly. Hydrogels act as mini-reservoirs that release water during dry spells, allowing nursery managers to reduce irrigation frequency without sacrificing plant health. This not only saves water but also reduces labor and energy costs associated with frequent watering.

For example, in mango or citrus nurseries, where young seedlings are sensitive to erratic moisture levels, hydrogel application has been shown to maintain soil moisture for extended periods and improve early growth.

2. Enhanced Seedling Establishment and Growth

Strong root systems are key in determining the future performance of fruit trees. Hydrogels contribute to better root development by:

1. Creating a moist and aerated root environment.
2. Reducing fluctuations in soil moisture that can stress young roots.



Studies have shown that seedlings grown with hydrogels often display longer roots, more lateral roots, and higher biomass compared with controls. These traits are especially valuable when seedlings are later transplanted to field conditions

3. Stress Mitigation Under Drought Conditions

Hydrogels help cushion plants from short periods of drought stress — a common issue in tropical and arid regions. When supplementary irrigation is delayed or inconsistent, hydrogels continue to supply moisture directly to the root zone. This ensures that physiological processes such as photosynthesis and nutrient uptake are maintained, minimizing growth setbacks.

In fruit crops like guava, pomegranate, and papaya, which are often cultivated in regions with uncertain rainfall, this benefit contributes significantly to nursery reliability.

4. Improved Fertilizer Efficiency

Although hydrogels do not release nutrients, by holding water and solutes close to the roots, they reduce nutrient leaching — especially in sandy or light media. This means that applied fertilizers remain available for longer, leading to better nutrient uptake and reducing wastage.

Nursery managers often pair hydrogel use with controlled-release fertilizers to synchronize water and nutrient availability, further improving seedling quality.

5. Reduced Transplant Shock

Transplant shock occurs when seedlings are moved from controlled nursery environments to field conditions. The sudden change in moisture, temperature, and soil properties can stress plants, slowing growth or even causing plant death.

Hydrogels applied at transplanting help maintain soil moisture around roots during this critical period. This gradual and sustained water supply reduces shock and increases survival rates.

Application Techniques in Nursery Settings

Hydrogels can be applied in several ways, depending on the nursery system:

Soil Incorporation

Hydrogels are mixed evenly into potting media or nursery beds before sowing or transplanting. Depending on the product and soil type, recommended rates typically range from 0.1% to 0.5% of soil weight.

Seed Coating

In some systems, seeds are coated with hydrogel particles prior to sowing. This helps

maintain moisture around germinating seeds, promoting faster and more uniform emergence — particularly useful for small or recalcitrant seeds.

Transplant Dipping

Seedlings can be dipped in a hydrogel solution before planting in fields or larger containers. This ensures hydrogel particles are concentrated around the root zone during establishment.

In-Pot Hydration

In container nurseries, hydrogel granules are mixed with the potting mix so that every container has a consistent water supply, significantly reducing watering needs.

Practical Considerations

Choice of Hydrogel Type

While synthetic polyacrylamide hydrogels are effective and long-lasting, concerns about environmental safety have led to increased interest in biodegradable hydrogels. Natural polymer options degrade over time and pose fewer environmental risks, though they may hold slightly less water.

Soil and Climate Compatibility

Hydrogels are most effective in sandy or coarse soils with low water retention. In heavy clay soils, their relative benefit may be reduced, although they still improve aeration and root environment.

In hot climates with high evapotranspiration, hydrogels can significantly reduce water stress, but careful irrigation management is still needed to avoid salt accumulation.

Cost–Benefit Analysis

While initial costs of hydrogels are higher than traditional soil conditioners, benefits such as reduced irrigation costs, improved seedling quality, and higher survival rates often justify the investment — especially in high-value fruit crops.

Case Studies in Fruit Nurseries

Mango Nursery Management

- Mango seedlings are prone to water stress during establishment. Nursery trials have shown that hydrogel application:
- Increased soil moisture retention by up to 30%.
- Improved seedling height and stem girth compared to non-treated controls.

- Reduced watering frequency from daily to once every 2–3 days under similar climate conditions.

Citrus Nursery Enhancement

- In citrus nurseries, hydrogels have been incorporated into media mixtures with organic compost. The result was:
- More uniform seedling growth.
- Higher root biomass.
- Enhanced tolerance to temporary dry spells.
- These case outcomes indicate that hydrogels can be particularly beneficial in nurseries where water availability is limited or costly.

Challenges and Future Directions

- Despite their benefits, hydrogels are not a silver bullet. Challenges include:
- Cost limitations for smallholder nurseries.
- Potential build-up of salts in soil when irrigation water quality is poor.
- Unclear long-term soil impacts if synthetic hydrogels are repeatedly applied.
- Future research is focusing on:
- Developing biodegradable hydrogel blends with nutrient-release capabilities.
- Optimizing application rates for specific fruit species.
- Integrating hydrogels with precision irrigation and smart nursery systems.

Conclusion

Hydrogels are a powerful tool in the nursery management of fruit crops. By enhancing soil water retention, improving root environments, and increasing nutrient use efficiency, hydrogel applications can contribute to stronger seedling establishment, reduced irrigation needs, and better overall plant performance. While cost and environmental considerations remain important, the controlled use of hydrogels offers sustainable advantages for growers, particularly in water-limited environments.

When integrated with good nursery practices — careful irrigation scheduling, balanced fertilization, and quality media preparation — hydrogels can play a key role in producing robust, market-ready fruit crop seedlings.

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FIRST REPORT OF PHYLLODY-LIKE FLORAL MALFORMATION ON *IXORA SPP.* IN NAMAKKAL DISTRICT, TAMIL NADU, INDIA

Article ID: AG-VO6-I01-42

Jebin Raj. S^{1*}, Devanathan. L² and Aadhikesavan. V³^{1,2&3} Student, PGP College of Agricultural Sciences, Namakkal, Tamil Nadu – 637405, India

*Corresponding Author: Jebin Raj. S

Abstract

A phyllody-like floral malformation was observed on *Ixora spp.* growing in the ornamental garden of PGP College of Agricultural Sciences, Namakkal District, Tamil Nadu, India, during November 2025. Affected plants exhibited dense leafy proliferations replacing normal inflorescences, giving rise to compact, green, leaf-like clusters resembling witches'-broom. This report documents the first field observation of phyllody-like symptoms on *Ixora* from Namakkal District. The identification is based solely on visual symptomatology, and no laboratory confirmation (PCR or microscopic studies) was conducted. This short report is intended to document the occurrence, assist in future monitoring, and serve as a baseline for further diagnostic work.

Introduction

Phyllody refers to the abnormal transformation of floral organs into leafy structures and is commonly associated with physiological disorders, stress factors, or phytoplasma infections in a wide variety of crops and ornamentals. Characteristic symptoms include leafy flowers, proliferation of vegetative structures within inflorescences, partial virescence, and witches'-broom. Similar visual symptoms are well documented in ornamentals such as marigold, periwinkle, chrysanthemum, and rose, and in crops including sesame, brinjal, and cucurbits. Reports of phyllody-like malformations in *Ixora* are limited, although the genus is widely cultivated as an ornamental hedge plant across tropical India.

Field Observation and Methods

In November 2025, several *Ixora* plants grown in the institutional landscape at PGP

College of Agricultural Sciences (Namakkal District, Tamil Nadu) exhibited abnormal floral development. Observations were made visually and photographed in situ. No destructive sampling, molecular diagnostics, or microscopic examinations were performed.

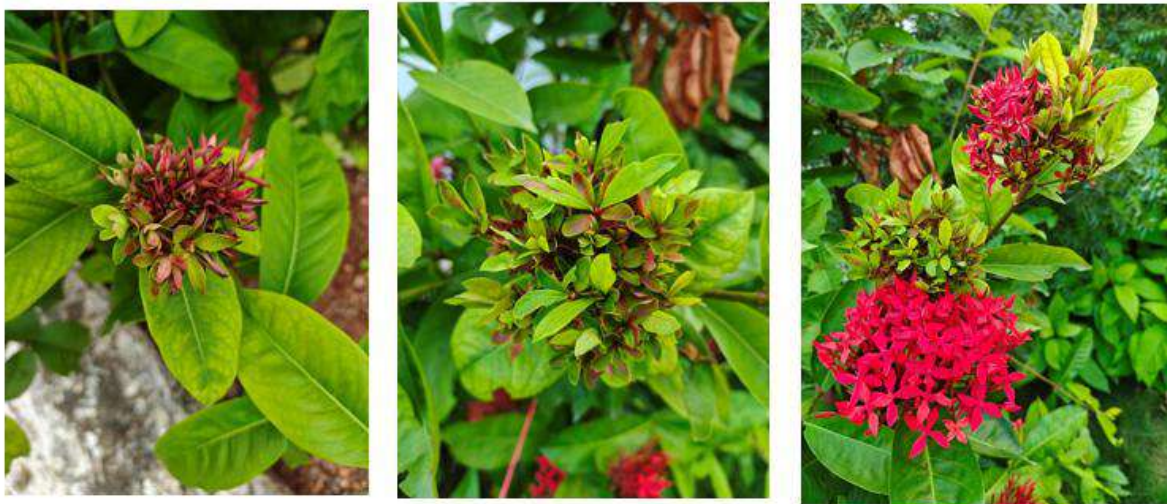


Plate 1. Phyllody-like malformation observed on *Ixora* spp. at PGP College of Agricultural Sciences, Namakkal District

Symptoms included:

- Replacement of floral buds with compact, leaf-like structures;
- Dense proliferation of small green bracts forming rounded clusters;
- Witches'-broom-like appearance on terminal shoots;
- Partial reddish coloration on some malformed bracts.
- Plants showed otherwise normal foliage growth and no obvious insect damage at the time of inspection.

Conclusion

This note documents the first visual report of phyllody-like floral malformation on *Ixora* spp. in Namakkal District, Tamil Nadu. While the symptoms closely resemble phyllody associated with biotic or abiotic disorders, confirming the causal agent would require laboratory diagnostics (e.g., PCR for phytoplasmas, mite examination, nutrient analysis). Nevertheless, this preliminary field record is valuable for horticultural monitoring and alerts gardeners, students, and local plant health workers to the presence of this abnormality. Further systematic surveys and confirmatory tests are recommended.

SPEED BREEDING: TRANSFORMING AGRICULTURE FOR A FOOD-SECURE FUTURE

Article ID: AG-VO6-I01-43**Akshay Mamidi^{1,2*}, Vamshi Poloju^{1,2}, Sagar S. P³, Vajramma Boggala⁴ and Dori Bhavana²**¹ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, 500030.²Professor Jayashankar Telangana Agricultural University, Telangana, 500030.³Division of Microbiology, ICAR-Indian Agricultural Research Institute, New Delhi-110012.⁴CSB-Central Sericultural Research and Training Institute, Mysuru, 570008, India***Corresponding Author: Akshay Mamidi**

Abstract

Speed breeding has emerged as a transformative approach in modern plant breeding, offering unprecedented opportunities to accelerate varietal development in the face of rising food demand, climate change, and diminishing natural resources. Conventional breeding approaches often require 8–12 years to release a new cultivar, limiting the pace at which improved crop varieties reach farmers. Speed breeding overcomes this constraint by manipulating environmental factors such as light intensity, photoperiod, and temperature to shorten crop generation cycles and enable multiple generations per year. Under controlled conditions, major crops including wheat, rice, chickpea, soybean, canola, and several vegetables can achieve four to eight generations annually. When integrated with contemporary breeding tools such as single seed descent, doubled haploids, marker-assisted selection, genomic selection, and genome editing, speed breeding significantly enhances genetic gain and breeding efficiency. The approach has already demonstrated success in cereals, pulses, oilseeds, and vegetable crops, enabling rapid development of high-yielding, stress-tolerant, and nutritionally improved varieties. Despite challenges related to infrastructure costs and crop-specific protocol optimization, speed breeding holds immense promise for strengthening crop improvement programmes. Its strategic adoption can play a pivotal role in ensuring food and nutritional security, particularly in climate-vulnerable regions such as India.

1. Introduction: Why Speed Matters in Plant Breeding

Global agriculture is standing at a critical crossroads. By 2050, the world's population is projected to exceed nine billion, demanding nearly double the current food production. At the same time, climate change, shrinking arable land, emerging pests and diseases, and erratic weather patterns are placing unprecedented stress on crop productivity. Developing improved crop varieties—those that are high-yielding, climate-resilient, and nutritionally superior—has therefore become an urgent global priority.

However, conventional plant breeding is inherently time-consuming. The pace of varietal development is largely dictated by a crop's generation time, often requiring 8–12 years to release a new cultivar. This slow progress has prompted breeders to seek innovative approaches that can dramatically shorten breeding cycles without compromising genetic gain.

One such revolutionary approach is speed breeding (SB). Speed breeding uses controlled environmental conditions, notably light, temperature, and photoperiod manipulation—to accelerate plant growth and reproduction. By enabling multiple generations per year, speed breeding allows breeders to move from cross to cultivar in a fraction of the traditional time (Watson et al. 2018). Today, speed breeding has emerged as a powerful, transformative tool in modern crop improvement, offering solutions to both productivity and sustainability challenges.

2. The Concept of Speed Breeding

Speed breeding is a collection of techniques designed to accelerate plant development, particularly flowering and seed set, by optimizing environmental conditions. Unlike conventional breeding that relies on seasonal field cycles, speed breeding exploits extended photoperiods, precise temperature control, and optimized light quality to keep plants photosynthetically active for longer durations.

Under speed breeding systems, crops such as wheat, barley, rice, chickpea, canola, and soybean can complete 4–8 generations per year, compared to just one or two under field conditions (Zheng et al. 2013; Watson et al. 2018). This rapid generation advancement enables the swift development of stable and homozygous lines, facilitates early-generation selection, and accelerates the deployment of new varieties.

Importantly, speed breeding is not a replacement for conventional breeding; rather, it is a complementary acceleration strategy that integrates seamlessly with established breeding pipelines.

3. Historical Evolution of Speed Breeding

The foundations of speed breeding were laid in the 1980s, when researchers at the United States Department of Agriculture experimented with artificial lighting to increase wheat cropping cycles. Around the same time, NASA, in collaboration with Utah State University, explored rapid generation advancement of wheat for space missions, leading to the development of the dwarf wheat cultivar USU-Apogee (Ghosh et al. 2018; Hickey et al. 2019).

A major technological breakthrough occurred in the 1990s with the advent of light-emitting diode (LED) technology, which enabled precise control over light intensity and wavelength while reducing energy costs. Building on these advances, researchers at the University of Queensland formally coined the term “speed breeding” in the early 2000s, standardizing protocols that dramatically shortened wheat breeding cycles.

Since then, speed breeding has evolved rapidly, incorporating advances in controlled environment agriculture, growth chambers, and photothermal regulation, and is now widely adopted across research institutions and breeding programs worldwide.

4. Integrating Speed Breeding with Modern Breeding Technologies

One of the greatest strengths of speed breeding lies in its compatibility with advanced breeding tools. When combined with techniques such as single seed descent (SSD), doubled haploids (DH), marker-assisted selection (MAS), genomic selection, and genome editing, speed breeding can significantly amplify genetic gains.

For example, genome editing technologies such as CRISPR/Cas9 have been successfully integrated with speed breeding to rapidly fix beneficial mutations. In wheat, targeted gene editing has enhanced yield potential and drought tolerance, while in tomato, CRISPR-mediated modification of ethylene biosynthesis genes has improved fruit shelf life (Shan et al. 2013; Liu et al. 2021). Similarly, TALEN-based editing in rice has conferred resistance to bacterial blight.

By shortening generation cycles, speed breeding allows breeders to quickly validate edited lines, advance generations, and assess phenotypes, thereby bridging the gap between molecular innovation and field application.

5. Core Principles and Protocols of Speed Breeding

Manipulation of Light and Photoperiod

Light is the most critical factor in speed breeding. Most protocols rely on extended photoperiods of 20–22 hours, allowing plants to photosynthesize almost continuously. Light

sources emitting photosynthetically active radiation (PAR) between 400–700 nm, with intensities ranging from 360–650 $\mu\text{mol m}^{-2} \text{s}^{-1}$, are commonly used (Watson et al. 2018).

Photoperiod manipulation has proven effective across a wide range of crops, including wheat, rice, chickpea, canola, and pea. In chickpea, exposure to a 12 h light/12 h dark cycle using incandescent bulbs induced early flowering and significantly reduced generation time (Samineni et al. 2020).

6. Temperature Regulation

Temperature management is equally crucial in speed breeding systems. Optimal temperature ranges promote rapid vegetative growth, flowering, and seed maturation. For example, wheat and barley embryos germinate efficiently at 20–22 °C, while chickpea immature seeds require around 25 ± 1 °C for successful germination (Zheng et al. 2013; Samineni et al. 2020).

However, excessive temperatures above 33 °C can reduce pollen viability and induce male sterility in crops such as rice, sorghum, and soybean, emphasizing the need for precise thermal control (Hatfield and Prueger 2015; Singh et al. 2015).

7. Rapid Generation Advancement and Homozygosity

Speed breeding accelerates the attainment of homozygous lines by enabling multiple selfing cycles within a year. Techniques such as early seed harvest, immature embryo culture, and SSD are frequently employed. This rapid fixation of alleles not only saves time but also reduces resource consumption and facilitates early-generation selection.

8. Crop-Wise Applications of Speed Breeding

Cereals

Speed breeding has been most extensively validated in cereal crops, particularly wheat and barley. Under controlled environments, wheat can achieve up to 7–8 generations per year, compared to one generation under field conditions (Zheng et al. 2013; Watson et al. 2018). Barley has shown similar success, enabling rapid development of disease-resistant and drought-tolerant lines.

In rice, innovative greenhouse systems using high-density planting and photothermal control have enabled four generations per year, with harvesting completed within 95–105 days after planting (Collard et al. 2017).

Oilseeds

Canola has responded exceptionally well to speed breeding. By manipulating light, temperature, irrigation, and embryo culture, breeders have achieved four to seven generations per year, significantly accelerating pure-line development (Yao et al. 2016).

Soybean speed breeding protocols incorporating LED lighting, CO₂ supplementation, and early seed harvest have enabled up to five generations annually (Nagatoshi and Fujita 2019; Jahne et al. 2020).

Legumes and Pulses

Legumes, particularly cool-season pulses such as chickpea, lentil, pea, and faba bean, have benefitted substantially from speed breeding. Chickpea can produce up to seven generations per year under optimized light regimes (Samineni et al. 2020), while lentil has achieved up to eight generations annually using combined in vitro and in vivo techniques (Mobini et al. 2015). In pigeonpea, immature seed germination has enabled three to four generations per year, a remarkable improvement for this traditionally long-duration crop (Saxena et al. 2017).

Vegetables and Tuber Crops

Speed breeding protocols have also been standardized for vegetable crops such as tomato, pea, radish, and potato. In tomato, tolerance to continuous light has been linked to the CAB-13 locus, enabling cultivation under 24-hour illumination and rapid generation cycling (Velez-Ramirez et al. 2014).

In potato, extended photoperiods in controlled environments have resulted in earlier flowering, faster tuber development, and accelerated breeding cycles (Sood et al. 2020). Onion breeding, traditionally requiring 10–12 years, has been significantly shortened through dormancy breaking and rapid bulb maturation (Khosa and Dhatt 2020).

9. Achievements and Success Stories

Speed breeding has already delivered tangible successes. High-profile examples include the development of wheat varieties such as ‘DS Faraday’, known for high protein content and improved sprouting tolerance, and disease-resistant barley cultivars like ‘Scarlett’, developed in just two years using accelerated backcrossing (Hickey et al. 2017).

In rice, speed breeding facilitated the release of salt-tolerant varieties such as ‘YNU31-2-4’, while in legumes, rapid cycling has enabled the development of improved chickpea, lentil, and pea lines with enhanced stress tolerance. These successes highlight speed breeding’s potential to

revolutionize crop improvement, especially when integrated with molecular breeding tools.

10. Challenges and Limitations

Despite its promise, speed breeding is not without challenges. Establishing and maintaining controlled environment facilities requires significant initial investment, with lighting and temperature control accounting for over 50% of operational costs (O'Connor et al. 2013). Specialized expertise and infrastructure are also essential for effective implementation. Additionally, not all crops respond equally to extended photoperiods, and protocols must be carefully optimized on a crop- and genotype-specific basis. Integrating speed breeding with field trials remains essential to ensure agronomic performance under real-world conditions.

11. Future Opportunities and Outlook

As technologies advance and costs decline, speed breeding is expected to become increasingly accessible, even for resource-limited breeding programs. The integration of speed breeding with genomics-assisted breeding, high-throughput phenotyping, and digital agriculture holds immense potential to further accelerate genetic gains.

By reducing breeding timelines, optimizing resource use, and enabling rapid deployment of improved cultivars, speed breeding stands poised to play a pivotal role in ensuring global food security under changing climatic conditions.

Conclusion

Speed breeding represents a paradigm shift in plant breeding, offering a powerful means to overcome the time constraints of conventional varietal development. Through strategic manipulation of light, temperature, and photoperiod, breeders can dramatically accelerate generation advancement, achieve rapid homozygosity, and integrate modern breeding technologies with unprecedented efficiency. While challenges related to cost and infrastructure remain, the demonstrated successes across cereals, pulses, oilseeds, and vegetables underscore speed breeding's transformative potential. As global agriculture confronts mounting challenges, speed breeding emerges as a vital innovation—one that can help deliver resilient, high-yielding crops for a food-secure future.

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PROTECTED CULTIVATION SCENARIO OF FRUIT CROPS

Article ID: AG-VO6-I01-44**M. Shifana**

Post Graduate Student, Department of Fruit Science,
Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India.

Abstract

Protected cultivation has emerged as a modern and resilient approach to fruit crop production, particularly under the challenges posed by climate change, resource scarcity, and increasing quality standards in domestic and international markets. By enabling partial or complete control over the crop microclimate, protected cultivation minimizes environmental stress, enhances resource use efficiency, and improves fruit quality and productivity. In recent years, technological advancements, government support, and rising consumer demand for premium fruits have accelerated the adoption of protected cultivation systems. This article discusses the concept, importance, present and recent scenario, technological interventions, advantages, limitations, and future prospects of protected cultivation in fruit crops.

Introduction

Fruit crops constitute a vital component of horticultural agriculture, contributing significantly to nutritional security, farm income, employment generation, and export earnings. India, with its diverse agro-climatic zones, is uniquely positioned to cultivate a wide range of tropical, subtropical, and temperate fruits. However, traditional open-field fruit cultivation is increasingly constrained by unpredictable climatic conditions, including erratic rainfall, heat waves, frost, and prolonged droughts. These factors adversely affect flowering, fruit set, yield stability, and fruit quality.

In addition to climatic challenges, fruit growers face issues such as pest and disease outbreaks, inefficient resource utilization, high post-harvest losses, and fluctuating market prices. In response to these constraints, protected cultivation has emerged as a promising alternative that

allows fruit crops to be grown under controlled or semi-controlled environments. Protected cultivation offers opportunities to stabilize production, reduce risk, enhance quality, and achieve year-round or off-season fruit supply, thereby improving profitability and sustainability.



Concept and Importance of Protected Cultivation

Protected cultivation refers to the practice of growing crops within structures that provide protection from adverse environmental conditions while allowing controlled manipulation of growth factors such as temperature, humidity, light, and moisture. Common structures used include polyhouses, net houses, shade houses, low tunnels, and greenhouses. These structures act as a barrier against extreme weather conditions, pests, and diseases, creating a favorable microclimate for crop growth.

In fruit crops, protected cultivation is particularly valuable due to the perennial nature of many fruit plants and their sensitivity to environmental stress during critical growth stages. Fruits grown under protected environments generally exhibit improved growth vigor, uniform flowering, enhanced fruit set, better size, color, and shelf life. Moreover, protected cultivation supports efficient use of water, fertilizers, and plant protection inputs, making it a resource-efficient production system.

Protected Cultivation Practices in Fruit Crops

The adoption of protected cultivation in fruit crops involves scientific planning and precision management. Crop selection plays a crucial role, with high-value and climate-sensitive fruits such as strawberry, banana, papaya, grapes, citrus, dragon fruit, and certain minor fruits responding well to protected environments. The selection of suitable varieties adapted to

protected conditions ensures optimal growth and yield performance.

Water and nutrient management are key components of protected fruit cultivation. Drip irrigation combined with fertigation enables precise application of water and nutrients directly to the root zone, reducing wastage and improving nutrient use efficiency. The controlled environment reduces evapotranspiration losses and maintains optimal soil moisture, which is essential for sustained fruit growth and development.

Canopy management practices such as pruning and training are effectively implemented under protected conditions, ensuring proper light penetration and air circulation. This results in enhanced photosynthetic efficiency and reduced incidence of pest and disease problems. Mulching is commonly practiced to conserve soil moisture, suppress weeds, and regulate soil temperature.

Recent Scenario of Protected Cultivation in Fruit Crops

In the recent scenario, protected cultivation of fruit crops has gained increasing attention in India due to rising climate uncertainties and changing market demands. While protected cultivation was initially more popular in floriculture and vegetable production, fruit growers are now adopting this technology for high-value and exotic fruit crops. Fruits such as strawberry and dragon fruit have shown significant expansion under protected structures, particularly in non-traditional growing regions.

Government initiatives under national horticulture development programmes have played a major role in promoting protected cultivation by providing subsidies, technical guidance, and infrastructure support. These schemes have encouraged farmers, especially young and progressive growers, to invest in protected fruit production systems. The increasing popularity of exotic fruits among urban consumers has further boosted demand for fruits grown under protected conditions due to their superior quality and consistent supply.

Technological advancements have strengthened the present scenario of protected cultivation. Sensor-based monitoring systems, automation, and climate control technologies are increasingly being integrated into protected structures. These innovations allow real-time monitoring of temperature, humidity, and soil moisture, enabling timely management interventions. Although high-tech greenhouses involve higher initial investment, they offer greater precision and are suitable for export-oriented fruit production.

In recent years, protected cultivation has also contributed to off-season fruit production, enabling farmers to supply fruits during lean periods when market prices are high. This has improved income stability and reduced dependence on seasonal production cycles. With growing awareness and institutional support, protected cultivation is gradually emerging as a viable solution for sustainable fruit production under changing climatic conditions.

Advantages and Limitations

Protected cultivation offers numerous advantages in fruit crop production, including higher yield, improved fruit quality, reduced pest and disease incidence, efficient use of water and nutrients, and enhanced market opportunities. It enables farmers to produce fruits with better appearance, uniformity, and shelf life, meeting the quality standards of modern consumers and export markets.

However, certain limitations exist, particularly the high initial cost of establishing protected structures and the need for technical expertise. Improper management of temperature and humidity can lead to physiological disorders if not handled correctly. These challenges highlight the importance of training, extension support, and appropriate policy interventions to ensure successful adoption.

Future Prospects

The future of protected cultivation in fruit crops appears promising, especially in the context of climate-smart agriculture and sustainable horticulture. Continued technological innovation, cost-effective structure designs, and capacity-building programmes will play a key role in expanding adoption. Integration of digital agriculture tools, precision farming techniques, and improved varieties suited for protected environments will further enhance productivity and profitability.

With increasing consumer preference for high-quality fruits and the need for resilient production systems, protected cultivation is expected to become an integral part of modern fruit farming. Strengthening research–extension–farmer linkages will be crucial in translating technological advancements into field-level success.

Conclusion

The protected cultivation scenario of fruit crops represents a significant transition from traditional farming towards a more scientific, resilient, and market-oriented production system. By mitigating climatic risks, improving resource use efficiency, and enhancing fruit quality,

protected cultivation offers a sustainable solution to the challenges faced by fruit growers. With supportive policies, technological advancements, and increasing awareness, protected cultivation has the potential to redefine the future of fruit production and contribute substantially to agricultural sustainability and economic growth.

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SOILLESS CULTIVATION OF STRAWBERRIES

Article ID: AG-VO6-I01-45**A.Aathirai**

Post Graduate Student, Department of Fruit Science,
Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India.

Abstract

Soilless cultivation of strawberries is an advanced production technology that involves growing plants without natural soil by using inert substrates or nutrient solutions. This method enables precise control over water, nutrients, and root-zone environment, thereby overcoming major constraints associated with conventional soil-based cultivation such as soil-borne diseases, salinity, nutrient imbalance, and poor drainage. Strawberries, due to their shallow root system and high sensitivity to soil conditions, are particularly well suited for soilless systems under protected environments like greenhouses and polyhouses. Various systems such as substrate culture and hydroponics, using media like cocopeat, perlite, and vermiculite, have shown significant improvements in yield, fruit quality, and resource-use efficiency. Proper management of nutrient solution composition, pH, electrical conductivity, temperature, light, and humidity is critical for successful production. Although the initial investment and technical requirements are relatively high, soilless strawberry cultivation offers higher economic returns through enhanced productivity, off-season production, and premium fruit quality. This article reviews the principles, systems, growing media, nutrient management practices, advantages, limitations, and future prospects of soilless cultivation of strawberries, highlighting its potential as a sustainable and profitable horticultural practice.

Introduction

Strawberry (*Fragaria* × *ananassa*) is one of the most popular and high-value fruit crops cultivated worldwide due to its attractive appearance, pleasant aroma, rich nutritional value, and high market demand. Traditionally, strawberries are grown in soil under open-field or protected

conditions. However, soil-based cultivation often faces challenges such as soil-borne diseases, salinity, nutrient imbalance, poor drainage, and inconsistent yields. To overcome these limitations and to achieve higher productivity with better quality fruits, soilless cultivation has emerged as a promising alternative.

Soilless cultivation refers to the growing of plants without natural soil, using inert substrates or nutrient solutions to supply water, oxygen, and essential nutrients directly to the plant roots. In strawberries, soilless systems are increasingly adopted in greenhouses, polyhouses, and vertical farming units, especially in areas with limited fertile land or unfavorable soil conditions.



This article discusses the principles, methods, growing media, nutrient management, advantages, limitations, and future prospects of soilless cultivation of strawberries.

Importance of Soilless Cultivation in Strawberry

Strawberry plants have a shallow root system and are highly sensitive to soil conditions. Even minor variations in moisture, aeration, or nutrient availability can significantly affect growth, yield, and fruit quality. Soilless cultivation offers precise control over these factors, making it particularly suitable for strawberry production.

Key reasons for adopting soilless cultivation in strawberries include:

1. Elimination of soil-borne pests and diseases
2. Efficient use of water and nutrients
3. Higher yield and uniform fruit quality
4. Suitability for protected and off-season cultivation
5. Reduced dependence on land quality

Types of Soilless Cultivation Systems for Strawberries

1. Substrate-Based Culture

In this system, strawberry plants are grown in inert or organic substrates instead of soil.

The substrate provides physical support, while nutrients are supplied through fertigation.

Commonly used substrates include:

Cocopeat

Perlite

Vermiculite

Rockwool

Sawdust

Peat moss (where available)

Plants are grown in grow bags, pots, troughs, or raised beds placed inside protected structures.

2. Hydroponic Systems

Hydroponics involves growing plants directly in a nutrient solution without any solid growing medium, or with minimal support material.

Popular hydroponic systems for strawberries include:

Nutrient Film Technique (NFT)

Deep Water Culture (DWC)

Drip hydroponics

Aeroponics (advanced system)

Among these, drip hydroponics and NFT are most commonly used for commercial strawberry production.

Growing Media for Strawberry Soilless Cultivation

The choice of growing medium is crucial for successful strawberry production. An ideal medium should have good water-holding capacity, adequate aeration, stability, and should be free from pathogens.

Common Growing Media:

Cocopeat: Widely used due to high water retention, good aeration, and eco-friendly nature.

Perlite: Improves drainage and aeration; often mixed with cocopeat.

Vermiculite: Enhances moisture retention and nutrient availability.

Cocopeat + Perlite (3:1 or 2:1): Most recommended combination for strawberries.

The media should be sterilized or pathogen-free before planting to prevent disease occurrence.

Planting Material and Varieties

Planting Material

Healthy, disease-free planting material is essential for successful soilless cultivation. **Common types include:**

Runner plants

Plug plants

Tissue culture plants

Plug plants are preferred in soilless systems due to their uniformity and better establishment.

Suitable Strawberry Varieties

Variety selection depends on climate, market preference, and production system. Commonly used varieties in soilless cultivation include:

Albion

Camarosa

Festival

Sweet Charlie

San Andreas

Winter Dawn

Day-neutral and everbearing varieties perform particularly well under protected soilless systems.

Nutrient Management

In soilless cultivation, plants depend entirely on nutrient solutions for their growth and development. Therefore, precise nutrient management is critical.

Nutrient Solution Composition

Essential nutrients required include:

Macronutrients: Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulphur (S)

Micronutrients: Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo)

pH and EC Management

Ideal pH range: 5.5 – 6.5

Electrical Conductivity (EC): 1.2 – 2.0 dS/m, depending on growth stage

Nutrient solutions are generally applied through drip irrigation at regular intervals.

Environmental Requirements

Temperature

Optimal day temperature: 18–25°C

Night temperature: 10–15°C

Light

Strawberries require adequate light for flowering and fruiting. Protected structures should ensure sufficient sunlight or supplemental lighting if necessary.

Humidity

Ideal relative humidity: 60–80% Excess humidity can lead to fungal diseases, while very low humidity may cause flower drop.

Training, Pollination, and Crop Management

Regular removal of old leaves and runners is essential to direct energy toward fruit production.

Pollination is critical for fruit set; honey bees or bumble bees are commonly introduced in protected structures.

Integrated Pest and Disease Management (IPDM) practices should be followed.

Advantages of Soilless Strawberry Cultivation

Higher yield per unit area

Superior fruit quality and uniform size

Reduced incidence of soil-borne diseases

Efficient use of water and fertilizers

Clean and residue-free fruits

Suitable for urban and vertical farming

Limitations and Challenges

High initial investment

Requirement of technical knowledge

Dependence on power and irrigation systems

Risk of rapid crop loss if nutrient management fails

Economic and Commercial Potential

Despite higher initial costs, soilless cultivation of strawberries is economically viable due to higher yields, premium fruit quality, and off-season production. It offers excellent opportunities for entrepreneurs, progressive farmers, and urban growers.

Future Prospects

With increasing demand for high-quality fruits, water scarcity, and declining soil health, soilless cultivation is expected to expand rapidly. Integration with precision farming, automation, and climate-controlled greenhouses will further enhance productivity and sustainability.

Conclusion

Soilless cultivation of strawberries is a modern, efficient, and sustainable production technology that addresses many challenges of conventional soil-based farming. By providing precise control over nutrients, water, and environmental conditions, it ensures higher yields, better fruit quality, and year-round production. With proper technical support and training, soilless strawberry cultivation can play a significant role in improving farm income and meeting the growing demand for premium strawberries.

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INTEGRATED SUBSURFACE DRAINAGE SYSTEMS AND THEIR BENEFITS IN SODIC SOILS

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***Sujal Sanjay Bachhav and Shubham Sanjay Palve**

Ph.D. Scholar, Department of Soil Science, Mahatma Phule Krishi Vidyapeeth,
Rahuri, (MS) India

*Corresponding Author: Sujal Sanjay Bachhav

Introduction

Sodic soils pose a major constraint to agricultural productivity due to poor soil structure, reduced infiltration, shallow water tables, and low crop yields. Subsurface drainage systems have emerged as an effective engineering intervention to lower water tables, improve soil physical and chemical conditions, and support reclamation of sodic lands. This article provides a comprehensive review of the principles and design of subsurface drainage systems, their benefits in sodic soils, field results from India and worldwide, and practical considerations for adoption. It concludes with guidance for researchers, extension professionals, and policymakers aiming to improve sodic land productivity through sustainable drainage solutions.

1. Introduction

Soils affected by excessive sodium, commonly referred to as **sodic soils**, are widespread in irrigated and semi-arid regions. The dominance of sodium ions on soil exchange sites degrades soil structure, reduces infiltration rates, and encourages shallow water tables that limit crop growth. Managing sodicity is critical for maintaining agricultural productivity and rural livelihoods.

Among available reclamation techniques, **subsurface drainage systems**—engineered networks of buried perforated pipes designed to lower the water table—have shown significant potential in ameliorating sodic conditions and enhancing crop performance. This article synthesizes current knowledge on how subsurface drainage works, the benefits it brings in sodic environments, and evidence from field trials.

2. Characteristics of Sodic Soils

2.1 Formation and Causes

Sodic soils develop when sodium replaces other cations (such as calcium and magnesium) on soil exchange sites, increasing the **exchangeable sodium percentage (ESP)**. High ESP leads to clay dispersion, poor soil structure, and reduced soil hydraulic conductivity. The combination of irrigation with high-sodium water and poor natural drainage accelerates sodic conditions in many agricultural landscapes.

2.2 Impacts on Soil and Crops

Key problems associated with sodic soils include:

- **Clay dispersion and pore clogging**, which impede water movement.
- **Waterlogging and high water tables** that limit root aeration.
- **Alkaline pH conditions**, reducing nutrient availability.

Together, these factors reduce plant root growth and nutrient uptake, significantly decreasing crop yields if not addressed.

3. Subsurface Drainage Systems: Principles and Design

3.1 What Is Subsurface Drainage?

A **subsurface drainage system** consists of a network of perforated pipes buried beneath the soil surface. These pipes intercept excess soil water and direct it away from the root zone by gravity flow, thereby **lowering the water table** and improving soil moisture dynamics.

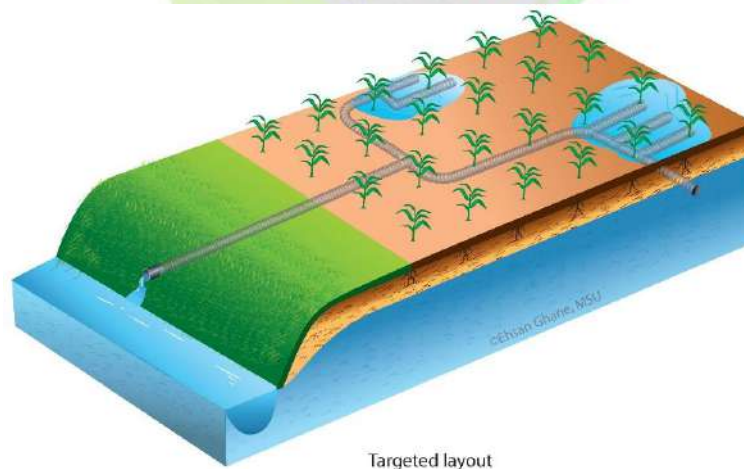


Figure 1. Subsurface drainage layout showing buried perforated drain pipes intercepting groundwater and redirecting it to an outlet. The lowered water table improves soil conditions for crop roots (adapted from drainage system guides).

3.2 Design Considerations

Key design factors include:

- **Drain spacing and depth** — typically based on soil hydraulic properties and desired water table depth.
- **Pipe material** — modern systems use perforated PVC or polyethylene tubing.
- **Outlets** — pipes discharge collected water to safe disposal areas.

Studies have demonstrated that proper drain spacing and depths significantly influence drainage effectiveness and soil improvement in sodic conditions. For example, in a study conducted in sandy loam sodic soils, perforated PVC pipes installed at specific spacings markedly improved soil conditions and crop yields. ([Agris](#))

4. Benefits of Subsurface Drainage in Sodic Soils

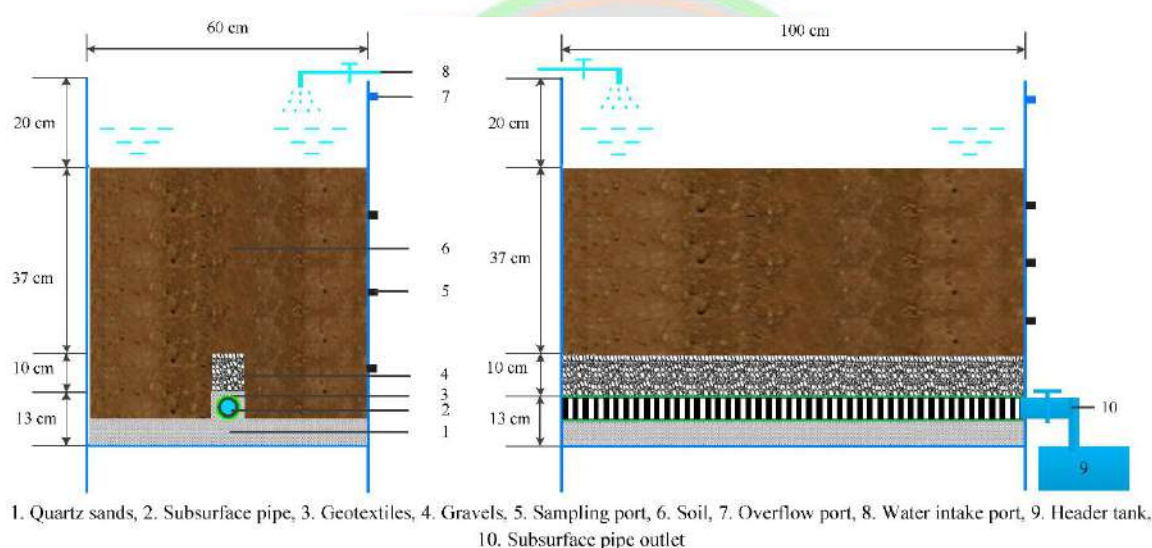


Figure 2. Water movement in soil with subsurface drains and elements used in drainage research.

4.1 Water Table Control

Controlling the water table is essential in sodic soils prone to waterlogging. Subsurface drainage effectively lowers the water table below the crop root zone, **preventing ponding and hypoxic stress** that limit root function and crop development.

4.2 Enhanced Salt Leaching

By facilitating downward movement of soil water, subsurface drains assist in **leaching soluble salts**, including sodium, away from the root zone. Long-term subsurface drainage in saline Vertisols demonstrated significant reductions in soil salinity and improvements in physico-chemical soil properties, such as soil organic carbon and hydraulic conductivity. ([ScienceDirect](#))

4.3 Improved Soil Physical Properties

With excess water removed:

- **Soil aeration improves**, enhancing root growth and microbial activity.
- **Bulk density decreases**, easing tillage and root penetration.
- **Hydraulic conductivity increases**, improving water movement through the soil profile.

These changes contribute to a more productive soil environment compared to sodic soils without effective drainage.

4.4 Increased Crop Yields

Field evidence supports improved crop performance following drainage installation. In sandy loam sodic soils with high water tables, crops such as **Til, Wheat, Pearl Millet, and Bengal Gram** recorded yield increases ranging from approximately 12% to 19% when subsurface drainage was installed, compared with undrained conditions. ([Agris](#))

4.5 Environmental and Soil Health Benefits

Effective drainage also supports:

- **Reduced duration of anaerobic soil conditions**, which can suppress beneficial microbial processes.
- **Improved nutrient cycling**, supporting sustainable soil health.

5. Indian Field Applications and Case Studies

5.1 Improvements in Indian Sodic Soils

India has seen successful adoption of subsurface drainage technology in saline and sodic soils. Research articles report that in an 8.1 ha sodic soil area near Rahuri (Maharashtra), subsurface drains installed with optimal depth and spacing significantly improved soil chemical and physical parameters over time. ([ARCC Journals](#))

5.2 Wider Adoption Across India

A recent review highlights that subsurface drainage technologies have been used to reclaim over 110,000 ha of waterlogged soils in India, supporting crop productivity and improving farmer incomes. However, challenges such as installation costs and machinery availability remain. ([ICAR E-Pubs](#))

Conclusions

Subsurface drainage systems have proven to be a valuable technology for improving sodic soils by lowering water tables, enhancing salt leaching, and improving crop yields.

Evidence from India and global research underscores their role in sustainable soil management. Integrated drainage design, combined with soil amendments and proper crop management, can transform sodic soils into productive agricultural land, bolstering both food security and farm profitability.

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VALUE ADDED FISH AND FISHERY PRODUCTS

Article ID: AG-VO6-I01-47**Nitesh Kumar Chandravanshi¹, Komal Prasad Sahu², Bhoopendra Chandravanshi¹**

¹Department of Fish Harvest and Post Harvest Technology, LSPN College of Fisheries
Kawardha, DSVCKV, Durg, (C.G.), India

²Department of Aquatic Environment Management, LSPN College of Fisheries Kawardha,
DSVCKV, Durg, (C.G.), India

* Corresponding Author: Nitesh Kumar Chandravanshi

Abstract

The world's population has grown significantly over the past few decades and is now growing quickly. Because of its low cost and excellent nutritional value, fish is regarded as a balanced food source to meet the growing need for food. Among its many health benefits, fish is a good source of polyunsaturated fatty acids and other nutrients that are in balance. Today's food market is determined by technology advancements in production, processing, and distribution. Changing lifestyles and rising affluence have spurred a new trend in consumer desire for premium cuisine. Strict quality control, value addition, and consumer appeal in food products have become crucial due to growing awareness of a healthy diet and overall health. The majority of medium and low value species, which make up the majority of landings, are either marketed fresh or processed for the domestic market, whereas the high value species are primarily processed for export. The development of value-added products is one way to address the post-harvest loss of resources, which is a key concern in this industry. This can also help to enhance the financial standing of those working in this industry. Technology to create a variety of value-added, ready-to-cook and serve products based on different fish and shellfish species—both wild and farmed—for both domestic and international markets is readily available.

Keywords: Value added fish Product , Omega -3-Fatty Acid, Sustainable Fisheries, Fish By Product, Fish processing, Post-Harvest Losses.

1. Introduction

The food processing sector, In India is among the biggest in terms of output, exports, consumption, and future growth possibilities. With a population of over a billion people, India might rank among the biggest markets for value-added agro-food products worldwide. The maritime industry accounts for 3.9 million of India's total 8.3 million tonnes of fish production potential, while the inland sector contributes 4.5 million tonnes. The present fish production, in contrast, is 5.96 million tonnes. The marine sector contributed 2.89 million tons, while the interior sector contributed 3.07 million tonnes (Vannuccini 2003).

Fish is widely consumed worldwide due to its health benefits. Because of changes in lifestyle and the belief that fish is a nutritious food that is high in digestible protein, polyunsaturated fatty acids (PUFA), and blood cholesterol-lowering properties, fish consumption has been gradually rising. The fish processing industry is rapidly expanding due to the introduction of new species, expansion of cold chain facilities, innovations in processing, preservation, and packaging, improved storage facilities, transportation options, and product diversification. As a result of these considerations, fish is becoming increasingly popular as a snack dish in addition to main courses. The growing demand for processed fish presents a career opportunity for those interested in this field.

Since fish is a highly perishable food item, it must be handled carefully during processing, packaging, storage, and transportation before it is consumed. By taking precautions during handling and processing, it is possible to preserve its quality, including its nutritional content, longer shelf life, higher economic return, and decreased post-harvest losses. Fish can be delivered to consumers as fresh, preserved, or value-added products. Fish can be processed and preserved using many technologies, including classic, modern, and high-input methods. To boost fish intake, a practical ready-to-cook and eat product is being developed. These value-added products are developed to meet consumer tastes, are nutritious, convenient, and have a long shelf life when stored properly (Singh et al., 2020). Fish is regarded as a significant source of food, nutrition, jobs, and revenue generating on a global scale. The combined production of fish from aquaculture and catch fisheries was around 154 million tons.

Approximately 131 million tons, or 85%, of the fish produced are used directly as food. Thus, over a ten-year period, the amount of fish consumed per person has increased by 17.5%. India's 2.02 million km² Exclusive Economic Zone boasts a varied range of marine fishing

resources, with an estimated yearly harvestable potential of 4.414 million metric tons. India's coastal coastline spans 8,129 kilometre's, with 3,827 fishing communities and 1,914 traditional fish landing centres. Despite being the world's second largest fish producer, India continues to lead in terms of average growth rate in fish production. Fish production has climbed by 18.86% during the last three years, including a 26% growth in the inland fisheries sector (Sundari et, al. 2019).

What is value addition?

A product can be economically enhanced by changing its present location, time, and form features to ones that are more desirable in the market. This is a broad definition of value added. For example, to economically improve an agricultural commodity (like wheat) by transforming it into a product (like flour) that customers (like bread bakers) desire would be a more constrained definition. Producers that add value should see themselves as a member of a food company that processes and sells products to consumers. This frequently entails constructing processing facilities in the geographic areas of the producers to handle locally grown products or livestock.

2.IMPORTANCE OF VALUE ADDITION

Value addition is a popular term in the fish processing sector, as it can increase profitability. Adding value to fish refers to increasing its value. A change in the physical state or shape of the fish. Producing a value-added fish product enhances its value, as indicated in a business strategy. Value addition enhances processing efficiency, aligns with consumer wants, and creates a diverse range of value-added fish products. Fish meat is a highly perishable product. With a moderate pH and high water activity (aw), it provides microorganisms with favourable nutrient availability conditions. In tropical nations, the issue of fish flesh's inherent suitability as a medium for microbial development is made worse by the high ambient temperature. Fish kept in these conditions is deemed rotten after 12 hours. By using methods for chilling, freezing, and canning, fish's shelf life can be increased. One of the biggest issues in fish processing worldwide is post-harvest fish losses, which can range from 5 to 10% as a result of insufficient post-harvest infrastructure. The biochemical and microbiological spoiling that takes place following fish death is frequently the source of post-harvest fish losses. Fish have built-in defence systems that help keep them from spoiling while they're alive. Fish can spoil more quickly due to a number of reasons, including handling procedures, temperature, time, and inadequate processing methods.

Fishery waste has become a global concern in recent years due to biological, technical, and operational reasons, as well as socioeconomic drivers. Fish waste refers to fish species with poor commercial value or unused resources. Over 50% of fish parts, including fins, heads, and skins, are collected as "fish wastes" during processing. Discards from global fisheries surpass 20 million tons annually about a quarter of the overall catch . This comprises by-products, waste from fish processing, and "non-target" species. Fish composition varies depending on species, sex, age, nutritional status, season, and health. Fishery waste has become a global concern in recent years due to biological, technical, and operational reasons, as well as socioeconomic drivers. Fish waste refers to fish species with poor commercial value or unused resources. Over 50% of fish parts, including fins, heads, and skins, are collected as "fish wastes" during processing. Discards from global fisheries surpass 20 million tons annually, accounting for 25% of total capture. This includes "non-target" species, fish processing wastes, and by-products. Fish composition varies depending on species, sex, age, nutritional status, season, and health. The significance of fish products with value additional value. It is possible to increase value by using trash fish and/or by catch, which are inexpensive and frequently captured by shrimp trawlers. There are more and more women im-n the workforce. Nowadays, urban dwellers are increasingly choosing microwaveable goods over deep-fried ones. Utilizing inexpensive fish helps cut down on waste. Saving on the time and work required to get ready for the meal. Prevent the loss of products flavour and taste through thawing, reprocessing and repackaging provides a large selection of enticing, healthy and secure cuisine

Consumer preferences for tropical fish and their products are influenced by several factors:

1. **Flavour and Culinary Versatility:** Tropical fish offer distinct and delectable Flavors that appeal to diverse culinary preferences. They can be grilled, fried, baked, or incorporated into seafood recipes, giving them a versatile option for consumers.
2. **Nutritional Benefits:** Essential components such as protein, omega-3 fatty acids, vitamins, and minerals are found in tropical fish. Customers that are concerned about their health enjoy the nutritional value and its inclusion in a balanced diet.
3. **Sustainable Sourcing:** As consumer awareness about sustainability grows, there is an increasing demand for responsibly sourced tropical fish. Consumers are more likely to

choose products that come from well-managed fisheries or sustainable aquaculture operations to support the long-term health of marine ecosystems.

4. **Local and Cultural Significance:** These fish are traditionally caught and consumed in locations with a strong cultural tie to them. Locals often favour these cultivars due to their heritage and culinary traditions.
5. **Availability and Accessibility:** Consumer choices for tropical fish are heavily influenced by their availability in the market. Retailers and restaurants who provide a diverse range of tropical fish items make it easier for customers to enjoy these delicacies. (S. Karunakaran *et,al.*2023)

3. TYPES OF VALUE-ADDED PRODUCT

Processing of coated-fish and fishery products

1. Fish finger or fish portion

Freshly landed Big Eye croaker (*Sciaena angus*) mince was used to make fish fingers. They decimated the fish. Ripped open and eviscerated. A hand mincer was used to separate the meat, and 10 and 5 g kg⁻¹ of salt and sodium polyphosphate were added, respectively. In a contact plate freezer set to -400C, the prepared mince was frozen. After being sliced into uniformly sized 7x2.5x1 me fingers, the frozen material was battered and breaded using egg and bread powder, respectively, and then frozen at -400C.

2. Fish blocks

They are the most popular beginning ingredient for breaded or fried fish sticks and portions. Over the past 10 to 20 years, the demand of fish blocks has increased significantly. Boneless fillets are arranged in a frame, compressed slightly, and then frozen to create a solid block with predetermined dimensions. The blocks are easy to handle, ship, and store. A typical 161/pound fish block measures 187/inch in length, 10 inches in width, and 2/inch in thickness. A sequence of band saws and a subsequent chopper split the blocks on the production line. While the chopper cut the sections into the appropriate width and form, the band saws decide the thickness of the portion. French cut, squares, rectangles, and wedges are the most popular shapes.

3. Shrimp products

Both wild and farmed shrimp can be used to make battered and breaded shrimp in a variety of ways. Butterfly, round tail-on, peeled and deveined (PD), nobashi (stretched shrimp), and others are the most significant. Shrimp are first shaped into the proper shape, and then they

are pre-dusted, battered, and breaded. After that, the breaded shrimp are packed in thermoformed trays, frozen in IQF form, and kept in cold storage

4. Squid products

The two most popular coated goods made from squid are stuffed squid and squid rings. After being cleaned, squid tubes are sliced into uniformly sized rings and fried for one to two minutes in a boiling brine (3%) before being cooled, breaded, and battered. After being flash-fried, the coated rings are cooled, frozen, and packaged. Typically, small animals are used to make stuffed squid. A stuffing mixture consisting of cooked squid tentacles, potatoes, fried onion, spice, and additional ingredients is then put into clean tube. After that, it is breaded, battered, and flash-fried.

5. Clam and clam related products

After being blanched in boiling brine, the meat extracted from depurated live clam is cooled, battered, breaded, flash-fried, and packed. The same technique can be used to turn other bivalves, such oysters, mussels, etc., into covered goods.

6. Fish fillets

They batter and bread the brined fillets. Additionally, coated items are made from freshwater fish fillets. The existence of fin bones is the only issue identified in this instance; their total removal remains a significant obstacle.

Mince based products

Fish cutlets, burgers, balls, and other coated items can be made with fish mince from both freshwater and marine fish.

1. Fish cutlet

The fish cutlets were prepared using, with slight adjustments, the recipe put out by A.S. Talab (2013) and Pawar et al. (2012). It entailed combining mince 75 percent with refined oil 6 percent, starch 8 percent, cumin 0.4 percent, coriander 0.5 percent, black pepper 0.6 percent, red pepper 0.5 percent, onion 1.5 percent, ginger 2 percent, and garlic 2.5 percent. After shaping it into different shapes, bread crumbs were added. After that, the cutlets were flash-fried in vegetable oil. They were placed in airtight containers, wrapped with aluminium foil, and kept in a refrigerator at $-12 \pm 2^{\circ}\text{C}$.

2. Fish balls

Typically, cheap fish mince is used to make fish balls. There are several methods for making balls. The simplest method is to combine the fish minced with flour, salt, and spices. After that, the mixture is shaped into balls and cooked in boiling 1% brine. After that, the fried balls are battered, breaded, and dusted in advance.

3. Crab claw balls

Crab leg that can swim can be employed for this. After removing the crab's claws from its body, the shell is cracked off and cleaned with cold drinking water. After removing the leg meat, 2 percent starch-based binder is added. The exposed end of the claw is then filled with this. As an alternative, you can stuff using the body flesh combined with the binder. The stuffed claw is then frozen, battered and breaded then flash fried. The coated goods are enclosed in cavities-filled thermoformed containers.

TRADITIONAL JAPANESE PRODUCTS

Kamaboko

After being steamed, kamaboko are usually cut into loaf-like pieces and serve cold with dipping sauces or mixed into hot soup and chicana, cheese-topped kamaboko snack. Certain shapes are tinted with traditional patterns that are indicative of local manufacturing. With crab flavouring, food colouring, and egg white, crab stick is a kind of kamaboko (Kanyama) that are typically consumed raw in salads. Emek, also known as doing, is a street meal that is cooked in broth and is a South Korean variation of kamaboko.

Koji

An essential component of making traditional fermented foods and spices in Japan is the saccharification of starch from grain or soybeans using koji. Mold spores and steamed rice or other grains are combined on a large permeable plate or piece of fabric. or in a wooden container that allows air to be routed through it at regulated temperatures and moisture levels, creating the ideal environment for Mold growth and enzyme synthesis. The most common Mold for growing koji cultivation is *Aspergillus oryzae*, which is used to make sake, shochu, miso, shoyu, and a type of pickle called tsukemono.

4. BENEFITS OF VALUE ADDED FISH AND FISHERY PRODUCTS

Every day, we may pick from a vast variety of foods on store shelves and at restaurants. Cardiovascular disease is one of these dietary and lifestyle-related ailments, and it was one of the

world's top ten causes of mortality in 2011, accounting for over 17 million fatalities (WHO, 2011). In people with high risk factors, consuming the omega-3 fatty acids docosahexaenoic acid (DHA C22:6) and eicosapentaenoic acid (EPA C20:5) can reduce cardiovascular risk (Delgado-Lista et al., 2012). In healthy people, omega-3 fatty acids may lower the risk of mortality from coronary heart disease (Harris et al., 2008; Schmidt et al., 2000).

I. Richest source of protein

Fish has been a staple diet for people worldwide from the beginning of time. It is now widely recognized that fish is an essential source of high quality, well-balanced, and readily digestible protein, vitamins, and polysaturated fatty acids. Fish are an excellent source of organic goods and rich quality protein. They are widely acknowledged as a good supply of protein and other components for maintaining a healthy body, and they are the most significant source of animal protein (Andrew, 2001). Consumption of fish and fisheries product has significantly expanded in several European countries in recent decades and is advised as a way to prevent cardiovascular and other ailments (Cahu et al., 2004).

II. Omega-3 fatty acid and cardiovascular disease

The American Heart Association (AHA) and other worldwide organizations claim that omega-3 fatty acids is good for heart in both healthy individuals and those who are at high risk or have cardiovascular disease (CD). Fish Consumption, Fish Oil, Lipids, and coronary heart disease was the subject of the American Heart Association's 1996 Science Advisory (Stone, 1996).

5. CONSUMER PREFERENCE

Farmers' markets offer both fresh vegetables and shelf stable value added products including sauce, jam, and fermented items. Farmers markets offer significant social and economic advantages to communities, farmers, and consumers. Farmers markets play a vital role in low-income urban areas that lack grocery stores and face significant food insecurity. Consumers are increasingly concerned about food quality and nutrition. Moringa, known for its nutritional and medicinal benefits, sees significantly lower domestic consumption of value-added products compared to its exports. While moringa is readily available in India and other countries, the demand for value added moringa product is on rise, highlighting need for a consistent year-round supply.



(Output: NVivo)

Fig: Word cloud of reasons for consumer preference toward value-added products

6. CURRENT MARKET TRENDS

The term "social media" encompasses all technological tools that facilitate the production and dissemination of user-generated content. The use of social media platform to promote dialogue and have positive influence on customer behaviour, such as product purchases, newsletter subscriptions, online community registrations, and other consumer actions, is known as social media marketing. If small business can use social media marketing properly, it gives them more chance to reach a wide target audience on a tight budget.

7. Future Possibilities

The future of value-added fish and fishery products is set to experience significant growth, influenced by changing consumer preferences, technological advancements, and the demand for sustainable seafood. Consumers are increasingly seeking ready-to-eat and cook seafood product, which is reflected in the popularity of frozen fish fillets, breaded seafood, and pre-cooked meals that cater to busy lifestyles. Additionally, there is a growing emphasis on health, leading to a shift towards seafood products that offer nutritional benefits. Value-added options highlighting omega-3 fatty acids and lowcalorie content are becoming more appealing, and incorporating functional ingredients can further enhance the marketability of these products (Santos-Yap, 1997).

Technological innovations are revolutionizing the fish farming industry. Advances in aquaculture, such as precision farming and data analytics, improve productivity and

sustainability by allowing for better monitoring of fish health and optimization of feeding strategies. Furthermore, sustainable practices aimed at reducing waste are becoming increasingly important. For instance, solarpowered freezers help maintain fish freshness in areas with limited electricity access, while cell-based fish production offers an environmentally friendly alternative to traditional fishing methods (ICAR Central Institute of Fisheries Technology, 2020).

There is also significant potential in product diversification within the seafood sector. Utilizing underexploited species and by-catch to create value-added products not only reduces waste but also opens new markets for lesser-known fish species. These can be transformed into high-value items like surimi or processed snacks. Moreover, introducing diverse product formats such as extruded snacks or fortified seafood options can cater to niche markets. Fish-based nutritional bars or pasta products are gaining traction among consumers looking for convenient yet healthy meal solutions (Palathra, 2020).

Conclusion

Fish is widely consumed globally because of its health advantages. Fish consumption has been steadily increasing due to lifestyle changes, perception of fish as a healthy food high in digestible protein, Polyunsaturated Fatty Acids (PUFA), and ability to lower blood cholesterol level. The development of value added fish and fishery product are crucial for meeting the increasing demand for fish while ensuring sustainable practices. By focusing on improving production methods, enhancing market access, and implementing effective regulatory frameworks, the fishery sector can significantly contribute to economic growth and food security. Value-added production is just one of many strategies that a business or policymaker must think about. To determine the best long-term strategy, alternative uses of the relevant economic resources must be assessed. Since fisheries products are crucial to our nation's economy, we must have a good understanding of value added fishery products.

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WATER HYACINTH AS BIOFUEL, COMPOST, AND BIOGAS: HOW A PROBLEM PLANT CAN BECOME A GREEN SOLUTION

Article ID: AG-VO6-I01-48**S. Bhaskar^{1*}, D. Manimekalai², Aparna A¹, Nazeela Barvin¹**

¹Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu

²Assistant Professor, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu.

*Corresponding Author: S. Bhaskar

Abstract

Water hyacinth is widely regarded as one of the most problematic invasive aquatic plants in tropical and subtropical regions. Its rapid growth, ability to form dense floating mats, and strong association with polluted water bodies have earned it a reputation as an ecological nuisance. However, recent scientific research and field-level innovations reveal that this fast-growing weed also holds significant potential as a renewable resource. Due to its high biomass production and organic content, water hyacinth can be effectively utilized for the production of biofuel, compost, and biogas. The ecological characteristics of water hyacinth, its transformation from an environmental burden into a useful resource, and the broader environmental, social, and educational significance of its sustainable utilization. The article highlights how adopting a resource-recovery approach can simultaneously address water pollution, energy demand, and waste management challenges as biofuel, biogas.

Keywords: water hyacinth, invasive aquatic plant, biofuel, compost, biogas, sustainable resource use

Introduction

Freshwater ecosystems such as lakes, ponds, reservoirs, and irrigation canals are essential for drinking water supply, agriculture, fisheries, and biodiversity conservation. However, these

systems are increasingly threatened by pollution, eutrophication, and invasive aquatic plants. Among these, water hyacinth stands out as one of the most aggressive and widespread species. At first glance, water hyacinth appears harmless, even attractive, with its glossy leaves and lavender flowers. Yet, its ecological impact is severe. The plant grows rapidly, forming thick mats that block sunlight penetration, reduce dissolved oxygen levels, and disrupt aquatic food webs. Fish mortality, loss of native biodiversity, obstruction of waterways, and increased mosquito breeding are common consequences of uncontrolled water hyacinth growth. Traditionally, management efforts have focused on physical removal, chemical control, or biological methods. While these approaches reduce infestation temporarily, they often fail to provide long-term solutions.

Species Classification of Water Hyacinth

Water hyacinth is a free-floating freshwater macrophyte scientifically classified as follows:

- **Kingdom:** Plantae
- **Division:** Angiosperms
- **Class:** Monocotyledonae
- **Order:** Commelinales
- **Family:** Pontederiaceae
- **Genus:** *Eichhornia*
- **Species:** *Eichhornia crassipes*

The plant is native to the Amazon Basin of South America but has spread across continents due to its ornamental value and adaptability. It reproduces both **vegetatively** (through stolons) and **sexually** (via seeds), making it extremely resilient and difficult to eradicate.

Abundance and Global Distribution

Rapid Proliferation

Water hyacinth is considered one of the world's fastest-growing aquatic plants. Under nutrient-rich conditions, its population can double within 10–15 days. A single plant can produce thousands of offshoots in a year, leading to explosive population growth.

Global Spread

Today, water hyacinth is widely distributed across: Asia (India, Bangladesh, Southeast Asia), Africa (Lake Victoria basin), North and South America, Australia and Pacific islands. In India, it is abundant in **eutrophic ponds, reservoirs, sewage-fed water bodies, irrigation canals and**

rivers, particularly in tropical and subtropical regions.

Biomass Availability

Due to its high abundance, water hyacinth produces enormous quantities of biomass annually. In heavily infested water bodies, biomass can exceed **200–400 tonnes (wet weight) per hectare per year**, making it a highly available raw material for bioenergy and compost production.

Ecological Characteristics of Water Hyacinth

Rapid Growth and Biomass Production

Water hyacinth is one of the fastest-growing plants in the world, capable of doubling its biomass within a short period under favourable conditions. This extraordinary growth rate allows it to dominate water surfaces quickly, especially in nutrient-rich environments.

Nutrient Absorption and Water Quality Impact

The plant absorbs large quantities of nitrogen, phosphorus, and other nutrients from polluted water. While this contributes to its aggressive spread, it also means that water hyacinth plays a role in nutrient recovery, making it useful in wastewater treatment and phytoremediation applications.

High Organic Matter Content

Water hyacinth tissues contain cellulose, hemicellulose, and organic carbon, which are key components required for energy generation and compost production. These properties make it suitable for biofuel and biogas production. ★ ★ ★ ★

Water Hyacinth as a Source of Biofuel

Solid Biofuel Production

One of the simplest ways to utilize water hyacinth is by converting it into solid biofuels such as briquettes and pellets. After harvesting, the plant is chopped, dried, and compressed to form fuel blocks that can be used for cooking and heating.

Advanced Biofuel Research

Researchers are also investigating the potential of water hyacinth for producing liquid biofuels, including bioethanol and bio-oil. Although its high moisture content poses technical challenges, appropriate pre-treatment and drying techniques can improve energy efficiency.

Environmental Significance

Using water hyacinth as biofuel helps reduce dependence on fossil fuels, lowers greenhouse gas emissions, and promotes renewable energy adoption.

For students, this represents a clear example of how biological resources can contribute to sustainable energy solutions.

Composting Water Hyacinth for Soil Health

Process and Nutrient Value

Composting is one of the most practical and accessible uses of water hyacinth. When mixed with other organic wastes and composted under controlled conditions, it decomposes into nutrient-rich organic manure.

Benefits to Agriculture

Water hyacinth compost improves soil structure, enhances moisture retention, and supplies essential nutrients to crops. It also reduces reliance on chemical fertilizers, supporting organic and sustainable farming practices.

Educational Relevance

For students of environmental science and agriculture, composting water hyacinth provides a hands-on example of waste recycling, nutrient cycling, and sustainable soil management.

Biogas Production from Water Hyacinth

Anaerobic Digestion Process

Biogas is produced when organic material is broken down by microorganisms in the absence of oxygen. Water hyacinth can be used as feedstock in biogas digesters, either alone or mixed with animal dung to improve gas yield.

Energy and By-products

The biogas generated is rich in methane and can be used for cooking, lighting, and electricity generation. The residual slurry is an excellent organic fertilizer, making the system nearly waste-free.

Role in Rural Energy Security

Biogas production from water hyacinth offers decentralized energy solutions for rural communities, reduces dependence on firewood, and contributes to cleaner household energy.

Methodology for Biofuel and Biogas Production from Water Hyacinth

Water hyacinth is harvested manually from ponds or lakes and washed to remove mud and impurities. The biomass is chopped into small pieces to improve processing efficiency. For biofuel production, the chopped material is sun-dried to reduce moisture content and then

compressed into briquettes or pellets, which can be used as solid fuel (Gopal, 1987; Malik, 2007). For biogas production, fresh or chopped water hyacinth is mixed with water and cow dung to form a slurry and fed into an airtight anaerobic digester. Under oxygen-free conditions, microorganisms decompose the biomass and produce methane-rich biogas within 20–40 days (Patil et al., 2011; Ndimele et al., 2011). The remaining digested slurry is used as organic manure, making the process eco-friendly and waste-free.

Environmental and Socioeconomic Benefits

Environmental Advantages

- Reduces nutrient pollution and eutrophication
- Improves water quality
- Controls invasive plant spread
- Lowers methane emissions from decaying biomass

Socioeconomic Opportunities

Community-based harvesting and utilization of water hyacinth can generate employment, support small-scale enterprises, and promote local energy production. Women's self-help groups and rural youth can particularly benefit from such initiatives.

Challenges and Limitations

Despite its potential, large-scale utilization of water hyacinth faces several challenges. Collection and transportation of bulky biomass can be costly, and improper handling may cause odor problems. Seasonal availability and inconsistent supply also affect processing efficiency. Understanding these constraints is important for students and practitioners to develop realistic, location-specific solutions. Instead of relying solely on removal and disposal, resource recovery strategies integrate ecology, energy, agriculture, and social development. Water hyacinth serves as an excellent case study linking invasive species management, renewable energy, circular economy, and climate mitigation.

Conclusion

Water hyacinth has long been considered a symbol of water pollution and ecological imbalance. However, scientific research and practical applications demonstrate that this invasive weed can be transformed into a valuable resource. Through its use in biofuel production, composting, and biogas generation, water hyacinth offers solutions to energy shortages, soil degradation, and waste management challenges. By shifting our perspective from eradication to



utilization, water hyacinth can contribute to environmental restoration, sustainable livelihoods, and climate-friendly development. For students and young researchers, it highlights an important lesson: sustainable solutions often emerge not from eliminating nature's problems, but from understanding and working with them.

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YEAR-ROUND CULTIVATION OF CHRYSANTHEMUM UNDER PROTECTED CONDITIONS USING ARTIFICIAL LIGHTING

Article ID: AG-VO6-I01-49**A. Aathirai**

Post Graduate Student, Department of Fruit Science,
Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India.

Abstract

Chrysanthemum is one of the most important and widely grown ornamental flowers in India. It is popular for loose flowers, garlands, religious offerings, decoration, landscaping and cut flower purposes. Due to its attractive colours, long shelf life and wide consumer demand, chrysanthemum plays a significant role in the floriculture industry.

Traditionally, chrysanthemum is cultivated in open fields and flowers mainly during winter months. This seasonal production often leads to excess supply and low market prices during peak season, while flowers become scarce and costly during off-season periods. To overcome these limitations, protected cultivation combined with artificial lighting has emerged as an effective and profitable technology for year-round chrysanthemum production.

Why Artificial Lighting is Important in Chrysanthemum

Chrysanthemum is a short-day plant, meaning it requires longer nights and shorter days to initiate flowering. Under natural conditions, flowering occurs only when day length reduces during winter. When days are longer, plants continue vegetative growth and flowering is delayed.

Artificial lighting helps farmers control day length artificially. By extending light hours during the vegetative stage and stopping light at the right time, flowering can be scheduled according to market demand. This technology is especially useful under polyhouse or greenhouse cultivation, where environmental factors can be regulated efficiently.



Protected Cultivation of Chrysanthemum

Protected cultivation involves growing crops under structures such as polyhouses or greenhouses where temperature, light, humidity and irrigation can be managed.

Advantages of Protected Cultivation

- Protection from heavy rain, frost and extreme temperatures
- Reduced pest and disease incidence
- Better control over plant growth and flowering
- Efficient use of water and fertilizers
- Improved flower quality and uniformity
- Possibility of off-season and year-round production
- Under protected conditions, chrysanthemum plants show better growth, uniform flowering and higher market value.

Artificial Lighting Technology

Types of Lights Used

LED lights (most preferred)

Compact fluorescent lamps (CFL)

Incandescent bulbs (traditional method)



Among these, LED lights are highly recommended due to:

- Low electricity consumption
- Minimal heat production
- Long working life
- Availability of suitable light spectrum
- Environment-friendly and cost-effective
- Light Management for Chrysanthemum

Vegetative Growth Stage

- Artificial lighting is provided to extend day length to 13–14 hours
- Lights are switched on during evening or night hours
- This prevents early flowering and promotes healthy vegetative growth
- Flower Initiation Stage
- Artificial lighting is stopped
- Plants are exposed to natural short-day conditions (10–11 hours of light)
- Flower buds initiate uniformly within a few weeks
- This method allows growers to decide when the crop should flower, ensuring supply during high-price periods.

Installation of Artificial Lighting System

Light Arrangement

- LED bulbs of 7–12 watts are commonly used
- Lights are installed 1 to 1.5 metres above the plant canopy
- Uniform spacing ensures even light distribution
- Timing of Lighting
- Lights are operated for 3–4 hours per day
- Common timing: late night or early morning
- Automatic timers are preferred for accuracy and labour saving
- Effect of Artificial Lighting on Crop Performance

Use of artificial lighting under protected cultivation has shown several benefits:

- Enhanced vegetative growth and branching
- Uniform plant height and canopy

- Delayed flowering as per requirement
- Larger flower size and brighter colour
- Increased number of flowers per plant
- Higher yield and better market acceptance
- Farmers practicing this technology have reported 20–40% higher yields compared to open-field cultivation.

Water and Nutrient Management

- Drip irrigation is ideal under protected cultivation
- Frequent light irrigation ensures uniform moisture
- Balanced fertilization using NPK improves growth and flowering
- Foliar sprays of micronutrients enhance flower quality

Pest and Disease Management

Although protected cultivation reduces pest pressure, regular monitoring is essential.

Common pests include:

- Aphids
- Thrips
- Leaf miners
- Integrated pest management (IPM) practices such as sticky traps, neem-based products and need-based sprays are recommended.

Economic Advantages

- Higher productivity per unit area
- Off-season flowers fetch premium prices
- Reduced crop loss due to weather extremes
- Efficient energy use with LED lights
- Better return on investment in the long run
- Despite higher initial investment, protected cultivation with artificial lighting is economically viable and profitable.

Challenges

- Initial cost of protected structures
- Need for technical knowledge

- Dependence on electricity supply
- These challenges can be addressed through training, government subsidies and use of renewable energy sources.

Conclusion

Artificial lighting combined with protected cultivation offers a modern solution for sustainable chrysanthemum production. By controlling light duration and growth conditions, farmers can achieve year-round flowering, higher yields and superior flower quality. With increasing market demand and availability of affordable LED technology, this approach holds great potential for commercial floriculture and income generation.

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AI-BASED DECISION SUPPORT SYSTEMS FOR CROP MANAGEMENT IN AGRICULTURAL EXTENSION

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Ruchi Priya¹ and Chandan Kumar Panda^{2*}

¹PhD Research Scholar, ²Assistant Professor, Department of Extension Education,
Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

*Corresponding Author: Chandan Kumar Panda

Abstract

Timely, precise, and location-specific decisions about crop selection, sowing, nutrient management, irrigation, pest control, and harvesting are critical to effective crop management. Such precision-based advises are frequently difficult for conventional agricultural extension systems to provide because of their generic recommendations, staffing shortages, and slow information flow. By allowing data-driven, predictive, and customized crop management recommendations, artificial intelligence (AI)-based Decision Support Systems (DSS) present new ways to improve agricultural extension. The idea, elements, and uses of AI-based DSS in crop management within agricultural extension systems are covered. Additionally, it emphasizes the function of mobile applications, the advantages, difficulties, and potential of AI-enabled decision support raising the level of quality and efficacy of extension services.

Keywords: Artificial Intelligence, Decision Support Systems, Crop Management, Agricultural Extension, Digital Advisory

Introduction

The productivity, profitability, and sustainability of agriculture are significantly influenced by crop management choices. Crop and variety selection, sowing time, water and nutrient management, pest and disease control, and harvesting are among the many decisions that farmers must make on a regular basis. Field visits, demonstrations, training programs, and generalized advisories are used in traditional agricultural extension systems to support these decisions. Nevertheless, these methods frequently fall short in addressing the temporal and

spatial variability of crop conditions, weather, and soil.

New opportunities for enhancing agricultural extension services have been made possible by the rapid development of mobile technologies, big data analytics, artificial intelligence (AI), and remote sensing. According to studies (Ibrahim, 2023 and Yousaf et al., 2023) AI-based DSS can overcome the shortcomings of traditional agricultural extension systems by providing real-time, location-specific, and data-driven recommendations. Artificial Intelligence-based Decision Support Systems (DSS) have the ability to analyse large data sets and give recommendations that are timely and site-specific. For small farmers and marginal farmers, Artificial Intelligence-based DSS can increase the relevance, accuracy, and accessibility of crop management advisories when linked with agricultural extension services.

Concept of Decision Support Systems in Agricultural Extension

Computer-based systems called decision support systems are used to analyze data, models, and expert knowledge to assist in decision-making. DSS assists agriculturists and extension workers in agricultural extension services to understand a complex production environment and make decisions on the most suitable approaches. In agricultural production, a conventional DSS is to a large extent a static and rules-driven system. The foundation upon which crop management decisions are made using an orderly process has already been set using a DSSAT system (Desta Abayechaw, 2021). However, trainability based on data, adaptability to changing environments, and improvement in decision-making capabilities with AI-based DSS distinguish them from other systems. Decisions based on prediction and evidence now lead to decision-making based on reaction and experience. Hence, AI-based DSS systems are not a replacement but an effective assistant to extension personnel.

AI Technologies Used in Crop Management DSS

The application of learning machines, expert systems, image recognition, and predictive analysis helps in the generation of accurate and on-time recommendations in AI-based crop management decision support systems. It has been observed in many research works that through the analysis of complex agro-climatic and field data, learning machines such as neural networks, support vector machines, and deep learning can significantly enhance decisions in crop management (Liakos et al., 2108 & Wolfert et al., 2017). The early detection and effective action taken through image recognition-based AI can further enhance the diagnosis accuracy in diseases and pests (Asolo et al., 2024). Bibliometric analysis indicates that research on AI-based decision

support systems is growing rapidly, emphasizing their relevance in intelligent and sustainable agriculture (Yousaf et al., 2023).

Components of AI-Based Decision Support Systems

An AI-based DSS for crop management generally consists of the following components:

1. **Data Input Layer:** Data of soil, weather and crop, satellite imagery.
2. **Knowledge Base:** Scientific crop management knowledge and historical datasets
3. **AI Engine:** Algorithms that analyze data, learn patterns, and generate predictions
4. **Decision Module:** Converts analysis into actionable recommendations
5. **User Interface:** Mobile apps or web platforms for farmers and extension workers
6. **Feedback Mechanism:** Facilitates further improvement in recommendations through feedback received from users

These components together ensure continuous learning and improvement of the advisory system.

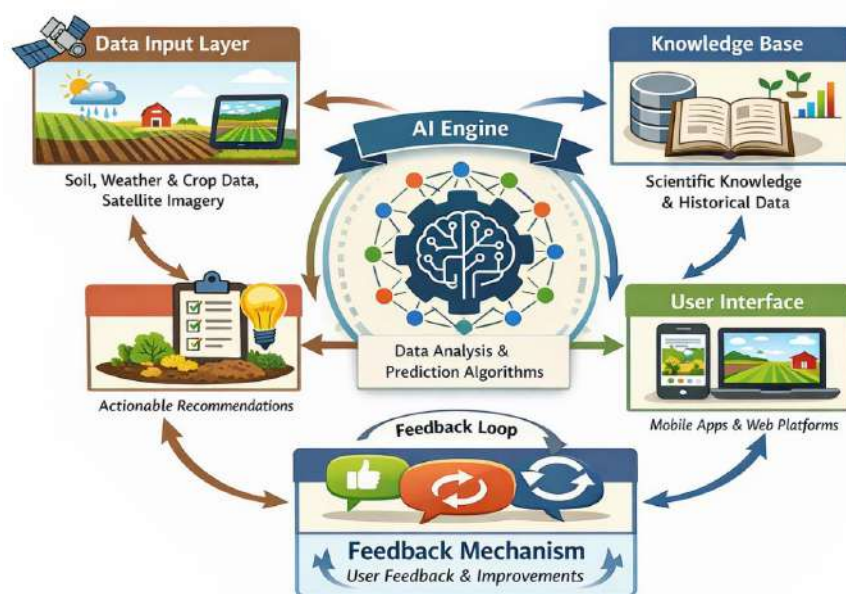


Fig.: - Components of AI-Based Decision Support Systems

Role of AI-Based DSS in Crop Management Decisions.

AI-driven DSSs are very important in many crop management practices. AI models analyze soil, climate, and historical yield information, and accordingly, relevant suggestions for cropping and variety are made, improving climate resilience (AgroDSS). AI-driven DSSs make site-specific suggestions for nutrient and irrigation management, using resources efficiently and reducing environmental impacts. It has been ascertained that AI-driven applications based on

images and AI chatbot DSSs, including applications like Plantix and AI-driven chatbot DSSs, enhance pest and disease diagnosis, improving the effectiveness of extension suggestions (Asolo et al., 2024). Likewise, effective harvest and post-harvest management suggestions are made by AI-driven platforms, linking production processes with market information, thereby improving farmers' stability of income.

Integration of AI-Based DSS with Agricultural Extension

Integrating AI-based DSS with current agricultural extension systems is crucial to their efficacy. In order to ensure human validation and contextualization of recommendations, research highlights that AI should serve as a decision-support tool rather than a replacement for extension staff (Ibrahim, 2023). AI-based DSS can improve climate-responsive extension services when paired with institutional support and capacity building, according to studies on agentic and adaptive AI frameworks (Vishwakarma et al., 2025).

Crop and Variety Selection

AI, powered Decision Support System (DSS) analyze soil attributes, agro, climatic factors, and performance record to recommend appropriate crop and varietal combinations. Example: Platforms like Plantix and ICAR, based advisory programs aid the field staff in providing farmers with climate, resilient cropping system options.

Sowing Time and Plant Population

Weather forecasts and historical climate data can be used by AI, based DSS to identify the best sowing period and plant population.

Example: With Kisan Suvidha and Meghdoot apps, the extension workers are better equipped to deliver advisories during monsoons that are delayed or irregular.

Nutrient and Fertilizer Management

AI, based DSS can utilize soil test results, crop growth stage, and expected yield to generate nutrient prescriptions that are specific to the location.

Example: Through the Soil Health Card Portal and IFFCO Kisan App, extension services can emphasize the importance of balanced fertilizer application.

Irrigation and Water Management

AI solutions integrate soil moisture levels, weather forecast, and crop water needs to figure out the best irrigation schedule.

Example: With the support of mKisan and smart irrigation advisory platforms, agricultural practitioners could use water more efficiently.

Pest, Disease, and Weed Management

AI, driven crop health monitoring tools, through image analysis, facilitate quick crop problem diagnosis and suitable treatment recommendations.

Example: By using Plantix and Pusa Krishi App, plant protection advisories can be made more accurate.

Harvesting and Post, Harvest Decisions

AI, driven DSSs are capable of determining the best time for harvesting and they integrate production choices with the market data. Example: The services could be extended to the farmers through the platforms e, NAM and Agri, market App.

Benefits and Challenges of AI-Based Decision Support Systems in Agricultural Extension

Using AI decision support systems can greatly benefit agricultural extension by offering more accurate crop management recommendations. These systems can analyze huge amounts of data such as: soil, weather, crops and various management techniques at the same time. Thus, they are able to provide very quick, location, specific, and data, driven recommendations. By generating very specific advice, AI, based DSS enhance the relevance and accuracy of extension messages, which ultimately results in farmers making better decisions. Also, by using inputs such as herbicides, water, and fertilizers more efficiently, these systems help decrease production costs and the negative impacts on the environment. Through mobile apps, extension services can provide their support to a greater number of farmers without spending a lot of money, which increases accessibility and inclusivity. Furthermore, by improving the timeliness, consistency, and reliability of advisories, AI, based DSS enhance the quality of extension services, and feedback mechanisms contribute to continuous development and higher farmer satisfaction.

Despite their tremendous potential, AI decision support systems in agricultural extension still face a number of challenges. One major constraint is data availability and quality as inaccurate or incomplete data can totally mislead the recommendations made by AI. Another factor that prevents large, scale adoption of these technologies is the digital divide among farmers who have limited access to cell phones, internet connectivity, and digital literacy. Another difficulty is to win over the farmers and extension staff to trust and accept the advice no

matter if the AI advice is different from the traditions or the local knowledge. The usage of digital platforms is also limited by the usability issues and the problem of the language mismatch. Besides that, in order to cover various agro, ecological situations, AI, based DSS need to be localized, validated, and updated constantly.

Future Prospects

The development of Artificial Intelligence-Based Decision Support (DSS) Systems will provide support for Climate Smart Agricultural through their functionality as skill or product development tools. The future development of AI-Based Decision Support Systems (AI-DSS) will provide support for the Climate Smart Agriculture Model and how it interacts with National Digital Agriculture Programs by providing real-time, individualised information to practitioners of Climate Smart Agriculture and via continuous skill enhancement/instruction and development.

Conclusion

Decision Support Systems (DSSs) Using AI to Support Agricultural Extension Services Can Be Enhanced Significantly Through the Use of AI Technology. Decision support systems help improve extension service timeliness, accuracy, and quality through the integration of science and data with the power of AI. Through pairing Intelligent DSSs with the expertise of extension agents and support from agriculture agencies, DSSs can support more sustainable agricultural development, benefiting farmers directly.

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AUTOMATION IN NURSERY MANAGEMENT

Article ID: AG-VO6-I01-51**Nandhana, S. and Anandhi, S.***

PG Scholar, Department of Floriculture and Landscape Architecture, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu

*Assistant Professor (Horticulture), Department of Floriculture and Landscape Architecture, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu, India

*Corresponding Author: Anandhi, S

Abstract

Advances in sensing and automation technologies are reshaping nursery crop production by improving efficiency, productivity, and resource management. Modern approaches such as automated irrigation systems using soil moisture sensors, tools for pest and disease control, and IoT-based nursery management platforms enable precise monitoring and management of nursery operations. These technologies help reduce labour requirements, optimize water and nutrient use, and enhance overall plant health. While adoption is still limited by cost, technical expertise, and integration challenges, ongoing research indicates significant potential for scalable, intelligent solutions in commercial nurseries. By combining real-time data collection with predictive analytics and automation could support more sustainable, cost-effective, and high-quality ornamental crop production. Overall, these innovations point to a future where data-driven management and automated processes play a central role in advancing horticulture.

Keywords: Automated, Nursery operations, IOT, Sensors, Disease Control

Introduction

Ornamental nursery crop production plays a crucial role in the horticulture industry, contributing to both economic growth and environmental aesthetics. Traditionally, nursery operations have relied heavily on manual labour for tasks such as irrigation, pest management, and plant monitoring, which can be time-consuming, labour-intensive, and prone to

inefficiencies. In recent years, technological advancements in sensing and automation have begun to transform these practices, offering data-driven solutions that improve productivity, resource efficiency, and crop quality. Sensor-based systems, automated irrigation, and decision support tools allow nursery managers to monitor soil moisture, plant health, and pest or disease outbreaks, while IoT-enabled platforms facilitate management and control of operations. Despite these promising developments, challenges such as high implementation costs, technical expertise requirements, and integration with existing practices remain. Nevertheless, the adoption of intelligent, automated systems in ornamental nurseries represents a significant step toward sustainable, efficient, and high-quality crop production.

Importance of automation in nursery

Several studies have demonstrated the growing importance of sensing and automation in nursery production. For example, Mahmud *et al.* (2023) highlighted the implementation of sensor-based systems for monitoring soil and environmental parameters, showing improvements in irrigation efficiency and crop health. Wheeler *et al.* (2021) reported case studies on automated soil moisture-based irrigation in woody ornamentals, illustrating practical applications in commercial nurseries. IoT-based nursery management systems, as discussed by Naik *et al.* (2022), helps for remote monitoring and real-time data collection for climate, irrigation, and plant health, which significantly reduces labour requirements and enhances operational efficiency.

Automation Technologies

Automation systems help to perform daily nursery tasks with minimal human interactions. They can be used in many operations related to the crop production in nurseries. Common automation practices include:

- a. **Automated Sensor based irrigation technologies:** Irrigation systems controlled by soil moisture sensors or timers to ensure appropriate water delivery to each plant or bed. This reduces water wastage and labour requirements while maintaining optimal soil moisture. Wheeler *et al.* (2021) explained that such systems reduce water consumption by up to 50% compared to conventional irrigation while maintaining optimal plant health. He reported that, during three geranium trials conducted in the spring of 2015, the use of soil-moisture–sensor-driven irrigation resulted has more precise water application compared with the conventional timer method.

- b. **Plant stress detention technologies:** The stresses such as drought, disease infection, and pest pressure, are recognized as having unfavourable condition that affects the growth. These technologies help the plants using sensors and advanced technologies for the detention of the stresses. This detection helps growers to identify problems and take preventive actions before stresses significantly damage plants or crops. Two types of stresses have been identified in ornamental crop production - abiotic plant stress and biotic plant stress. Abiotic plant stress includes drought, nutrient deficiency, salinity problems, floods, etc., while biotic stress refers to damage caused by fungi, bacteria, insects, or weeds. Sensors, including RGB, thermal, and spectral, have been utilized to monitor stresses in ornamental crop production. Mahmud et al. (2023).
- c. **Spraying technologies for diseases and pest control:** These technologies help in management of different types of pests as well as diseases to ensure high yield and higher quality crop production that can meet the market needs. Smart sprayers are automated systems designed to apply pesticides, herbicides, or foliar fertilizers precisely and efficiently. Radial air-assisted sprayers are the most used spray equipment for pesticide application in ornamental nurseries Mahmud et al. (2023). Laser sensing can be used as another method of spraying in which it used the laser scanners application of sprays in nurseries. Naik et al. (2022) explained that when integrated with IoT platforms, smart sprayers can be controlled remotely, allowing managers to schedule and monitor spraying operations from a centralized interface.
- d. **Plant biometrics:** Plant biometrics systems are advanced technologies that allow nurseries to monitor, recognize, and track individual plants automatically. Using sensors, imaging technologies etc these systems can identify plant species, detect growth stages in diverse conditions, and monitor overall health. Mahmud et al. (2023) highlighted that biometric identification is crucial in ornamental nurseries, where multiple species are grown together and require individualized care. These systems typically use computer vision or multispectral imaging to analyse leaf shape, colour, size, and other morphological features. The data can then be integrated with IoT platforms or decision support systems to provide customized irrigation, fertilization, and pest management recommendations for each plant. Different sensors, including cameras and LiDAR, have been utilized for nursery plant biometrics Mahmud et al. (2023). When we consider a tree the measured characters of it will

be tree height, tree canopy volume, Canopy cover, Crop growth and Other physiological characteristic.

- e. **Soil moisture sensors:** Soil moisture sensors measure the water content in the root zone and are essential for optimizing irrigation schedules. Overwatering or underwatering can lead to poor growth, increased susceptibility to disease, and resource wastage. Wheeler et al. (2021) explained that automated irrigation systems using soil moisture sensors can deliver water only when required and conserves water while maintaining optimal plant health. Mahmud et al. (2023) further highlighted that integrating these sensors with IoT platforms allows nursery managers to receive real-time alerts and remotely control irrigation, ensuring consistent soil moisture levels for different plant species.
- f. **Plant health sensors:** Plant health sensors detect early signs of stress, nutrient deficiencies, or pest infestations. These sensors use techniques such as spectral imaging, chlorophyll fluorescence measurement, or leaf moisture detection to provide actionable insights.
- g. **IOT based nursery management:** Internet of Things (IoT) technology has become a crucial component of modern nursery operations because it enables continuous monitoring and automated control of key environmental parameters. IoT systems create a platform where nursery managers can track real-time information on soil moisture, temperature, humidity, and irrigation schedules. One of the most important contributions of their IoT model is the ability to automate irrigation based on live sensor feedback, eliminating the guesswork that often leads to overwatering or water stress. IoT-based systems improve accuracy and reduce resource wastage. The various sensors used by IOT are:
 - i. Temperature and humidity sensors: To measure the temperature and humidity of the growing plants.
 - ii. Gas sensors: To detect the emission of harmful gases in the environment. This can be attached to any automatic system and when the gas emits the sensor automatically shuts the systems.
 - iii. Photoconductor: To measure the intensity of light in the growing plants.

Advantages of automation in nursery

- Increased Precision and Consistency
- Reduced Labor Requirement
- Enhanced Water and Nutrient Efficiency

- Early Detection of Stress, Pests, and Diseases
- Higher Productivity
- Improved Safety for plants
- Consistent Quality of Plant Produce

Disadvantages of automation in nursery

- High Initial Investment
- Requires Technical Knowledge
- Dependence on Technology & Power Supply
- Maintenance Costs
- Over-Reliance on Data

Conclusion

The integration of sensing and automatic technologies, IoT platforms, automated irrigation systems are transforming the nursery industry into a more efficient production system. Across the reviewed studies, it is evident that automation improves water-use efficiency, enhances climate control, supports early detection of plant stress, and reduces labour dependency. Innovations such as soil-moisture based irrigation, IoT-based centralized monitoring, and imaging-based crop assessment collectively demonstrate the potential for a fully data driven nursery ecosystem. Although challenges exist such as high installation costs, maintenance needs, and technical skill requirements the long term benefits will come on top of these limitations for most commercial nurseries. Overall, the future of nursery production lies in smarter, interconnected, and highly responsive technologies that support sustainable, high quality plant cultivation.

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HERBAL THERAPEUTICS IN FISH HEALTH MANAGEMENT: AN ALTERNATIVE APPROACH

Article ID: AG-VO6-I01-52**M.M. Priyadharshini, P. Sivasankar and B. Chrisolite**

Department of Fish Pathology and Health Management

Fisheries College and Research Institute, Thoothukudi – 628008, Tamil Nadu, India

*Corresponding Author: M.M. Priyadharshini

Abstract

Aquaculture is a vital sector in the supply of protein-rich foods for human consumption. Nevertheless, the increasing intensification of production practises has imposed a range of constraints such as reduced growth performance and poor fish health, which diminish the economic returns of intensive culture production systems. The widespread use of chemotherapeutic agents for disease management and reproductive manipulation through hormone injections still largely carries the connotations of production-driven, raising the issues on sustainability with respect to environmental resources. Consequently, the improvement of the productivity of the aquaculture practises should focus on eco-friendly and sustainable methodologies. The use of plant-derived materials as immunostimulants is a promising natural approach to pathogen control. Bioactive constituents present in medicinal plants supplement the immunity and strengthen resistance against disease in fish. This article explains the promise of plant-based immunostimulants on fish health and sustainable management of disease in aquaculture.

Keywords: Aquaculture; Medicinal plants; Immunostimulants; Fish immunity; Disease management

Introduction

The global aquaculture sector has seen a rapid growth in the past decades, and now supplies almost half the fish consumed globally. Although this growth is necessary for global food security, it has been accompanied with mounting challenges related to disease outbreaks,

declining water quality and ecological sustainability. Infectious diseases are responsible for a significant percentage of economic losses, which can be attributed to high mortality rates, lower growth performance and production costs. Conventional management practises dependent on antibiotics and chemical management have been the cause of antimicrobial resistance, environmental degradation and accumulation of chemical residues in aquatic organisms. In this regard, medicinal plants are promising ecological alternatives which can demonstrate potential in improving growth performance, immune response and disease resistance which will reduce the dependence on antibiotics. Plant-based interventions are a sustainable and multifunctional way of achieving environmentally responsible and health-focused aquaculture systems. By means of tackling disease control, feed efficiency and water quality with eco-friendly applications of phytogenics, aquaculture can be better placed in terms of blue economy principles and United Nations Sustainable Development Goals. Future progress will need to be made in multidisciplinary integration of botanical research with molecular, ecological, and aquaculture sciences, to realise the full potential of medicinal plants in sustainable aquaculture.

Biological activities of medicinal plants and their mechanism of actions

Medicinal plants contain bioactive secondary metabolites such as flavonoids, alkaloids, saponins, terpenoids, and polysaccharides, which contribute to growth promotion, immunostimulation, antioxidant activity, and disease resistance in aquaculture species. These compounds are extracted using conventional and green technologies, with optimized extraction conditions improving yield and efficacy.

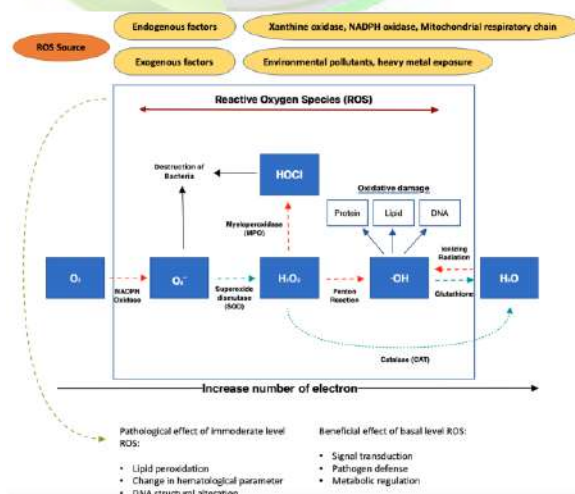


Fig. 1 Pathway of reactive oxygen species (ROS) formation and enzymatic defence mechanism against ROS along with source and effect of ROS towards animals

Phytochemicals enhance digestive efficiency, regulate oxidative balance by scavenging reactive oxygen species (Fig. 1) and strengthen innate immune responses through increased phagocytosis, lysozyme activity, and immune gene expression (Table 1). Dietary supplementation with plant extracts and essential oils improves growth performance, stress tolerance, gut health, and resistance to bacterial infections. Overall, medicinal plant-based additives provide eco-friendly alternatives to synthetic chemicals for sustainable fish health management.

Table 1. Mechanisms of action of medicinal plants as immunostimulants in aquaculture
(Source : Sumana et al., 2025)

Medicinal Plant	Part Used	Bioactive Compounds	Mechanism of Action	Immune Effects
<i>Allium sativum</i>	Bulb	Allicin, flavonoids	Enhances macrophage activity, increases lysozyme production	Boosts pathogen clearance, enhances phagocytosis
<i>Ocimum sanctum</i>	Leaves	Flavonoids, polyphenols	Increases respiratory burst activity in leukocytes	Enhances non-specific immunity, improves survival against <i>A. hydrophila</i>
<i>Aloe vera</i>	Gel/Leaves	Polysaccharides, saponins	Activates complement system, enhances mucosal immunity	Strengthens GALT, reduces <i>Saprolegnia</i> infections
<i>Zingiber officinale</i>	Rhizome	Gingerol, shogaol	Stimulates lymphocyte proliferation, regulates cytokine expression	Enhances adaptive immune response, improves disease resistance against <i>A. hydrophila</i>
<i>Nigella sativa</i>	Seeds	Thymoquinone, flavonoids	Improves gut microbial diversity, increases SCFA production	Enhances gut mucosal immunity, reduces oxidative stress
<i>Thymus vulgaris</i>	Leaves	Essential oils (thymol, carvacrol)	Antioxidant and antimicrobial properties	Reduces oxidative stress, inhibits bacterial pathogens

<i>Scutellaria baicalensis</i>	Aerial parts	Baicalin, wogonin	Regulates gut microbiota, replaces antibiotics	Fights pathogenic bacteria, improves gut health in fish
<i>Pandanus tectorius</i>	Leaves	Phenolic compounds	Reduces oxidative stress, enhances immune status	Improves disease resistance in <i>Cyprinus carpio</i>
<i>Elaeagnus angustifolia</i>	Leaves	Flavonoids, tannins	Modulates hematological and immunological parameters	Enhances growth, antioxidant activity in common carp
<i>Mentha piperita</i>	Leaves	Menthol, menthone	Improves growth performance, hematological parameters	Boosts immune response in Caspian whitefish
<i>Excoecaria agallocha</i>	Bark/Leaves	Diterpenoids	Enhances non-specific immune responses	Increases disease resistance against <i>S. agalactiae</i> in tilapia
<i>Melocanna baccifera</i>	Leaves	Phenolic acids	Nontoxic phyto-prophylactic against low pH stress and <i>Saprolegnia</i>	Improves immunity and survival in <i>Labeo rohita</i>
<i>Camellia sinensis</i>	Leaves	Catechins, polyphenols	Antiparasitic activity against ectoparasites	Effective against <i>Ichthyobodo necator</i> in salmon
<i>Achillea cucullata</i>	Aerial parts	Sesquiterpene lactones	Antioxidant, antimicrobial, and antidiabetic activities	Enhances overall health and disease resistance
<i>Carica papaya</i>	Seeds/Leaves	Carpaine, alkaloids	Antiprotozoal activity against <i>Ichthyophthirius multifiliis</i>	Reduces parasitic infections in fish
<i>Curcuma longa</i>	Rhizome	Curcumin, tannins	Inhibits pro-inflammatory cytokines,	Prevents excessive inflammation, enhances resilience
<i>Rosmarinus officinalis</i>	Leaves	Polyphenols, terpenes	Enhances expression of antioxidant enzymes	Reduces oxidative stress, prevents immune suppression

Source of medicinal plant

Medicinal plants provide multiple usable parts—leaves, rhizomes, roots, fruits, bark, seeds, and bulbs—which serve as rich sources of bioactive compounds including alkaloids, flavonoids, and tannins.

Role of medicinal plants in fish and shrimp health

As antibacterial and antifungal agents

Plant-derived compounds such as alkaloids, flavonoids, terpenoids, and phenolics exhibit antibacterial and antifungal activity by disrupting microbial membranes, enzymes, and mitochondrial function, interfering with proton flux, and inhibiting amino acid biosynthesis (Ng et al., 2024). Cinnamaldehyde and allicin damage bacterial and fungal membranes and inhibit biofilm formation. Combined plant extracts and dietary supplements, including *Boesenbergia pandurata*, *Solanum ferox*, *Zingiber zerumbet*, *Psidium guajava*, *Mimosa pudica*, thymol, and chitosan nanoparticles, enhance fish immune parameters, gut morphology, nutrient absorption, and resistance against bacterial and viral pathogens. Seaweeds (*Avicennia marina*, *Sargassum* spp.) and phytobiotics like thyme, cinnamon, *Curcuma longa*, and *Lepidium meyenii* improve shrimp survival, modulate gut microbiota, and inhibit pathogen colonization. Thymol and carvacrol further enhance antibacterial activity by disrupting pathogen membranes and inhibiting ergosterol biosynthesis (Ng et al., 2024).

As antiparasitic agents

Fish are susceptible to parasitic infections from protozoans, worms, and parasitic crustaceans (Ng et al., 2024). Conventional chemotherapeutics such as ivermectin, praziquantel, formalin, and trichlorfon control parasites but may leave toxic residues affecting fish and human health. Certain plant compounds—polyphenols, terpenoids, saponins, and alkaloids—exhibit antiparasitic activity by disrupting membrane permeability, causing swelling, vacuolization, cytoplasm leakage, and parasite death. Extracts such as *Dioscorea colletti* (diosin) and *Dillenia suffruticosa* have been effective against *Gyrodactylus kobayashii* and marine leeches, respectively, by damaging tegument microvilli and reducing parasite survival. Essential oils and herbal extracts, including *Zingiber officinale*, *Cymbopogon citratus*, and *Melaleuca cajuputi*, inhibit parasite development, movement, and reproduction through membrane disruption and oxidative stress.

As antiviral agents

Viral infections in aquaculture are highly contagious and often untreatable, making prevention critical. Medicinal plants exhibit antiviral activity through mechanisms such as direct viral inactivation, inhibition of attachment and replication, disruption of protein synthesis, and immunomodulation (Ng et al., 2024). Compounds like polyphenols, flavonoids, terpenes, glycyrrhizin, quercetin, genipin, luteolin, and matrine have shown activity against viruses including SGIV, VHSV, WSSV, and SVCV in fish and shrimp. These compounds can block viral entry, inhibit genome replication, promote apoptosis, and enhance host immune responses, including upregulation of Toll-like receptors, NF- κ B, C-type lectins, and antioxidant enzymes, thereby improving survival and immunity.

Application technology of medicinal plants in aquaculture

The efficacy of medicinal plants depends on the abundance of bioactive compounds, which varies with plant part, age, geographical origin, and preparation method (Reverter et al., 2021). Commonly used forms include dried powdered plants, ethanolic or aqueous extracts, and essential oils (EO). Powdered plants are inexpensive but have lower biological activity due to indigestible and anti-nutritional compounds, while alcoholic extracts yield more phytochemicals but may exhibit toxicity at high concentrations. EO are widely used as feed supplements due to their safety and low toxicity, and have been shown to improve antioxidant status and immunity in fish.

Herbal extracts can be administered orally, by injection, or immersion, depending on fish size, species, and purpose. Oral administration is the most practical and widely used, especially in tilapia farming, as it is stress-free and suitable for all fish. Injection and immersion are effective but labor-intensive, stressful, and costly, and are generally used for rapid treatment or ectoparasite control.

Conclusion

Medicinal plants are increasingly recognized as effective alternatives for disease management in aquaculture, offering minimal adverse effects on animals and the environment. However, further research is needed on their toxicological profiles to ensure safe use. Limited studies have explored the synergistic or antagonistic effects of combined herbal treatments, highlighting the need to determine optimal dosages and concentrations. Additionally, regulatory standards for herbal products in aquaculture should be harmonized globally, as issues such as

adulteration, improper storage, and inadequate preparation can compromise product quality and efficacy. Overall, integrating medicinal plant supplementation with immunoprophylaxis, approved antibiotics, prebiotics, and robust biosecurity measures has the potential to significantly enhance fish health, immunity, and survival rates.

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ECO-FRIENDLY FODDER PRODUCTION THROUGH NATURAL FARMING PRACTICES FOR HEALTHY LIVESTOCK

Article ID: AG-VO6-I01-53**P. Aruna¹ and B.V.Subramanyam²**

¹Scientist (Agronomy), Livestock Research Station, Sri Venkateswara Veterinary University, Palamaner-517 408, Chittoor (D.st), Tirupati (Andhra Pradesh), India.

²Assistant Professor, Animal Husbandry Polytechnic College, Palamaner, Sri Venkateswara Veterinary University, Tirupati (Andhra Pradesh), India.

*Corresponding Author: P. Aruna

Introduction

Healthy soil is the foundation for sustainable fodder production. To maintain soil fertility and protect the environment, it is essential to avoid synthetic fertilizers, herbicides, and pesticides. Perennial fodder crops require a continuous supply of nutrients for proper growth, and these needs can be effectively met through natural farming practices. Natural farming inputs such as Beejamrit, Jeevamrit, Ghanajeevamrit and cover crops enrich the soil by enhancing natural nitrogen fixation and increasing beneficial microbial populations. These practices improve soil structure, nutrient cycling, and moisture retention, resulting in vigorous and healthy fodder growth. By completely avoiding chemical fertilizers and pesticides, natural farming also prevents the movement of heavy metals and harmful chemical residues through the food chain. This stops contamination from soil → fodder → livestock → humans, ensuring safe and nutritious feed for animals while protecting human health. As a result, fodder produced under natural farming systems remains free from agro-chemical residues, leading to improved animal health, better digestion and enhanced livestock productivity. Thus, natural farming-based fodder production supports sustainable livestock systems and promotes a cleaner, safer agricultural environment.

ADVANTAGES OF FODDER PRODUCTION USING NATURAL FARMING INPUTS

1.No External Inputs Required

When fodder is grown only for livestock, farmers can prepare all natural farming inputs using

on-farm resources such as cow dung and cow urine, without purchasing external inputs.

2. Low Cost of Cultivation

Natural farming inputs reduce dependence on chemical fertilizers like urea, thereby lowering the cost of fodder production.

3. Synergistic Crop–Livestock System

Natural farming creates a mutual benefit between fodder crops and livestock, where livestock provide inputs and fodder supports animal nutrition.

4. Healthy Vegetative Growth in Perennial Fodders

Instead of applying urea after each harvest, natural farming inputs support sustained and balanced vegetative growth in perennial fodder crops.

5. Improved Soil Health

Regular use of natural inputs enhances soil fertility, microbial activity and soil structure, ensuring long-term productivity.

6. Safe for Livestock

Fodder produced using natural inputs is free from chemical residues, making it safer and healthier for livestock.

7. Beneficial to Human Health

Avoidance of chemical fertilizers reduces indirect risks to human health through the food chain.

8. Environment-Friendly Practice

Natural farming inputs reduce soil and water pollution, contributing to eco-friendly and sustainable agriculture.

9. Sustainable Fodder Production

Continuous use of natural inputs ensures long-term sustainability of fodder production systems.

10. Easy Adoption by Farmers

Preparation and application of natural farming inputs are simple, farmer-friendly, and easily adoptable at field level.

11. Improvement in Fodder Quality

Natural farming inputs help in producing soft, palatable, and nutritious fodder, which improves feed intake by livestock.

12. Better Animal Health and Productivity

Regular feeding of naturally grown fodder supports better digestion, immunity, and overall

animal health, leading to improved milk yield and growth.

13. Moisture Conservation and Drought Tolerance

Natural farming improves soil organic matter and water-holding capacity, helping fodder crops withstand dry spells.

14. Suitable for Small and Marginal Farmers

As inputs are prepared on-farm, natural farming is highly suitable for small and marginal livestock farmers.

15. Year-Round Fodder Availability

Healthy perennial fodder crops under natural farming show better regeneration after each harvest, ensuring continuous fodder supply.

16. Long-Term Sustainability

Natural farming ensures sustainable fodder production, healthy soils, and resilient farming systems for future generations.

Scientific basis and supportive research

Sushant Kumar *et al.* (2024) revealed that fodder sorghum and fodder oat recorded plant population of 20.96 m⁻¹ and 71.83 m⁻¹, plant height of 190.00 cm and 112.42 cm, leaf-to-stem ratio of 0.74 and 0.38, green fodder yield of 274.46 q ha⁻¹ and 263.90 q ha⁻¹ and dry fodder yield of 68.61 q ha⁻¹ and 65.97 q ha⁻¹, respectively. The quality parameters at harvest, namely crude protein content (8.83% and 7.84%), crude protein yield (6.06 q ha⁻¹ and 5.17 q ha⁻¹), ADF (40.22% and 44.31%), and NDF (65.59% and 73.61%), were significantly improved by different organic treatments over the control. The highest values were recorded under FYM @ 5 t ha⁻¹ + natural farming with mulch, followed by FYM @ 5 t ha⁻¹ + natural farming without mulch.

Priyanka Kumari *et al.* (2023) revealed that integrated nutrient management practices, namely 50% recommended nitrogen + FYM @ 10 t ha⁻¹ + Jeevamrit @ 10% and 50% recommended nitrogen + FYM @ 10 t ha⁻¹ + Jeevamrit @ 5% and recommended NPK through inorganic sources (which remained at par) resulted in better crop growth parameters such as plant height, number of shoots, leaf–stem ratio and percentage proportion. These treatments also produced higher green and dry fodder yields, greater NPK uptake, and higher crude protein yield compared to organic treatments (FYM @ 10 t ha⁻¹ + Jeevamrit @ 10% and FYM @ 10 t ha⁻¹ + Jeevamrit @ 5%) and natural farming treatments (Beejamrit + Jeevamrit @ 5% and 10%).

Priyanka Kumari and Naveen Kumar *et al.* (2025) reported that recommended NPK through inorganic sources and integrated nutrient management (50% recommended N + FYM + Jeevamrit) were comparable and resulted in improved crop growth (plant height and shoot number), higher green and dry fodder yields, increased uptake of N, P, and K, and higher crude protein yield compared to organic (FYM @ 10 t ha⁻¹ + Jeevamrit) and natural farming (Beejamrit/Jeevamrit + Jeevamrit) treatments. Application of recommended NPK recorded the highest net returns (₹1,13,347 ha⁻¹) and benefit–cost ratio (2.95), followed by integrated nutrient management. The study suggested that a fodder oat + sarson mixture was more productive and economically rewarding under integrated nutrient management.

Conclusion

Natural farming–based fodder production focuses on developing a sustainable, low-cost, and eco-friendly system for producing quality green fodder without the use of chemical fertilizers and herbicides. The integration of cereal fodders with legume intercropping, Sesbania border planting and natural inputs such as Beejamrit, Jeevamrit and Ghanajeevamrit enhances soil fertility, improves fodder yield and quality and ensures long-term productivity.

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SELECTIVE BREEDING IN AQUACULTURE: ESTABLISHMENT OF BASE POPULATIONS, BREEDING STRATEGIES, AND ACHIEVEMENTS

Article ID: AG-VO6-I01-54***J. Sam Rejin and B. Asvitha**

UG Student, College of Fisheries Science, St. Devasahayam Institute of
Fisheries Science & Technology, Amanattantheri, Kanniyakumari, Tamil Nadu - 629 193.

*Corresponding Author Email ID: J. Sam Rejin

Abstract

Aquaculture is one of the fastest-growing food-producing sectors in the world, and its sustainability largely depends on the development of efficient and genetically improved farmed stocks. Selective breeding plays a vital role in enhancing growth rate, survival, disease resistance, and feed efficiency of cultured aquatic species. Establishing a genetically diverse base population is the cornerstone of any successful breeding program, as it prevents inbreeding and ensures long-term genetic gain. A structured selective breeding program involves careful selection of parents, performance evaluation, pedigree recording, controlled mating designs, and dissemination of improved stocks to farmers. Globally successful programs such as Atlantic salmon breeding, GIFT tilapia, Jayanthi rohu, GI scampi, and Amrit catla demonstrate the immense potential of selective breeding in improving aquaculture productivity. By aligning genetic improvement with commercial and environmental goals, selective breeding contributes significantly to sustainable aquaculture development, increased production efficiency, and enhanced adaptability to changing market and farming conditions.

Keywords: Selective breeding, Genetic improvement, Brood stock management, Growth performance, Disease resistance, Sustainable aquaculture, Fish breeding programs, Improved strains, Genetic diversity.

Introduction

Aquaculture has become one of the fastest-growing food-producing sectors worldwide, and its long-term success depends on sustainable and efficient production systems. A

fundamental objective of any breeding program is to lay a strong foundation for sustainable aquaculture by developing productive, domesticated stocks. Compared to unimproved or wild animals, domesticated and genetically improved individuals utilize feed, water, and land resources more efficiently, resulting in higher productivity and reduced environmental impact. Despite these advantages, genetically improved stocks currently contribute to less than 10% of global aquaculture production, highlighting the vast potential for improvement through structured breeding programs.

The establishment of a genetically diverse base population is a critical first step in any selective breeding program. A broad genetic base helps to avoid rapid inbreeding and maximizes the potential for long-term genetic gain. Past failures of several fish breeding programs have often been attributed to low genetic variation in the founding populations. Therefore, careful selection of brood stock whether from wild populations, farmed stocks, or pedigreed lines is essential to ensure adequate genetic diversity and effective population size.

Selective breeding is a systematic genetic improvement strategy that enhances the breeding value of a population by choosing and mating individuals with superior phenotypic traits, such as faster growth, higher body weight, or desirable coloration. When supported by a well-designed base population and low initial selection intensity, selective breeding can maintain genetic variability while achieving sustained genetic progress, thereby contributing significantly to the sustainability and efficiency of aquaculture production.

Steps in the Process:

- Choosing of parents
- Selection of desirable traits
- Mating between selected parents
- Choosing best offspring's
- Repeat the process

Steps of Selective Breeding Programme:

1. Collection of Strains

- A total of four base populations were produced, reflecting the four-year generation interval of the species.
- Each of the four base populations included brood stock originating from eight to 24 river strains.

- Collect genetically diverse strains from different riverine environments and wild stocks.
- Include strains adapted to various temperature, salinity, and disease resistance profiles.

2. Formation of Broad Base Population

- Create a founder population comprising 100 males and 100 females.
- Ensure random mating to capture and maintain broad genetic diversity.

3. Tagging and Pedigree Recording

- Individually tag all fish using PIT tags or genetic fingerprinting.
- Record:
 - i. Initial body weight
 - ii. Initial body length
 - iii. Pedigree data (parental IDs)
- Maintain centralized data records for performance tracking and selection accuracy.

4. Performance Evaluation

a) Challenge Tests

- Evaluate growth performance under controlled aquaculture conditions.
- Monitor:
 - i. Growth rate
 - ii. Feed conversion ratio (FCR)
 - iii. Health and survival

b) Field-Level Tests

- Conduct performance tests in commercial-scale sea cages or freshwater farms.
- Validate performance across diverse farming environments.

5. Selection of Brooders

- Apply individual selection based on:
 - i. Superior growth performance
 - ii. Good health and survivability
 - iii. Desired body shape and market traits
- Use Estimated Breeding Values (EBVs) derived from performance and pedigree data.

6. Mating Design

- Employ a nested mating design:

- Each selected male mated with 2–3 females.
- Facilitates pedigree tracking and genetic parameter estimation.
- Helps control inbreeding and allows estimation of heritability.

7. Heterosis Observation

- Test crosses between lines or families to assess heterosis (hybrid vigor) for growth traits.
- If heterosis is significant, consider crossbreeding strategies or developing composite strains.

8. Dissemination of Genetic Gain

- Multiply selected brood stock.
- Distribute improved stock to commercial hatcheries and farms.

Expected Outcome

- Faster growth rate. Improved production efficiency.
- Enhanced performance in commercial aquaculture systems.

Examples of Selective Breeding Programme:

1) Atlantic salmon selective breeding

In 1971, AKVAFORSK began breeding experiments for Atlantic Salmon and Rainbow Trout in Norway, which eventually became a national breeding program.

Breeding Goal

To improve the growth rate of Atlantic Salmon through a scientifically designed and data-driven selective breeding program.

2) GIFT (Genetic Improvement Farmed Tilapias) selective breeding programme

GIFT Tilapia developed by World fish Centre, ICLARM Malaysia in 1988 to 1997. The World Fish Center's GIFT (Genetically Improved Farmed Tilapia) initiative produced a tilapia strain with faster growth, greater survival rates, and improved disease resistance.

Breeding Goal

To improve the growth rate, survival rate, disease resistance of GIFT Tilapia through a structured and scientifically designed selective breeding program.

Jayanthi Rohu selective breeding programme

In India, a selection experiment was carried out at CIFA (Central Institute of Freshwater Aquaculture) with rohu carp (*Labeo rohita*).

Breeding Goal

To improve the growth rate of the Jayanthi Rohu (*Labeo rohita*) in aquaculture systems, enhancing its marketability and production efficiency while maintaining or improving overall health and disease resistance.

3) GI Scampi selective breeding programme

The ICAR-Central Institute of Freshwater Aquaculture (ICAR-CIFA) has made significant advancements in freshwater prawn research, leading to the creation of CIFA-GI SCAMPI a genetically enhanced strain of *Macrobrachium rosenbergii*. Beginning in 2007, ICAR-CIFA partnered with WorldFish, Malaysia, to launch a structured selective breeding program aimed at producing a faster growing scampi variety.

Breeding Goal

This improved strain has demonstrated a cumulative growth gain of 7.2% over 16 generations. Improved traits: Growth rate and disease resistance

4) Amrit Catla

CIFA has launched a genetically modified Catla (*Catla catla*) called AMRIT CATLA, a Selective breeding program which began from 2010.

Breeding Goal

A 35% cumulative gain by 3rd generation for improved aquaculture productivity. Better feed efficiency, higher survival rates and better disease resistance.

Other Examples of Selective Breeding programme:

Table. 1 Examples of Selective Breeding programme

Fish Species	Countries
Coho salmon (<i>Oncorhynchus kisutch</i>)	Chile
Atlantic salmon (<i>Salmo salar</i>)	Chile, Iceland, Ireland and Scotland
Rainbow trout (<i>Oncorhynchus mykiss</i>)	Denmark, Norway, Finland, Chile, France and USA
Brown trout (<i>Salmo trutta</i>)	France
Shire tilapia (<i>Oreochromis shiranus</i>)	Malawi
Multi-species tilapia hybrid	Israel
Gilthead sea bream (<i>Sparus aurata</i>)	Greece

Mediterranean Sea bass (<i>Dicentrarchus labrax</i>)	France and Italy
Channel catfish (<i>Ictalurus punctatus</i>)	USA
Turbot (<i>Scophthalmus maximus</i>)	Norway and Spain
Rohu (<i>Labeo rohita</i>)	India
Blunt snout bream (<i>Megalobrama amblycephala</i>)	China
Tench (<i>Tinca tinca</i>)	The Czech Republic
Pacific oyster (<i>Crassostrea gigas</i>)	Australia, USA
Sydney rock oyster (<i>Saccostrea glomerata</i>)	Australia
White Pacific Shrimp (<i>Litopenaeus vannamei</i>)	Brazil, Colombia, Mexico and USA
Kuruma shrimp (<i>Penaeus japonicas</i>)	Australia
Brown tiger prawn (<i>Penaeus esculentus</i>)	Australia
Giant tiger prawn (<i>Penaeus monodon</i>)	Australia, Thailand and USA
Banana shrimp (<i>Penaeus merguensis</i>)	Australia
Abalone (<i>Haliotis</i> sp)	Australia
Common carp (<i>Cyprinus carpio</i>)	Russia, France, Vietnam and Serbia
Artic Charr (<i>Salvelinus alpinus</i>)	Sweden
Asian seabass (<i>Lates calcarifer</i>)	Australia
Red sea bream (<i>Argyrops spinifer</i>)	Japan
Crab (<i>Portunus trituberculatus</i>)	China
Red claw crayfish (<i>Cherax quadricarinatus</i>)	Australia

Applications of selective breeding program

- Selective breeding involves selecting species with desirable features as parents for future generations, increasing the incidence of those traits over time.
- This approach aims to improve the Genetic composition of aquatic organisms for aquaculture applications.
- Including genetic considerations and well-designed selective breeding programs in aquaculture can improve success rates.
- This requires careful planning. Implementation of breeding strategies to attain desired characteristics.

- Selective breeding involves human intervention in adaptation, replacing natural selection with controlled breeding methods.
- This modification of the natural evolutionary process can result in both. Aquaculture can have both beneficial and harmful results depending on the qualities used.
- Selective breeding programs inside the aquaculture business may be more efficient and aligned with commercial goals, notwithstanding academic institutions' contributions to genetic data collection and research.
- Selective breeding aims to assist the aquaculture business adapt to changing market needs by developing superior stocks with desirable features.
- Increased production: Selective breeding can result in quicker growth rates, larger yields, and increased overall productivity, potentially lowering costs per unit of production.
- Improved disease resistance: Selective breeding can increase disease resistance, lower mortality, and improve the general health of farmed fish.
- Reduced feed costs: Breeding for features such as increased feed efficiency can greatly reduce the cost of aquaculture operations.
- Market demand: Selective breeding allows fish to be tailored to certain market demands such as size, color, and nutritional content.
- Adaptability: Breeding for features that make fish more adaptable to specific situations can boost their resilience and reduce stress.

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INNOVATIVE SERICULTURE BY YOUNG FARMER BOOSTS INCOME IN MADHA, SOLAPUR

Article ID: AG-VO6-I01-55**¹P. N. Madavi, ¹V.G.Vairagar*, ¹T. R. Walkunde, ¹D. N. Kshirsagar**

¹Krishi Vigyan Kendra, Mohol (Solapur-II), Mohol, Solapur, Maharashtra, Mahatma Phule
Krishi Vidyapeeth, Rahuri, Maharashtra, India

*Corresponding Author: V.G. Vairagar

Abstract

Sericulture is an important agro-based enterprise that offers sustainable income and employment opportunities for rural households. This article highlights the success story of Mr. Ahinandan Sanjay Mohite, a progressive sericulture farmer from Uplai village in Madha taluka, Solapur district, Maharashtra. In 2018, with financial support from the District Sericulture Office, Solapur, and technical guidance from Krishi Vigyan Kendra Mohol Dist Solapur, he initiated mulberry cultivation and silkworm rearing on 2 acres, using the V1 mulberry variety. By adopting scientific rearing practices, maintaining hygiene, and ensuring quality chawki procurement, Mr. Mohite successfully conducts eight silkworm rearing batches annually. From a single batch, he harvested 194 kg of high-quality cocoons, which fetched a premium price of ₹ 811 per kg at the Ramnagar cocoon market in Karnataka. His enterprise demonstrates that sericulture, when supported by technology, institutional assistance, and effective market linkage, can significantly enhance farmers' income and livelihood security.

Keywords

Sericulture, Mulberry cultivation, Silkworm rearing, Cocoon production, Farmer success story, Solapur district

Introduction

Sericulture plays a vital role in enhancing rural livelihoods by providing regular income, employment, and scope for value addition. It is particularly suitable for small and marginal farmers because of its low land requirement, quick returns, and year-round employment

potential. In India, sericulture contributes significantly to the textile industry while supporting millions of farm families.

Maharashtra has considerable potential for sericulture development due to favourable climatic conditions, availability of irrigation facilities, and strong institutional support from the sericulture department. However, successful adoption depends on scientific mulberry cultivation, quality silkworm seed, effective disease management, and assured marketing facilities.

In this context, documenting farmer success stories is important to motivate and guide other farmers. This article describes the successful sericulture journey of Mr. Ahinandan Sanjay Mohite of Upalai village, Madha taluka, Solapur district, who has demonstrated how planned investment, technical guidance, and market-oriented production can transform sericulture into a profitable agri-enterprise.



Beginning of the Sericulture Venture

The family established the sericulture unit in 2018. In 2024, Mr. Ahinandan Mohite, aged 21, with a diploma in Mechanical Engineering from Government Polytechnic, Solapur, and a diploma in Sericulture from Shivaji University, Kolhapur, took over the enterprise, driven by the need for a sustainable, year-round source of income. Recognising the potential of sericulture

under irrigated conditions, he established a 2-acre mulberry plantation, selecting the high-yielding V1 mulberry variety, known for its superior leaf quality and suitability for bivoltine silkworm rearing.

To strengthen the enterprise, Mr. Mohite received financial assistance of ₹2.90 lakh from the District Sericulture Office, Solapur, along with an own contribution of ₹1.50 lakh, amounting to a total investment of ₹4.40 lakh. This support was crucial for developing basic infrastructure, including rearing sheds and a mulberry plantation. Timely technical support from KVK Mohol, Solapur, was also provided, along with training to improve scientific management.

Scientific Rearing Practices

Mr. Mohite follows scientific sericulture practices and undertakes 8 silkworm rearing batches per year, ensuring a steady income throughout the year. Each batch lasts 35 days, including preparation of rearing materials and silkworm management.

For quality production, he procures chawki (young-age) silkworms from Karnataka, purchasing 200 disease-free layings (DFLs) per batch at ₹8,000. Strict hygiene and preventive measures are followed to minimise disease incidence and improve cocoon quality.

Cost of Silkworm Rearing (Per Batch)

Mr. Mohite carefully manages expenses to maintain profitability. The major costs per batch include:

- Sterilization of rearing shed: **₹2,000**
- Labour charges (last 7 days): **₹2,500**
- Application of “Badal dose” to mulberry plot: **₹5,000**
- Lime fumigation: **₹2,000**
- Transportation cost: **₹5,000**

These inputs ensure healthy silkworm growth and consistent cocoon yield.

Table 01- Cost of Production in Sericulture (Per Batch)

Sr. No.	Particulars	Amount (₹)
1	Purchase of chawki silkworms (200 DFLs)	8,000
2	Sterilization of rearing shed	2,000
3	Labour charges (last 7 days)	2,500
4	Badal dose to mulberry plot	5,000

5	Lime fumigation	2,000
6	Transport charges	5,000
	Total Cost of Production (Per Batch)	24,500

Table 02: Returns, Net Profit and B:C Ratio in Sericulture (Per Batch)

Sr. No.	Particulars	Quantity / Value
1	Cocoon yield	194 kg
2	Market price of cocoons	₹811 per kg
3	Gross return	₹1,57,334
4	Total cost of production	₹24,500
5	Net profit (Gross return – Cost)	₹1,32,834
6	Benefit–Cost (B:C) ratio	1 : 6.42

Harvesting and Marketing Success

Through proper feeding, timely bed cleaning, and disease management, Mr. Mohite achieves excellent cocoon quality. From each batch, he harvests an average of 194 kg of top-quality cocoons.



The cocoons are marketed at the Ramnagar Cocoon Market in Karnataka, a well-known bivoltine cocoon trading centre. During the reported harvest, he received an impressive market rate of ₹811 per kg, reflecting the superior quality of his cocoons.

Economic Impact and Recognition

Sericulture has significantly increased Mr. Mohite's farm income and provided regular employment for family members. The enterprise ensures a steady cash flow throughout the year and has reduced dependence on seasonal crops.

Today, Mr. Mohite is recognised as a successful sericulture farmer in Madha taluka, inspiring fellow farmers to adopt mulberry cultivation and silkworm rearing as a viable agribusiness.

Conclusion

Ahinandan Sanjay Mohite's success story clearly demonstrates that scientific sericulture, supported by institutional backing and market linkages, can generate sustainable income for rural farmers. His journey from mulberry planting to premium cocoon marketing serves as a model for sericulture development in Solapur district and across Maharashtra.

Farmer's Message

Sericulture is a reliable livelihood for farmers and rural youth, offering steady income with proper planning, systematic management, and dedication. It creates rural employment, especially for family members, women, and landless laborers. Young farmers are encouraged to adopt sericulture, which requires discipline and quick returns. I've distributed mulberry planting material for 40–45 acres, helping farmers start sericulture. Over 161 farmers have visited my unit, learned improved practices, and gained confidence. Sericulture has transformed my life and can do the same for others. Let's work together to make sericulture a successful and profitable enterprise in our district.

Acknowledgement

Krishi Vigyan Kendra, Mohol, Dist. Solapur, sincerely acknowledges the support of the Director, ICAR-ATARI, Zone VIII, Pune, and the Director of Extension Education, MPKV, Rahuri, for their technical, administrative, and financial assistance. Gratitude is also extended to the young farmer and participating sericulture workers of Madha, Solapur, for their cooperation and valuable contributions in documenting innovative sericulture practices and occupational health aspects.

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SUCCESS STORY ON IMPROVED VARIETY AND INTEGRATED CROP MANAGEMENT TECHNOLOGY IN PIGEONPEA UNDER CFLDS

Article ID: AG-VO6-I01-56**¹S.G. Jadhav, ²T.R. Walkunde, ²P.N. Madavi, ²V.G. Vairagar***¹Krishi Vigyan Kendra, Jalgaon (Jalgaon-II), Jalgaon, Maharashtra²Krishi Vigyan Kendra, Mohol (Solapur-II), Mohol, Solapur, Maharashtra, Mahatma Phule

Krishi Vidyapeeth, Rahuri, Maharashtra, India

Corresponding Author: V.G. Vairagar

Abstract

Pigeonpea is a major pulse crop in Maharashtra, predominantly cultivated under rainfed conditions, where productivity is often constrained by climatic variability, traditional varieties, and suboptimal crop management practices. To address these limitations, Cluster Frontline Demonstrations (CFLDs) on pigeonpea were conducted by Krishi Vigyan Kendra (KVK), Mohol, Dist. Solapur, during 2022–23, with an emphasis on varietal replacement and Integrated Crop Management (ICM) technologies. The demonstrations involved the improved high-yielding variety GRG-152 (Bhima) along with scientific practices such as seed treatment with biofertilisers and biocontrol agents, moisture conservation measures, integrated nutrient and pest management, and promotion of mechanical harvesting. A total of 50 farmers covering an area of 20 ha were benefited under the cluster approach. The CFLD plots recorded a significantly higher mean yield of 21.4 q ha⁻¹ compared to 16.5 q ha⁻¹ under farmer's practice, resulting in a yield enhancement of 29.69 per cent. Economic analysis revealed higher net returns (Rs. 76,840 ha⁻¹) and B:C ratio (2.19) under demonstration plots compared to farmer practices. The results clearly established the superiority of the improved variety GRG-152 coupled with ICM practices in enhancing productivity, profitability, and resilience of pigeonpea under rainfed conditions, indicating strong potential for horizontal dissemination in semi-arid regions.

Keywords: Pigeonpea, Cluster Frontline Demonstrations, Integrated Crop Management, GRG-152 (Bhima), Rainfed agriculture, Varietal replacement, Krishi Vigyan Kendra

Introduction

Pigeonpea (*Cajanus cajan* L.) is one of the most important pulse crops in Maharashtra, contributing significantly to nutritional security, farm income, and the sustainability of rainfed farming systems. In Solapur district, pigeonpea is predominantly grown under rainfed conditions and is often affected by a late monsoon onset, intermittent dry spells, and labour constraints. Despite its importance, pigeonpea productivity in the district remains low due to several production constraints, including the use of old local varieties, poor crop management practices, a high incidence of insect pests and diseases, and the non-adoption of improved technologies.

To address these challenges, Krishi Vigyan Kendra (KVK), Mohol, implemented Cluster Frontline Demonstrations (CFLDs) on pigeonpea during 2022–23, focusing on varietal replacement and Integrated Crop Management (ICM) practices. The demonstrations aimed to enhance the productivity, profitability, and resilience of pigeonpea under rainfed conditions and promote climate-smart and farmer-friendly technologies.

Farming Situation and Climatic Vulnerability

The selected villages fall under semi-arid agro-climatic conditions, where agriculture depends largely on monsoon rainfall. The major climatic vulnerability is the late onset of the monsoon, which often delays sowing and affects crop establishment. In addition, erratic rainfall distribution during the crop season causes moisture stress at critical growth stages.

Major Problems Identified

- ✚ Low yield due to traditional varieties
- ✚ High incidence of insect pests and diseases
- ✚ Labour shortage during weeding and harvesting
- ✚ Poor adoption of scientific crop management practices

These constraints necessitated an integrated technological intervention rather than isolated practices.

Technological Intervention

Table 01-Improved Variety and Integrated Crop Management Technology (ICM)

Particulars	Details
Crop	Pigeonpea (<i>Cajanus cajan</i> L.)
Improved Variety	GRG-152 (Bhima)

Seed Rate	5 kg ha ⁻¹
Sowing Time	June to 15 July
Spacing	180 × 30 cm
Cropping System	Sorghum / Maize – Pigeonpea

Key Components of the Technology

1. Varietal Replacement

Adoption of the high-yielding pigeonpea variety GRG-152 (Bhima), suitable for both timely and late sowing and compatible with mechanical harvesting.

2. Seed Treatment

Seeds treated with Rhizobium, Phosphate-Solubilising Bacteria (PSB), and Trichoderma to enhance nutrient uptake, biological nitrogen fixation, and protection against soil-borne diseases.

3. Moisture Conservation Practices

Opening of furrows at regular intervals and timely intercultural operations to conserve soil moisture under rainfed conditions.

4. Integrated Nutrient Management

Application of the recommended dose of fertilisers (25:50 kg N:P per ha) along with foliar application of micronutrients to correct hidden hunger.

5. Integrated Pest Management (IPM)

Adoption of IPM practices, including the use of biopesticides, monitoring tools such as sticky traps, and need-based plant protection measures.

6. Weed Management

Deep ploughing before sowing, timely hand weeding, hoeing, and the use of weedicides wherever required.

7. Harvesting Practices

Promotion of mechanical harvesting to reduce labour costs and post-harvest losses.

Methodology and Efforts Made by Krishi Vigyan Kendra, Mohol, Dist. Solapur

Krishi Vigyan Kendra, Mohol, Dist. Solapur, adopted a participatory and systematic approach to the successful implementation of CFLDs. The following activities were undertaken:

- Selection of Farmers and Villages under the Cluster Approach

- On-campus and off-campus training programmes on improved pigeonpea production technology
- Supply of critical inputs such as improved seed, bio-fertilisers, micronutrients, and biopesticides
- Method demonstrations on seed treatment and the use of sticky traps
- Regular diagnostic field visits and advisory services
- Field days and interaction meetings for the horizontal spread of technology



Training



Seed Distribution



Method Demonstration:Seed treatment



Method Demonstration:Sticky traps





Field Visits

Output, Outcome and Impact of the Intervention

Coverage under CFLDs

- **Adopted village**
 - Number of farmers benefited: **50**
 - Area covered: **20 ha**

The intervention resulted in a 29.69% higher yield than the farmer's practice due to the combined adoption of improved variety GRG-152 and ICM practices.

Field-level Advantages Observed

- Uniform crop growth and optimum plant population
- Reduced incidence of fusarium wilt and sterility mosaic disease
- Better tolerance to climatic stress
- Suitability for mechanical harvesting
- Reduced cost of cultivation and higher net returns

Table 02-Performance of Technology vis-à-vis Farmer's Practice

- Productivity and Economic Returns (Pooled Data)

Practice	Area (ha)	No. of demonstrations	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practice	20.0	50	16.5	66,100	1,08,900	43,100	1.64
Demonstration	20.0	50	21.4	64,400	1,41,240	76,840	2.19
% Increase	—	—	29.69	-3.34	29.69	78.28	33.53

The CFLD plots recorded significantly higher yields and profitability, clearly demonstrating the superiority of improved technology over existing farmer practices.

Table 03- Individual Farmer Success Story

Particulars	Details	
Name of Farmer	Shri Bhimrao Chandrabhan More	
Village	Adopted village under KVK Mohol, Dist. Solapur	
Technology Demonstrated	• High yielding variety: GRG-152 (Bhima) • Seed treatment with Rhizobium and PSB • Use of biopesticide: HaNPV • Application of micronutrient: Phule Micrograde-II • Integrated Crop Management (ICM) practices	

Institutional Support

Krishi Vigyan Kendra, Mohol, Dist. Solapur, provided training, quality seed, critical inputs, method demonstrations, and regular technical guidance through diagnostic field visits.



Field Visits





CFLD Pigeon pea Field Day

Results Achieved

- Demonstration yield : 24.75 q/ha
- Potential yield of variety : 21.90 q/ha
- District average : 5.95 q/ha
- State average : 7.21 q/ha

Table 04- Economic Performance

Practice	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practice	16.5	66,100	1,08,900	43,100	1.64
Demonstration	24.75	64,400	1,63,350	98,950	2.53
% Increase	50.00	-3.34	50.00	129.58	54.26

Success Points Highlighted by the Farmer

- Uniform crop stand and vigorous growth
- Effective weed control and reduced pest incidence
- More number of pods per plant
- Reduced harvesting cost due to mechanical harvesting

- Better grain quality and grading using a spiral separator

Farmer Feedback

- The farmer expressed high satisfaction with the pigeonpea variety GRG-152, highlighting its high yield potential, disease resistance, adaptability to late sowing, and suitability for mechanical harvesting. He expressed willingness to continue and expand the technology in the coming seasons.

Conclusion

The CFLDs on pigeonpea conducted by KVK Mohol during 2022–23 successfully demonstrated the potential of Improved Variety GRG-152, coupled with Integrated Crop Management Technology, under rainfed conditions. The intervention led to substantial improvements in productivity, profitability, and resilience of pigeonpea farming. The positive response from farmers, higher B:C ratio, and visible field-level benefits indicate strong scope for the horizontal spread of the technology. Adoption of such integrated approaches can play a crucial role in enhancing pulse production, farmer income, and sustainability in the semi-arid regions of Maharashtra.

Acknowledgement

Krishi Vigyan Kendra, Mohol, Dist. Solapur, is grateful to the Director, ICAR-ATARI, Zone VIII, Pune, and the Director, Extension Education, MPKV, Rahuri, for excellent technical, administrative, and financial support in conducting the CFLD, and to the participating farmers for their cooperation in the successful conduct of the CFLDs.

BLOOD TRANSFUSION IN DAIRY COWS

Article ID: AG-VO6-I01-57**Dr. C. Inbaraj**

Assistant Professor, Department of Veterinary Medicine, Veterinary College and Research Institute, Udumalpet, TANUVAS, Tamil Nadu, India

Introduction

Blood transfusion involves the transfer of whole blood consisting of plasma, red blood cells, white blood cells and platelets. Whole blood transfusion is highly recommended that an individual with a pack cell volume (PCV) of less than 10-12% , severe anemia, intravascular volume expansion and oxygen support. Fresh Whole Blood that is less than 8 hours old and has not been refrigerated. Whole Blood is blood that is more than 8 hrs old. It can be stored at 33.8-42.8 °F (1 - 6 °C) for a maximum of 28-35 days.

Indications for blood transfusion

Acute blood loss - Trauma, excessive bleeding during a surgical procedure, abomasal ulceration, coccidiosis, caudal vena cava syndrome associated with liver abscesses and uterine trauma (Total Uterine Prolapse).

Hemolytic causes - Anaplasmosis, Babesiosis, Theileriosis, leptospirosis, autoimmune conditions, onion poisoning, hemoglobinuria (Post Parturient Haemoglobinuria), and disseminated intravascular coagulation.

In severe anemic conditions clinical signs are animals shows tachycardia, pale / Icteric mucous membrane, respiratory distress.



Icteric mucous membrane

Donor criterias

A healthy mature adult, free of known contagious diseases, PCV rang between 24-40%, good body condition (BCS>3.5, beef BCS>6), easy to handle and not in the 3rd trimester of pregnancy are ideal donors.

In the majority of cases, cross matching is not necessary when using the **same breed** between donor and recipient and first blood transfusion is always safe in bovine clinical practice.

Blood types in Bovine:

Every species has specific cell surface antigens on its RBC which differ leading to the development of the blood groups in animals. These factors cause a devastating role in causing adverse-systemic reactions following transfusion.

Cattle – **11 blood groups** (A,B,C,F,J,L,M,R,S,T,Z)

Cross matching

- The procedure involves the reaction of the donor's blood in the recipient (**haemolysis or agglutination**)
- **Major crossmatching** - donor's erythrocyte with recipient serum
- **Minor crossmatching** – recipient erythrocyte with donor's serum

Anticoagulants

- **Sodium citrate 3.8% (100 ml per 1 litre of blood) - commonly used**
- Citrate-phosphate-dextrose-adenine (CPDA-1)
- Acid-citrate-dextrose (ACD)

Procedure for blood collection

- If the donor and recipient PCV is known, the following formula $[(desired\ PCV - current\ PCV) / PCV\ of\ the\ donor] - (BW(kg)\ of\ recipient \times 0.08)$, can be used to calculate the amount of blood needed to reach the desired PCV. Can expect to raise the recipients **PCV by 0.5-0.75% per liter of blood** volume administered.
- The blood transfusion kit consists of a blood collection bag having a capacity of 2 liters with an anticoagulant.
- Anticoagulant Sodium citrate (100ml/L of blood), Acid citrate dextrose (50ml/450ml of blood) can be used.
- Cattles can donate blood up to 1.6% of its body weight (**As a rule of thumb 10-15 ml/kg of body weight**).

- Once everything is prepared, restrain the animal if the donor is not cooperative, Xylazine at the dose of 0.05-0.1 mg/kg intramuscularly can be used. Blood can be collected by jugular venipuncture. Collect blood with anticoagulant by slowly shake it.



Blood collection from the donor animal

Procedure for blood transfusion

- A thorough physical examination must be performed and pre transfusion basal parameters, cardiac and pulmonary conditions to be recorded.
- It is recommended to administer an isotonic crystalloid fluid prior to the transfusion.
- Blood to be given to the recipient **10-20 ml/kg**
- The indicated transfusion rate for the first 5-10 minutes is 2-5ml/kg/hr.



Collected blood transfused to the recipient (Patient) animal

- It is recommended that a base line TPR is performed and then a **TPR performed** every 5-10 minutes to ensure any reactions are occurring. Once no adverse reaction like

tachypnea, muscle tremors, and hypothermia, tachycardia, sweating, violent movements is seen, the rate may be increased to 10-20mls/kg/hr.

- Transfusion should be done carefully by noticing the adverse reaction even though the effect is less during the first transfusion.
- **Epinephrine (Adrenaline) dose** if any allergic reactions **0.002 mg/kg (IV) or 0.01 mg/kg (IM)**
- Do not administer calcium or hypotonic fluids immediately after blood transfusion, as it may lead to hemolysis.



ROBOTICS IN VEGETABLE GRAFTING

Article ID: AG-VO6-I01-58**R. Rajalakshmi^{3*}, Sherly. J² and V. Kanthaswamy¹**

¹ Professor, Dept. of Horticulture, Pandit Jawaharlal Nehru college of Agriculture and Research Institute, Karaikal, Tamil Nadu, India

² Assistant Professor, Dept. of Horticulture, Pandit Jawaharlal Nehru college of Agriculture and Research Institute, Karaikal, Tamil Nadu, India

³ PG Research Scholar (Dept. of Horticulture- Vegetable Science), Pandit Jawaharlal Nehru college of Agriculture and Research Institute, Karaikal, Tamil Nadu, India

*Corresponding Author: R. Rajalakshmi

Abstract

Grafting is an essential technique in modern vegetable production due to its numerous agronomic benefits, including improved disease resistance, stress tolerance and yield. Traditional manual grafting is labour-intensive, time-consuming and requires skilled workers, which has led to the development of robotic grafting systems. Robotic grafting replaces manual operations with mechanical automation, enhancing efficiency, precision and survival rates of grafted seedlings while reducing labour demands. These systems are classified by automation level into semi-automatic machines, which require manual seedling placement and fully automatic machines, which use conveyor-based gripping mechanisms. Based on grafting method, automatic systems are further categorized into pasting, needle and sleeve types. Since the first commercial vegetable grafting robot appeared in 1993, key technologies such as automated seedling handling, precise cutting, scion–rootstock alignment, fixation and integrated system control have advanced considerably. Despite challenges like high initial costs and reduced efficiency with non-uniform seedlings, ongoing technological progress is expected to improve accessibility and support sustainable vegetable production.

1. Introduction

The demand for vegetables and higher quality standards is increasing with rapid urbanization and improved living standards. Grafting has emerged as a crucial practice in vegetable production due to its ability to enhance yield, stress tolerance and crop uniformity. However, traditional manual grafting is highly labour-intensive, time-consuming and requires considerable technical skill. During peak production seasons, large numbers of seedlings must be grafted within a short period, further increasing labour intensity and reducing operational efficiency. Rising agricultural labour costs have therefore accelerated the need for automated grafting solutions.

Automatic grafting technology refers to the replacement of manual grafting operations with mechanical and robotic systems. Automation improves grafting efficiency, operational consistency and survival rates of grafted seedlings by mechanizing key steps such as seedling selection, handling, cutting, joining and planting. Robotic grafting systems significantly reduce labour dependence and allow unskilled workers to perform tasks that previously required trained personnel, thereby improving productivity and economic feasibility (Yan *et al.*, 2022).



Fig.1. Robotics in Vegetable Grafting

2. Benefits of Grafting in Vegetable Production

Grafting offers multiple agronomic advantages that significantly enhance vegetable crop performance in both greenhouse and open-field conditions.

- a) **Disease resistance:** Grafting susceptible vegetable scions onto disease-resistant rootstocks provides effective protection against soil-borne pathogens such as *Fusarium*, *Verticillium* wilt, nematodes and other root-infecting organisms, thereby reducing dependence on chemical control measures.
- b) **Increased productivity:** Grafted plants often exhibit greater vigour and higher yields due to improved water and nutrient uptake efficiency conferred by vigorous rootstocks.
- c) **Abiotic stress tolerance:** Grafting enhances tolerance to environmental stresses, including salinity, drought and temperature extremes, allowing crops to perform well under adverse growing conditions.
- d) **Extended growing season:** Improved stress tolerance enables earlier or later planting, extending the production season and increasing cropping flexibility.
- e) **Improved fruit quality:** In many cases, grafting leads to enhanced fruit size, uniformity, flavour and shelf life, meeting higher market quality standards.
- f) **Stronger root systems:** Robust root development in grafted plants increases anchorage and resilience to unfavourable soil conditions and root damage.

Overall, grafting is an effective strategy for improving productivity, resilience and sustainability in vegetable crops such as tomato, cucumber, eggplant and pepper under both protected and open-field cultivation systems.

3. Advantages of Robotic Grafting

Robotic grafting offers several significant advantages over conventional manual grafting, particularly in modern horticulture and precision agriculture systems.

- a) Precision and accuracy
- b) High efficiency and speed
- c) Reduced labour costs
- d) Improved grafting success
- e) Enhanced hygiene and disease control
- f) Scalability
- g) Operation in controlled environments
- h) Integration of artificial intelligence

4. Types of Grafting Robots

Based on the level of automation, grafting robots are classified into **semi-automatic** and

fully automatic systems. Semi-automatic grafting machines, first commercialized in 1993 for cucumber grafting, require manual feeding of seedlings and supervision by skilled workers. These systems can graft approximately 600–800 seedlings per hour, equivalent to the output of several skilled labourers and are widely used for cucurbit and solanaceous crops. A notable example is the multipurpose semi-automatic grafting machine developed by Helper RoboTech (Korea), valued for its affordability, versatility and ease of operation.



Fig.2. JFT-A1500T semi-automatic grafting robot developed by Hefei Jiafute Robot Technology Co., Ltd.

Fully automatic grafting machines require minimal human intervention, with seedlings supplied via belt conveyors and robotic gripping mechanisms. These systems typically achieve 750–1,000 grafts per hour with success rates around 90%.

Automatic grafting machines are further classified by crop type (Solanaceae, Cucurbitaceae or universal) and grafting method, including pasting, needle, sleeve and plug-in techniques.

5. Key Technologies for Automated Vegetable Grafting

5.1. Mechanized Seedling Grabbing Technology: It focuses on the accurate removal of rootstock and scion seedlings from culture trays without causing mechanical damage. A critical requirement is maintaining uniform cotyledon orientation to ensure reliable clamping and

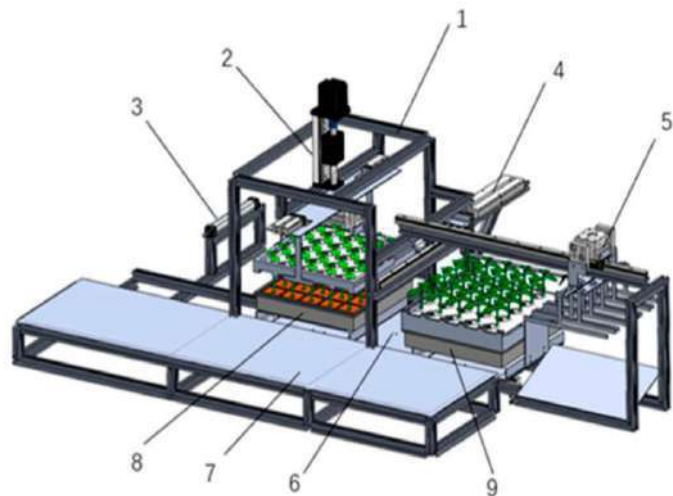


Fig.3. HAU-22 fully automatic grafting robot developed by Huazhong Agricultural University: 1. Rack; 2. Clamping-lifting device; 3. Seedling-lowering device; 4. Synchronous-cutting device; 5. Clamping and transferring device for the upper half of the rootstock seedlings; 6. Plug tray-positioning device; 7. Upper seedling platform; 8. Scion-seedling plug tray; 9. Rootstock-seedling plug tray.

smooth downstream automation. These systems typically consist of a seedling removal mechanism and a separation support unit, enabling seedlings to be pushed out from trays, lifted, and positioned upright. Advanced systems employ negative-pressure air suction to handle delicate Cucurbitaceae seedlings, reducing damage during handling. Integration of machine vision allows automatic identification and correction of cotyledon orientation, ensuring precise alignment before grafting.

5.2. Automatic Seedling Transportation Technology: It transfer seedlings between grafting stations using conveyor belts or robotic arms. Industrial robotic arms are widely adopted due to their flexibility, accuracy, and compatibility with high-throughput operations. Combined with vision-guided orientation control, these systems enable efficient delivery, positioning and alignment of seedlings. Current technologies support large-scale automated grafting of Cucurbitaceae and Solanaceae crops by integrating seedling feeding, steering and placement functions.

5.3. Stock and Scion Cutting Technology: It directly influences graft union quality and seedling survival. Key parameters include cutting speed, angle, blade shape and positioning. Common cutting methods include flat cutting, bevel cutting and rotary cutting. Rotary cutting mechanisms, developed in the late 1990s, allow simultaneous cutting of rootstock and scion using a single rotating unit, offering compact design and simplified control. Straight cutting methods, including oblique and flat cutting, are widely used due to their simplicity and adaptability. Flat cutting is particularly suitable for Solanaceae crops using flat or cleft grafting techniques.

5.4. Rootstock–Scion Joining and Fixing Technology: The success of grafting largely depends on effective joining and fixation of the rootstock and scion. Automated grafting machines commonly use pasting, needle or sleeve methods, each requiring specific fixing mechanisms. Grafting clips are widely used to secure the graft union and must be automatically positioned, opened and clamped during operation. Vibratory plates and automated feeding devices ensure correct orientation and consistent application of fixing components, enhancing graft survival rates.

5.5. Automatic Grafting System Control Technology: It requires precise coordination of multiple actuators and workstations, demanding high levels of temporal and spatial synchronization. Control systems, typically based on PLCs, PCs or microcontrollers, collect real-

time data from sensors such as cameras, encoders and photoelectric switches. These inputs guide motors, cylinders and solenoid valves to ensure smooth and synchronized machine operation. Future developments are expected to focus on more integrated, intelligent and user-friendly control systems to further improve grafting efficiency and reliability.

6. Important Elements of an Automated Grafting System

Automated grafting systems rely on several key components to ensure precision, efficiency and minimal damage to seedlings.

- i. **Grippers:** Grippers are used to hold, orient and position seedlings during the grafting process. Common types include vacuum suction grippers, pneumatic grippers and soft robotic grippers. Their primary function is to ensure gentle yet secure handling of delicate seedlings while preventing mechanical injury.
- ii. **Actuators:** Actuators enable controlled force application and precise movement of system components. Hydraulic, pneumatic and electric actuators are commonly employed to regulate seedling transport, alignment and cutting operations, ensuring consistent graft quality.
- iii. **End effectors:** End effectors are the functional tools mounted at the tip of robotic arms. Typical examples include precision cutting blades, grafting clip applicators and laser cutters. These tools perform critical tasks such as making accurate grafting cuts and securely joining the rootstock and scion.

7. Protocol for Grafting

7.1. Preparation of Vegetable Seedlings for Grafting: Successful vegetable grafting depends on careful seedling preparation, including proper selection of rootstock and scion, standardized seedling size and synchronized growth to ensure compatibility and high survival rates.

- a) **Rootstock and Scion Selection:** The rootstock provides disease resistance, vigour and tolerance to biotic and abiotic stresses, while the scion determines fruit quality, yield and growth characteristics. Appropriate pairing is essential for graft compatibility.
- b) **Seedling Size Requirements for Robotic Grafting:** Robotic grafting requires uniform seedling length and stem diameter to ensure precise cutting, alignment and graft union formation. Optimal dimensions vary with crop species and grafting method.
- c) **Synchronization of Rootstock and Scion Growth:** Matching stem diameters (typically 1.5–2.5 mm for tube grafting) is critical. Synchronization techniques include staggered

sowing (rootstock 2–5 days earlier), temperature regulation, nutrient management and trimming excessive foliage.

7.2. Robotic Grafting Techniques in Vegetables

Robotic grafting techniques must be precise, scalable and compatible with automation.

- a) **Splice (tube) grafting:** Highly suitable for tomato, pepper and eggplant; widely adopted due to high automation feasibility.
- b) **Cleft grafting:** Commonly used for cucumber, watermelon and pumpkin; moderate automation feasibility.
- c) **Hole insertion grafting:** Ideal for watermelon and melon; offers high automation potential and is widely used in Korea and Japan.

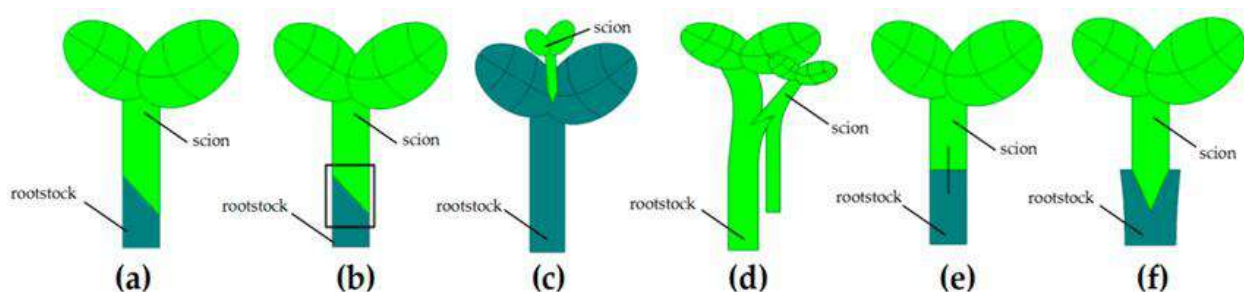


Fig.4. (a) Splice grafting; (b) Tube grafting; (c) Insertion grafting; (d) Approach grafting; (e) Pin grafting; (f) Cleft grafting.

7.3. Healing, Acclimatization and Recovery of Grafted Seedlings: Post-grafting care is essential for graft union formation and seedling survival. Healing chambers provide controlled conditions of temperature, humidity, light and airflow.

a) Importance of Healing and Acclimatization

Proper healing ensures strong vascular connection between rootstock and scion, reduces water stress and transplant shock, and accelerates nutrient and water transport.

b) Healing Chamber Conditions

- **Temperature:** 22–28°C, depending on crop species.
- **Relative humidity:** 85–95% initially, gradually reduced during acclimatization.
- **Light:** Low or indirect light during early stages, followed by gradual exposure.
- **CO₂ and airflow:** Limited ventilation initially to reduce transpiration, then gradually increased to prevent fungal diseases.

c) Stages of Healing and Acclimatization

- **Initial healing (0–3 days):** High humidity (90–95%) and low light.
- **Intermediate healing (4–7 days):** Reduced humidity (80–85%) and gradual light exposure.
- **Acclimatization (7–14 days):** Transition to normal greenhouse conditions with increased light and airflow; humidity reduced to 60–70%.

d) Factors Affecting Healing Success: Healing success depends on grafting technique, crop species, scion–rootstock compatibility and stable environmental conditions. Sudden fluctuations in temperature or humidity can significantly reduce graft survival.

8. Vegetable Grafting Robots Developed Worldwide

Year	Model	Research Unit	Suitable Crops	Productivity (plants/hour)	Survival Rate	Automation
1992	MGM600	Mitsubishi Group, Japan	Solanaceae	600	95%	Semi-automatic
1998	2JSZ-600	China Agricultural University	Melons	600	95%	Semi-automatic
2006	2JC-350	Northeast Agricultural University, China	Melons	350	>90%	Semi-automatic
2010	Graft1200	ISO Group, Netherlands	Melons & Solanaceae	1050	99%	Fully automatic
2013	AFGR-800CS	Helper Robotech, Korea	Melons & Solanaceae	800	95%	Fully automatic
2021	JFT-A1500T	Hefei Jiafute Robot Technology, China	Melons & Solanaceae	1500	98%	Semi-automatic
2022	HAU-22	Huazhong Agricultural University, China	Melons	2134	67%	Fully automatic

9. Case Study: Standardization of Robotic Grafting in Bell Pepper:

(Shivanjali Sarswat *et al.*, 2020)

A study on robotic grafting of bell pepper was conducted during spring and summer 2018 at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. Five chili rootstocks - AVPP0205, PI-201232, Pant C-1, Surajmukhi and PBC-631 and the commercial bell pepper hybrid 'Indra' were used as scions. Seedlings were raised at intervals of 30, 30 and 45 days for scions and 30, 45 and 45 days for rootstocks.

Grafting was performed using the **GR-600 CS robotic grafting machine**, which conveyed, cut and joined the rootstock and scion. Post-grafting, seedlings were acclimated in a healing room to reduce wilting and accelerate union formation. The study determined the optimal combination as 45-day-old scions and rootstocks. While seedling age and rootstock interactions did not significantly affect pericarp thickness, the combination of scion 'Indra' and rootstock PI-201232 yielded the most successful grafts and is recommended for future cultivation.

10. Limitations of Robotic Grafting

Despite its advantages, robotic grafting faces constraints:

- High initial investment costs
- Limited availability of trained technicians
- Sensitivity to seedling size variability
- Need for precise environmental control during healing

These factors currently restrict adoption among small and medium-scale farmers.

11. Future Prospects

Future advancements will focus on:

- AI-driven seedling recognition and matching
- Adaptive cutting and joining using machine learning
- Automated replacement of failed grafts
- Cost reduction through modular design and material innovation

Such developments will enhance accessibility, efficiency and sustainability.

Conclusion

Robotic grafting has emerged as a transformative approach in vegetable production, replacing labour-intensive manual grafting with precise mechanical automation. It enhances

grafting efficiency, improves seedling survival rates and allows operations to be performed by unskilled workers, reducing labour dependence. With ongoing technological advancements, current limitations such as high initial costs and variable seedling handling can be minimized, increasing accessibility for farmers of all scales. Overall, robotic grafting holds significant potential to modernize nursery production, improve crop productivity and contribute to a more resilient and sustainable agricultural system.

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MODFLOW: AN OVERVIEW ON GROUNDWATER FLOW MODELING

Article ID: AG-VO6-I01-59**Dr. S. Anandhi**

Assistant Professor (Mathematics), Anbil Dharmalingam Agricultural College and Research
Institute, Tamil Nadu Agricultural University, Tiruchirappalli-620 027, India

Abstract

MODFLOW is a popular open-source groundwater flow model distributed by the U.S. Geological Survey. Since 1984, it has become the standard tool used by hydrologists, engineers, and environmental consultants worldwide. This article explains what MODFLOW does, how it works, and where it is commonly used. The software uses a modular design that allows users to build models suited to their specific needs. Understanding MODFLOW is valuable for professionals working in water resource management, environmental remediation, and infrastructure development.

Introduction

Groundwater provides drinking water for billions of people and supports agriculture worldwide. Managing this resource requires understanding how water moves through underground formations called aquifers. MODFLOW was created to help scientists and engineers make these predictions using numerical modeling. The program solves mathematical equations that describe groundwater flow, allowing users to test different scenarios and management strategies before implementing them in the real world.

The program's main strength is its modular structure. Instead of one large program trying to do everything, MODFLOW divides tasks into separate packages. Each package handles a specific part of the groundwater system, such as wells, rivers, or recharge from rainfall. Users select only the packages they need for their particular project. This approach makes the software flexible and easier to understand. It also means the program can be updated by adding new packages without changing the entire system.

The U.S. Geological Survey maintains detailed documentation and provides regular updates. A large user community shares knowledge through training courses, textbooks, and online forums. This article explains about the MODFLOW- an open-source groundwater flow model for new users to learn the features and applications of this software and to solve complex problems.

Basic Principles

MODFLOW calculates how water moves through the ground by solving a mathematical equation based on two physical laws. The first is conservation of mass, which means water cannot appear or disappear. The second is Darcy's law, which relates the speed of groundwater flow to the pressure differences driving it and the ease with which water moves through the rock or soil. The software divides the aquifer into a grid of cells, similar to a three-dimensional spreadsheet. Each cell represents a small volume of the aquifer with specific properties like how easily water flows through it and how much water it can store.

The program calculates water levels called hydraulic head at each cell for each time step in the simulation. For steady-state models, the calculation finds the stable water levels when inflows equal outflows. For transient models, the program tracks how water levels change over time in response to pumping, rainfall, or other stresses. Modern versions of MODFLOW use efficient algorithms that can handle models with millions of cells on standard computers.

Key Components

MODFLOW organizes its capabilities into packages. The Basic Package defines the model grid and sets general conditions like which cells are active or inactive. The Layer Property Flow Package assigns hydraulic properties to each cell, including how fast water moves horizontally and vertically through the formation. The Well Package simulates pumping or injection at specific locations. The Recharge Package applies water infiltration from precipitation across the model area. The River Package calculates exchange between groundwater and surface water based on the difference in water levels and the resistance of the riverbed materials.

Additional packages handle specialized processes. The Drain Package removes water at specified elevations, useful for modeling agricultural drainage systems or springs. The Evapotranspiration Package simulates water loss from shallow groundwater through plant uptake and direct evaporation. More advanced packages can model land subsidence from groundwater withdrawal, saltwater intrusion in coastal areas, and flow through the unsaturated zone above the

water table. Users activate only the packages relevant to their project, keeping models as simple as possible while still capturing the important processes.

MODFLOW Features

MODFLOW includes a range of features organized by function. The table below shows the main capabilities available to users.

Flow Simulation	Boundary Conditions	Special Processes	Analysis Tools
Three-dimensional flow	Rivers and streams	Land subsidence	Parameter estimation
Multiple aquifer layers	Lakes and wetlands	Saltwater intrusion	Flow path tracking
Time-varying simulation	Drain systems	Unsaturated zone	Water budget analysis
Variable properties	Pumping wells	Aquifer storage	Sensitivity analysis

Figure 1: Main features of MODFLOW organized by function

Common Applications of MODFLOW

Water supply agencies use MODFLOW to determine how much groundwater can be safely withdrawn without depleting aquifers. These analyses help plan for future water needs by testing different pumping scenarios and drought conditions. The models can show how water levels will respond to increased pumping or how long it will take for aquifers to recover after pumping stops. This information guides decisions about well placement, pumping rates, and the need for alternative water sources.

Environmental consultants use MODFLOW to assess contamination risks and design cleanup systems. When combined with transport models like MT3DMS, the software can predict how pollutants move through groundwater. This helps identify areas where drinking water wells might be at risk and shows whether natural processes will break down contaminants or if active cleanup is needed. The models also help design systems of extraction and injection wells to contain and treat contaminated groundwater.

Engineers use MODFLOW for construction projects that interact with groundwater. For example, building foundations below the water table require temporary pumping to keep excavations dry. MODFLOW helps design these dewatering systems by predicting how much water needs to be pumped and how far the water table will drop. The models also assess potential impacts on nearby wells or structures that might settle if water levels decline. Similarly, tunnel projects use MODFLOW to estimate inflow rates and plan drainage systems.

Coastal communities use MODFLOW to study saltwater intrusion. When too much freshwater is pumped from coastal aquifers, saltwater from the ocean can move inland and contaminate drinking water supplies. MODFLOW models with density-dependent flow capabilities can simulate this process and test management strategies to prevent or reverse saltwater intrusion. These strategies might include reducing pumping rates, relocating wells farther inland, or creating barriers of injected freshwater.

Working with MODFLOW

Building a MODFLOW model starts with developing a conceptual understanding of the groundwater system. This includes identifying the aquifer layers, their properties, and the boundaries of the study area. Users need data on aquifer thickness, hydraulic conductivity, and water levels. Information about wells, rivers, and recharge is also required. The quality and quantity of available data significantly affect model accuracy, so data collection is often the most time-consuming part of a modeling project. ★★☆☆

Most users work with MODFLOW through graphical interfaces rather than editing text files directly. Programs like ModelMuse, Groundwater Vistas, and Visual MODFLOW provide tools for building the model grid, assigning properties, and viewing results. These interfaces make it easier to set up models and catch errors before running simulations. They also provide visualization tools that help users understand model results and identify problems.

Calibration is the process of adjusting model parameters until the simulated water levels match observed measurements. This usually involves changing hydraulic conductivity values and recharge rates within reasonable ranges based on field data. Automated calibration tools can help find the best parameter values, but users need to ensure the final model makes physical sense. A well-calibrated model should match historical water levels and flow rates while using realistic aquifer properties.

Once calibrated, the model can be used for predictions. However, users must recognize that all models have limitations and uncertainties. Model predictions are most reliable when they stay within the range of conditions used during calibration. Predictions far into the future or for conditions very different from the calibration period should be viewed with appropriate caution. Sensitivity analysis helps identify which parameters most affect model predictions and where additional data collection might reduce uncertainty.

Software Developments

MODFLOW 6, released in 2017, represents a major update to the software. It uses a new code structure that makes it easier to couple with other models and add new features. The program can now use unstructured grids that conform to irregular boundaries and focus detail where needed while using larger cells elsewhere. This flexibility improves accuracy while managing computational demands. MODFLOW 6 also includes better algorithms for solving problems with unconfined aquifers where cells can go dry and rewet. More recent and specialized versions of MODFLOW are also important, including MODFLOW-NWT which uses a Newton formulation, MODFLOW-USG designed for unstructured grids, and the One-Water Hydrologic Flow Model (MF-OWHM).

Recent additions focus on better representing surface water and groundwater interactions, which are important for understanding how streams, wetlands, and aquifers affect each other. Developers are also working on improved methods for handling uncertainty and for integrating real-time monitoring data into models. These developments aim to make MODFLOW more useful for both planning studies and operational water management.

Conclusion

MODFLOW has become the standard tool for groundwater modeling because it combines scientific rigor with practical usability. The modular design allows users to build models appropriate for their specific needs without unnecessary complexity. The software is well-documented, freely available, and supported by a large community of users. These factors make it accessible to professionals who need reliable groundwater modeling capabilities.

For professionals new to groundwater modeling, MODFLOW provides a solid foundation. Understanding its basic principles and capabilities is valuable even if you work with specialized consultants who build the actual models. This knowledge helps in framing study objectives, evaluating model results, and making informed decisions based on model predictions. The

investment in learning MODFLOW pays dividends through better understanding of groundwater systems and more effective water resource management.

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THE WORLD OF BELA FLOWER (*JASMINUM SAMBAC*): PRODUCTION TECHNOLOGY, CONSTRAINTS AND FUTURE PROSPECTS

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Alok Kumar

Asstt. Prof.-cum-Junior Scientist, Department of Basic Science & Humanity (Genetics),
Nalanda College of Horticulture, Noorsarai, Nalanda, Bihar, India

Introduction

Bela flower (*Jasminum sambac* L.) is one of the most cherished aromatic flowering plants in India, celebrated for its intense fragrance, medicinal properties, and cultural significance. It holds a prominent place in religious ceremonies, ornamental gardens, perfumery, cosmetic industries, and traditional medicine systems like Ayurveda. The flowers are used in garlands, worship rituals, essential oil extraction, and preparation of perfumes, attars, and aromatherapy products.

India, being home to a variety of climatic zones, supports the cultivation of Bela across many regions, with West Bengal, Tamil Nadu, Karnataka, Uttar Pradesh, and Maharashtra being major centers of production. Despite its widespread utility, Bela cultivation faces constraints such as poor-quality planting material, pest and disease incidence, nutrient imbalances, and water scarcity. Adoption of improved varieties, integrated nutrient management, pest control, and modern horticultural practices can significantly enhance flower yield and quality (Singh *et al.*, 2022; Sharma *et al.*, 2023).

This technical bulletin synthesizes updated information on Bela production technology, agronomic practices, pest and disease management, harvesting, post-harvest handling, and emerging opportunities, supported by recent scientific literature (2020–2025).

Botanical Description and Origin

Bela belongs to the family Oleaceae and genus *Jasminum*. It is a small evergreen shrub or climber, typically reaching a height of 0.5 - 2 m. The plant has opposite, simple or compound leaves, and bears small, intensely fragrant, white flowers, generally with 5 - 9 petals. Flowers are

hermaphroditic, blooming in clusters, and have a long-lasting fragrance. Fruits are small, black, and non-edible, with the primary value lying in the flowers.

Jasminum sambac is believed to have originated in the Indian subcontinent and Southeast Asia. From here, it spread to other tropical and subtropical regions worldwide. The species has adapted to warm climates, thriving under moderate humidity and well-drained soils (Kumar *et al.*, 2021; Reddy *et al.*, 2022).



Figure: Bela (*Jasminum sambac*) plant



Figure: Bela (*Jasminum sambac*) plant in flowering stage

Climate and Soil Requirements

Bela is a tropical and subtropical plant, performing best under warm and humid conditions. The optimum temperature range is 25 - 35°C, while temperatures below 10°C or

above 40°C adversely affect flowering and growth. Bela can tolerate mild frost but prolonged cold spells damage young shoots and flowers. Moderate humidity (60–80%) and rainfall of 750 - 1500 mm per year favor optimum growth (Prasad *et al.*, 2021).

Well-drained sandy loam to clay loam soils with a pH of 6.0–7.5 is ideal. Heavy clay soils with poor drainage predispose plants to root rot and fungal infections. Organic matter enrichment improves moisture retention and nutrient availability, which is crucial for continuous flowering and higher flower quality (Thomas *et al.*, 2023).

Recommended Varieties

Several improved and locally adapted varieties of Bela are cultivated across India:

Gundumalli – Popular in southern India; highly aromatic with medium-sized flowers.

Mysore Mallige – Renowned for fragrance; suitable for essential oil extraction.

Rajasthan Bela – Drought tolerant, hardy variety for arid regions.

Double Bela – Double-petaled flower; highly valued for decorative purposes.

Local Assam varieties – Small flowers, highly fragrant, preferred in religious offerings.

Selection of region-specific varieties is critical to maximize yield, flower quality, and aroma intensity (Sarma *et al.*, 2021).

Propagation Techniques

Bela is primarily propagated vegetatively to maintain varietal characteristics:

Stem Cuttings – Semi-hardwood cuttings of 10–15 cm treated with IBA hormone (500–1000 ppm) and planted in well-drained soil.

Layering– Simple layering or mound layering is effective for large-scale propagation.

Grafting– T-budding and approach grafting onto rootstocks like *Jasminum multiflorum* improve vigour and stress tolerance.

Tissue Culture – Micropropagation allows rapid multiplication of elite, disease-free plants (Nath *et al.*, 2020).

Healthy, disease-free mother plants should be used to ensure high survival and uniform growth.

Nursery Practices

Successful Bela cultivation begins with a well-managed nursery:

Raise beds of 1–1.5 m width and 10–15 cm height. Solarize the soil to suppress pathogens.

Mix soil with 25–30% organic compost and apply Trichoderma-enriched biofertilizers to enhance root health.

Provide 50% shade and mist irrigation during summer to reduce transplant shock.

Scout regularly for early signs of fungal infections, aphids, and leaf miners.

Harden seedlings for 2–3 weeks before transplanting into the main field (Reddy *et al.*, 2022).

Planting and Orchard Establishment

Planting Season

Rainfed regions: June–July (monsoon)

Irrigated regions: February–March

Spacing

Standard spacing: 1 × 1 m for hedgerow planting

1.5 × 1.5 m for bush-type orchards

2 × 2 m for climbers or trellis systems

Pit Preparation

Dig pits of 45 × 45 × 45 cm.

Fill with 10–15 kg FYM, 500 g neem cake, 50 g SSP, and soil from the nursery.

Apply biological inoculants like Azotobacter and PSB.

Nutrient Management

Bela is a nutrient-demanding plant, requiring balanced macro- and micronutrients for continuous flowering.

Recommended Dose per Plant (Mature Plants):

Nitrogen: 150–200 g

Phosphorus (P_2O_5): 50–75 g

Potassium (K_2O): 100–150 g

FYM: 10–15 kg

Application:

Split N into 2–3 doses during active growth.

Phosphorus during pit filling and early growth.

Potassium during flowering and post-harvest stages.

Foliar sprays of ZnSO_4 (0.5%), FeSO_4 (0.2%), and MgSO_4 (0.5%) enhance flower size and aroma (Singh *et al.*, 2024).

Integrated nutrient management using organic manures, biofertilizers, and chemical fertilizers improves soil health and sustains flower production.

Irrigation Management

Bela has a shallow root system and requires regular watering, especially during:

Flower bud initiation

Full bloom

Petal development

Frequency:

Summer: 4–6 days

Winter: 10–12 days

Drip irrigation is recommended to save 30–50% water and improve flower quality. Mulching with straw or plastic helps conserve moisture and reduce weeds (Reddy *et al.*, 2023).

Intercultural Operations

Weed Management: Manual weeding, mulching, and directed herbicide application.

Pruning: Remove dead branches, weak shoots, and overcrowded stems. Pruning after harvest stimulates new growth.

Flower Induction: Balanced fertilization, light pruning, and application of plant growth regulators like GA_3 (20–30 ppm) can enhance flowering (Chauhan *et al.*, 2021).

Flowering and Harvesting

Bela flowers multiple times a year, with major flushes during spring and autumn. Flowers should be harvested early morning when fully open for maximum fragrance and oil content. Harvesting should be done carefully to avoid stem damage, using clippers or hand plucking.

Post-harvest handling: Grade flowers by size and freshness, store in cool, ventilated rooms at 12–15°C.

Major Insect Pests

Sl. No.	Insect Pests	Symptoms	Control
1.	Aphids (<i>Aphis gossypii</i>)	Cause leaf curling and reduce flower bud formation.	Spray Neem oil (2%) or Imidacloprid (0.3 ml/L).

2.	Whiteflies (<i>Bemisia tabaci</i>)	Suck sap and spread viral diseases.	Yellow sticky traps, biocontrol agents like <i>Encarsia formosa</i> .
3.	Caterpillars (<i>Spodoptera spp.</i>)	Defoliate tender shoots.	Handpicking or spraying <i>Bacillus thuringiensis</i> (Bt).

Major Diseases

Sl. No.	Major Diseases	Symptoms	Control
1.	Powdery Mildew (<i>Oidium spp.</i>)	White powder on leaves and buds.	Spray Sulphur (0.2%) or Potassium bicarbonate.
2.	Leaf Spot (<i>Colletotrichum spp.</i>)	Brown spots on leaves, premature leaf fall.	Copper oxychloride (0.3%) spray, remove infected leaves.
3.	Root Rot (<i>Phytophthora spp.</i>)	Waterlogged soils, root decay.	Improve drainage, drench with Metalaxyl-M, use Trichoderma-enriched compost.

Yield and Economics

Average flower yield: 2–3 kg per plant per year under traditional practices.

Improved practices: 4–6 kg per plant/year with better varieties, drip irrigation, and integrated nutrient management.

Economic returns are high due to domestic demand for garlands, attar, and essential oil.

Emerging Technologies and Future Prospects

High-density planting- using dwarfing rootstocks for maximum space utilization.

Sensor-based irrigation - for precise water management.

Nano-fertilizers - for targeted nutrient delivery.

Biostimulants - to enhance stress tolerance and flower quality.

Climate-resilient cultivars - resistant to heat, drought, and pest incidence.

Organic and residue-free Bela production - targeting domestic and export markets.

With rising demand for aromatic flowers and essential oils, Bela cultivation offers promising opportunities for smallholders and commercial growers.

Conclusion

Bela flower (*Jasminum sambac*) holds immense economic, cultural, and medicinal value

in India. Scientific orchard establishment, integrated nutrient and pest management, proper irrigation, pruning, and adoption of improved varieties are crucial to enhance flower yield and quality. Future strategies must focus on climate-smart practices, organic cultivation, high-density planting, and precision agriculture tools. This technical bulletin provides comprehensive guidance for sustainable Bela cultivation in India.

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GAMIFICATION APPROACHES FOR ENHANCING AGRICULTURAL PRACTICES AND LEARNING - AN OVERVIEW

Article ID: AG-VO6-I01-61***Hariharasudhan S¹, Sahana S² and Bhavana K S¹**

¹M.Sc. student, Department of Agricultural Extension Education, KSNUAHS, Shivamogga, Karnataka, India.

²Professor and Head, Department of Agricultural Extension Education, KSNUAHS, Shivamogga, Karnataka, India.

*Corresponding Author: Hariharasudhan S

Abstract

Over recent decades, education has experienced significant change as a result of rapid developments in digital technology. The integration of online learning platforms, multimedia resources, and the broad access to high-speed internet has fundamentally reshaped how educational content is delivered and accessed, altering traditional teaching and learning practices. Gamification is the process of using game design elements such as points, challenges, leaderboards in non-game settings, has emerged as a dynamic strategy to improve knowledge sharing, motivation, and engagement. By integrating engaging factors in learning process with the help of modern technologies like virtual reality, augmented reality, simulations, gamification has the potential to foster more meaningful learning experiences, strengthen learner's involvement in agricultural innovation, and promote the long-term adoption of sustainable and climate-smart practices. This paper discusses how gamification can revitalize agricultural learning and extension practices, especially among youth, smallholder farmers, and underserved communities.

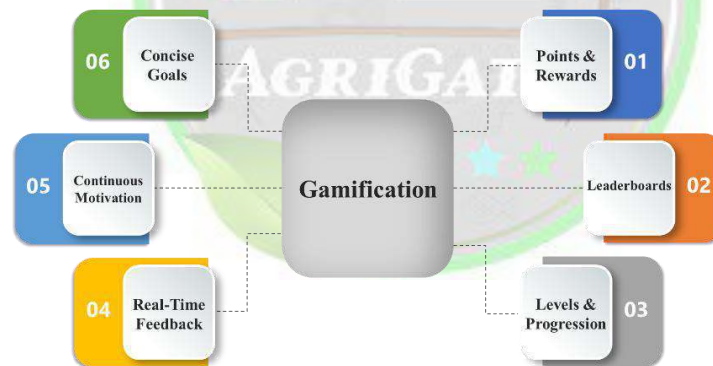
Introduction

Virtual learning has become an essential modality for agricultural education, extension, and capacity building, especially since the early 2020s when digital infrastructure and institutional e-learning offerings expanded rapidly. By overcoming geographical barriers, the

online platforms allow students to access learning materials and engage with instructors at their own pace and convenience, thereby promoting more inclusive education, especially for learners in remote and underserved areas. The core components of technology-enhanced learning include learner engagement, platform interactivity, and content design within virtual learning environments. These components underpin the development of more advanced digital education approaches, such as gamification, simulation-based systems, and virtual reality (VR) or augmented reality (AR) applications. In agricultural education in particular, where experiential and hands-on learning is vital, these factors play a crucial role in addressing the challenges of delivering field-based training virtually and in improving overall learning experiences.

Concept of Gamification in Agricultural Education

Gamification is the use of elements like points, leaderboards, levels, badges, storytelling, and challenges in learning, training and advisory platforms. Gamification does not necessarily need complex video games but uses game mechanics to enhance learning and give it a sense of purpose through Virtual Learning. Virtual learning refers to the use of electronic platforms to facilitate educational experiences, utilizing a mix of media such as text, video, audio, and interactive modules.



The key elements of Gamification are,

1. **Points and Rewards** - providing to participants after successful completion of every task to actively participate in learning like certificates, badges or access to advanced module.
2. **Leaderboards** - ranking the participants based on performance to improve competing behaviour.
3. **Levels and Progression** - basic concepts are lower levels, advanced concepts are higher levels. To see their growth and build confidence for learners.

4. **Real time feedback** - participants can understand their mistakes and rectify it within short span of time in simulation kind of tools.
5. **Continuous motivation** - participants keep motivated through daily tasks and challenges, tracking their progress and small achievements.
6. **Concise goals** - makes complex concepts into clear, short-term activities.

Tools and Technologies used in Gamification approach

The modern technologies are used to integrate gamification in learning. They are,

1. Simulation Software

Simulation software uses computer models to represent real agricultural processes such as crop growth, irrigation scheduling, fertilizer application, climate effects, and pest outbreaks. It helps students, researchers, and farmers analyse outcomes of different farming decisions without field experiments.

2. Virtual Reality (VR)

Virtual reality creates a fully immersive digital farming environment using headsets and controllers. In agriculture, VR is used for training on tractor operation, greenhouse management, livestock handling, and farm safety without physical risk or resource loss.

3. Augmented Reality (AR)

Augmented reality enhances the real farm environment by overlaying digital information on crops, soil, or equipment through mobile devices or smart glasses. Farmers can view real-time data such as disease symptoms, nutrient deficiencies, or spray instructions while standing in the field.

4. M- Learning apps

M-learning apps refers to the mobile learning apps which provide agricultural education and advisory services through smartphones. These apps support farmers with crop calendars, weather forecasts, pest alerts, soil testing guidance, and market price updates, enabling learning anytime and anywhere.

5. Online learning platforms

Online learning platforms offer structured agricultural education through videos, live classes, discussion forums, and digital certificates. They are widely used for farmer training, extension education, and skill development in areas like organic farming, precision agriculture, and agribusiness.

6. Learning Management System

A learning management system is a digital platform that manages agricultural training programs by organizing courses, tracking learner progress, conducting assessments, and storing learning materials. Universities and extension agencies use LMS for structured agricultural education.

7. AI-based adaptive learning tools

It uses artificial intelligence to customize agricultural education based on learner performance, interests, and farming context. These tools adjust lessons, recommend resources, and provide personalized guidance for crops, soil conditions, and farming practices.

Application of Gamification approaches in Agricultural education

The potential areas where gamification can be applied in agricultural education are, Crop production and Agronomy, Soil Science and Nutrient Management, Crop protection (Pest and Diseases), Agricultural Extension Education, Climate Smart Agriculture and Precision farming.

Crop production and Agronomy

Gamification enhances farm management by converting everyday agricultural decisions into engaging, measurable activities supported by real-time feedback through scores, progress indicators, and digital dashboards. By rewarding optimal actions in areas such as planting, irrigation, fertilization, and harvesting, farmers are motivated to closely monitor their fields and adopt recommended practices, resulting in greater efficiency, reduced input waste, and more stable yields. At the same time, gamification promotes sustainable farming by turning environmental objectives—such as conserving water, improving soil health, and minimizing chemical use—into achievable challenges, with visual performance indicators helping farmers align productivity with long-term ecological sustainability.

Soil Science and Nutrient Management

Gamification can be applied in soil science and nutrient management by transforming soil assessment, nutrient planning, and conservation practices into interactive, goal-oriented activities supported by feedback and rewards. It can be used on topic such as interpreting soil health indicators correctly, applying balanced nutrient recommendations, and adopting practices such as organic amendments or precision fertilization. With the help of Virtual reality technology, soil structure can be created virtually for better understanding of learners. By making soil and

nutrient management measurable and engaging, gamification improves understanding, promotes best practices, and supports sustainable soil fertility management.

Crop protection (Pest and Diseases)

Gamified tools are especially effective for training farmers in pest and disease identification. Interactive quizzes, simulations, and scenario-based challenges help users practice diagnosing crop problems and selecting appropriate control measures. Immediate feedback reinforces correct decisions, while incorrect choices demonstrate potential yield losses or environmental damage. This approach improves early detection, reduces misuse of pesticides, and strengthens integrated pest management (IPM) adoption.

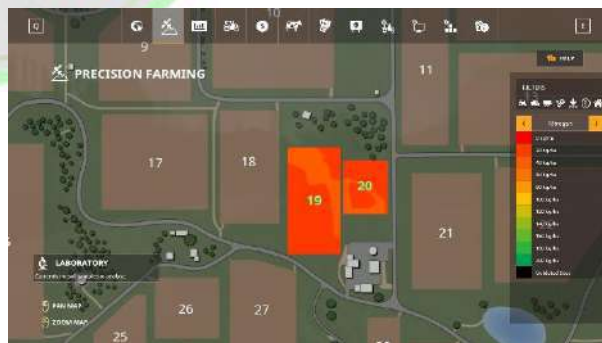
Agricultural Extension Education

Gamification modernizes agricultural training and extension services by transforming learning into interactive experiences. Training content is structured as missions or levels aligned with crop growth stages. Farmers progress through modules on soil preparation, crop nutrition, pest control, and post-harvest management, earning certificates or status levels upon completion. This approach increases knowledge retention, accelerates technology adoption, and makes extension services more accessible, especially through mobile platforms.

Climate Smart Agriculture and Precision farming

Crop production is highly exposed to risks such as climate variability, pests, and market fluctuations. Gamified simulations allow farmers to explore “what-if” scenarios involving drought, floods, disease outbreaks, or price changes.

The practical case studies are conducted for gamified platforms in precision farming call Farming Simulator-22 which is funded by European Union. It integrates principles of precision Farming in simulation game with real world geographical data. The key features are inclusion of Environmental scores, GPS based navigation, Farm management strategies, Variable Rate Technology(VRT) and Soil & crop information through satellite images.



Benefits of Gamification in Agricultural Education

1. Enhanced Engagement and Motivation - making learning more enjoyable and habitual. Learners are more likely to return to a platform that makes them feel successful and acknowledged.



2. Improved Knowledge Retention - Repetition, feedback, and interactive learning inherent in gamification improve how well users remember and apply new information.

3. Behaviour Change and Practice Adoption - Gamified systems that simulate real-world consequences foster risk-free experimentation. Seeing virtual outcomes helps motivate farmers to adopt new techniques in real life.

4. Inclusivity and Accessibility - When designed appropriately, gamified tools can transcend literacy barriers through audio, visuals, and local languages, making them accessible to women, youth, and marginalized groups.

5. Promotes Sustainability: Drives adoption of eco-friendly methods like agroforestry and efficient water use, supporting climate action goals.

Limitations of Gamification in Agricultural Education

- 1. Over-simplification:** Complex farming systems and ecological interactions may be reduced too much.
- 2. Resource constraints:** Requires devices, internet, and software not always available in rural areas.
- 3. Limited practical skills:** Virtual rewards can't fully replace hands-on field experience.
- 4. Teaching Competence:** Educators may lack training to design or use gamified tools effectively.
- 5. Assessment challenges:** Hard to measure real-world competency through game outcomes alone.

Conclusion

Gamification offers significant promise in transforming agricultural education, extension services by introducing interactive, engaging, and scalable learning experiences for farmers. Unlike traditional methods that often rely on passive information transfer, gamified approaches

can actively involve learners in problem-solving, decision-making, and behaviour change. Although gamification is not a one-size-fits-all solution, it serves as a powerful complement to conventional extension strategies by addressing long-standing issues such as limited farmer engagement, low retention of knowledge, and challenges in reaching remote or marginalized communities. When thoughtfully designed, gamified tools can tailor content to local contexts, accommodate varying literacy levels, and incorporate culturally relevant incentives, thereby enhancing their effectiveness.

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VALUE ADDITION IN AGRICULTURE: A PATHWAY TO SUSTAINABLE FARMER INCOME AND RURAL TRANSFORMATION

Article ID: AG-VO6-I01-62**Dr. S.R.Padma**

Assistant professor (Agricultural Extension)

Tamil Nadu Agricultural University, Coimbatore-3, Tamil Nadu, India

Introduction

Indian agriculture has witnessed significant progress in production over the past few decades, yet farmers' income remains unstable and often inadequate. One of the major reasons is that most farmers sell their produce in raw form, receiving only a small share of the final consumer price. Middlemen, transporters, processors, and retailers capture most of the value, leaving farmers vulnerable to market volatility.

Value addition in agriculture refers to the process of enhancing the economic value of agricultural produce by changing its form, place, time, or utility. For example, converting paddy into rice, milk into curd or cheese, coconuts into oil or virgin coconut oil, and fruits into jams and juices are all examples of value addition. These processes increase shelf life, improve quality, meet consumer preferences, and create new market opportunities.

In the context of rising production costs, climate uncertainties, and changing consumer demand, value addition has become essential for making farming profitable and sustainable.

Concept and Meaning of Value Addition

Value addition involves improving the worth of agricultural products through processing, grading, packaging, branding, and marketing. It can occur at any stage between harvesting and consumption. The objective is to make the product more attractive, useful, and profitable.

For instance, selling raw tomatoes yields a low price and involves high spoilage risk. However, converting tomatoes into sauce, puree, or dried flakes increases shelf life and fetches a higher market price. Similarly, millets processed into ready-to-eat foods or breakfast cereals command premium prices in urban markets.

Thus, value addition shifts agriculture from a production-oriented activity to a market-oriented enterprise.

Importance of Value Addition in Agriculture

Value addition plays a crucial role in transforming traditional agriculture into a profitable and sustainable sector.

Firstly, it increases farmers' income. By processing and marketing their produce, farmers can capture a larger share of the consumer price. Instead of selling groundnuts cheaply, a farmer can earn more by producing roasted nuts, oil, or peanut butter.

Secondly, value addition reduces post-harvest losses. A large portion of fruits, vegetables, and perishables is wasted due to poor storage and marketing facilities. Processing and preservation help extend shelf life and prevent wastage.

Thirdly, it generates rural employment. Agro-processing units, packaging centers, and storage facilities create jobs for rural youth and women, reducing migration to cities. Fourthly, it strengthens food security. By preserving and processing food, availability is maintained throughout the year.

Finally, it promotes entrepreneurship and innovation in rural areas.

Forms of Value Addition

Value addition can be classified into several forms.

Physical Value Addition

This includes activities such as cleaning, grading, milling, drying, and processing. For example, converting wheat into flour or turmeric into powder.

Time Value Addition

Storing produce and selling it when prices are higher increases its value.

Place Value Addition

Transporting produce to better markets where demand and prices are higher adds value.

Form Value Addition

Changing the form of the product, such as converting milk into cheese or fruits into jams.

Knowledge-Based Value Addition

Organic certification, branding, and labeling enhance market appeal and price.

Value Addition and Farmer Income

Farmers who engage in value addition are less dependent on local traders and can directly

access consumers or niche markets. This improves their bargaining power and income stability.

For example, coconut farmers who sell raw nuts often face fluctuating prices. However, producing virgin coconut oil, coconut sugar, or desiccated coconut ensures steady income and export potential.

Similarly, millet farmers can earn more by selling millet-based health foods instead of raw grains.

Role of Value Addition in Climate Resilience

Climate change has increased the risks of crop failure, price crashes, and income instability. Value addition provides a buffer against these risks.

Processing and storage reduce dependence on immediate sale after harvest, allowing farmers to wait for better prices. Diversified products also reduce vulnerability. For instance, crop residues can be used to make compost, bio-bricks, or animal feed, turning waste into income.

Thus, value addition supports both economic and environmental sustainability.

Crop-Specific Value Addition Opportunities

Coconut

Coconut offers immense value addition opportunities such as coconut oil, virgin coconut oil, coconut milk, coir products, shell charcoal, and coconut sugar. These products have high domestic and export demand.

Millets

Millets can be processed into biscuits, noodles, breakfast cereals, and health drinks, meeting the growing demand for healthy foods.

Fruits and Vegetables

Processing into juices, pickles, dehydrated products, and frozen foods helps reduce wastage and increase profitability.

Spices

Spices can be value-added through grinding, blending, and packaging for export markets.

Role of Institutions and Extension Services

Agricultural universities, Krishi Vigyan Kendras, and extension agencies play a vital role in training farmers on processing techniques, quality control, and marketing. Farmer Producer Organizations (FPOs) can pool resources and establish processing units.

Government schemes such as food parks, MSME support, and startup incentives encourage agro-processing.

Challenges in Value Addition

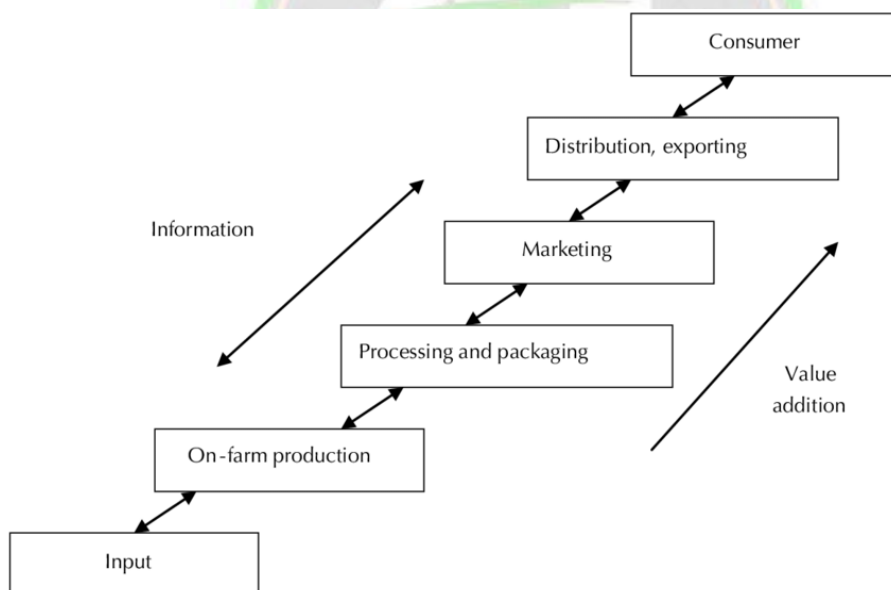
Despite its benefits, value addition faces several challenges. Lack of awareness and skills among farmers is a major constraint. Limited access to credit, poor infrastructure, and market linkages also hinder growth. Quality standards, packaging requirements, and competition from large companies further add to the difficulty.

Addressing these challenges requires training, financial support, and policy backing.

Policy Implications and the Way Forward

To promote value addition, governments should invest in rural processing infrastructure, cold storage, and logistics. Training programs must focus on entrepreneurship and market-oriented production. Digital platforms can help farmers sell directly to consumers.

Encouraging women and youth in value-added enterprises will accelerate rural development.



Conclusion

Agriculture in developing countries, including India, is largely characterized by small and marginal farmers who depend heavily on the sale of raw produce. This dependence exposes them to price fluctuations, post-harvest losses, and limited income growth. Value addition in agriculture offers a powerful solution to these challenges by transforming raw farm produce into processed, packaged, and market-oriented products that fetch higher prices. This article explores

the concept of value addition, its importance, various forms, and its role in enhancing farmer income, reducing post-harvest losses, generating rural employment, promoting agri-entrepreneurship, and supporting climate resilience. The paper also discusses crop-specific value addition, particularly in coconut, millets, fruits, and traditional crops, along with challenges and policy implications. Value addition is not merely a business opportunity but a development strategy that can strengthen food systems, empower farmers, and promote sustainable rural development.

Value addition is not merely a technical process; it is a transformation of agriculture from subsistence to enterprise. By adding value, farmers can increase income, reduce risks, create jobs, and build sustainable livelihoods. In a rapidly changing world, value addition is the bridge that connects farmers to markets, consumers, and a better future.

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AN ECONOMIC ANALYSIS OF JASMINE CULTIVATION, EXPORT POTENTIAL AND PROFITS IN INDIA

Article ID: AG-VO6-I01-63**Dr A.Malaisamy**

Professor and Head, Department of Agricultural Economics, Tamil Nadu Agricultural University
Tamil Nadu, India

Introduction

The Jasmine is one of the most fragrant and ancient flowers in India. It is known as the Queen of Flowers and is often called the "Queen of Fragrance" or "Belle of India." Jasmine flowers are used in various cultural and religious ceremonies, as well as in perfumes and essential oils. In many cultures, the Jasmine flower symbolizes purity, love, and beauty. Its captivating aroma is believed to have calming and therapeutic properties, making it a popular choice for aromatherapy.

Jasmine belongs to the genus *Jasminum*, which represents a diverse and widespread group of flowering plants within the family *Oleaceae*. The genus *Jasminum* contains 200 species, however there are only 89 true species within it. Total of 40 species of jasmine are cultivated in India, among which 20 species are cultivated in south India. *J. sambac*, *J. auriculatum*, and *J. grandiflorum* are three important species commonly cultivated for commercial purposes. It is a climbing, trailing, and erect shrub; there are both evergreen and deciduous species with pinnate or simple leaves and fragrant flowers containing the oil of commerce.

Jasmine can be grown on a variety of soils. Their cultivation requires rich, loamy soil that drains well and has a pH between 6.5 and 7.5. Jasmine grows best in climates with mild winters, warm summers, moderate amounts of precipitation, and sunny days. Jasmine needs particular temperatures and humidity levels for optimum growth and is sensitive to changes in climate. Variations in the climate can affect yield and quality. The ideal annual rainfall for growth and development of jasmine is between 800 and 1000 mm.

Jasmines are grown across the country, but commercial cultivation mainly happens in Madurai, Coimbatore, Dindigul, Bangalore, Mysore, Kolar, Jaunpur, Gazipur, Kannuj, Jaipur, Udaipur, Kota, Ajmer, Kolaghat, Pancskura, Ranaghat, and some areas of Andhra Pradesh and Maharashtra.

In India, the leading states in jasmine cultivation are Karnataka and Tamil Nadu. Four varieties of jasmine in India have been given GI tag. Madurai Malli, Mysore Malligae, Udupi Malligae, Hadagali Malligae, in which Madurai Malli is cultivated in Tamil Nadu and other three are cultivated in Karnataka.

Madurai Malli

Madurai Malli got its GI-tag for its aromatic fragrance and thick petals which is responsible for its longer shelf life. The heavy fragrance of the flower is a result of the accumulation of alkaloids such as 'jasmone' and 'alpha terpineol'. These alkaloids accumulate owing to the topography of the Madurai region where the flowers are harvested. The heavy fragrance of the flower is a result of the accumulation of alkaloids such as 'jasmone' and 'alpha terpineol'. These alkaloids accumulate owing to the topography of the Madurai region where the flowers are harvested. Tamil Nadu holds the second rank for jasmine production in India. In Tamil Nadu, 12,000 hectares are used for jasmine cultivation. Of this, 3,000 hectares are in Madurai, which accounts for 25 percent of total production.

Tamil Nadu Jasmine cultivation:

In terms of the area used for flower cultivation, Tamil Nadu is ranked second among other states. Tamil Nadu has 20,000 hectares of flower agriculture land in which 7800 ha is jasmine. An estimated 60,000 tons of jasmine are grown in Tamil Nadu each year. The deadline for planting is June to November. The flower appears six months after planting, which could happen between March and April. The blooming season for jasmine is from February to April. By the end of August, there will be less flower blooming. Because growing jasmine only produces a good harvest for seven months out of the year, farmers suffer greatly during the remaining months. The March to June is the peak Season and has good yield because of Summer Season, so the cultivation of jasmine is good and the sales for poor price. The October to January is the Lean Season of the jasmine and poor yield because of Monsoon Rain, So the jasmine sales for good price. In July, August, September there is no yield and the quantity is too less. In peak season 4580 per day and in Lean season 2580 per day, the average production of jasmine in TN.

Table 1 Season, Month and Profit of Jasmine

Season	Month	Price	Profit
Peak Season	March to June	Rs 19.67 to 63.14 per 100g	Low profit in May and High profit in March
Lean Season	Oct to Feb	Rs 45 to Rs 108.62 100g	Low profit in Oct and High profit in December
Lean Season 2	July -Sep	Rs 200 to Rs 250 100g	High profit in all three months

Advantages of jasmine cultivation:

- The jasmine flower is well-liked and in great demand, particularly in the cosmetics and perfume sectors. A steady market demand for their goods might be advantageous to small and medium-sized farmers.
- Value-added products like essential oils, fragrances, and scented candles, jasmine growers can expand their business and boost their profit margins. For example, breathing in jasmine oil improved psychological states and brain wave activity.
- Jasmine plants naturally repel pests, fewer artificial pesticides are needed, and healthier, more ecologically friendly farming practices are encouraged.
- In many communities, jasmine is prized for its religious and cultural significance, which maintains a steady demand for it at customary events like weddings and festivals and provides growers with a steady stream of income.

Benefits of Jasmine cultivation:

- Growing jasmine can improve rural livelihoods and foster economic stability by providing small and medium farmers with a reliable source of revenue. For tiny and marginal farm women, jasmine farming has become a viable alternative source of income.
- Growers can hone their horticultural and plant-care skills by cultivating jasmine, which requires specific knowledge and expertise.
- Promoting biodiversity and reducing the need of artificial fertilizers and pesticides, jasmine cultivation can contribute to environmental conservation when done correctly.

- Growing jasmine often involves the entire community, sustaining cultural traditions and fostering social ties.

Export of Loose flowers:

Traditional crops like marigold, jasmine, and similar flowers are traded by weight. Depending on when they are available, the typical cost of certain flowers in large markets varies significantly. Cut flower exports from floriculture are probably going to increase in February. February's demand was higher than that of previous months. Cut flowers are the largest group, accounting for around 72% of the value of exports from floriculture.

The overall value of loose flower exports has grown from US \$7673073 in 1999–2000 to a peak of US \$22853283 in 2013–2014,. It demonstrates that over the course of 15 years, the total value of loose flower exports from India in US dollars has climbed 29 times. The annual growth rate of loose flower exports reached a maximum of 334.55 percent in 2005–2006 and a minimum of -71.59 percent in 2004–2005. It explains why during the course of the study period, India's annual growth rate for loose flower exports has fluctuated. Over the last 15 years, India's loose flower export compound growth rate has barely increased by 7%.

Challenges in Jasmine cultivation:

- The growing of jasmine is climate-sensitive. Extreme temperatures, unforeseen rains, and unpredictable weather patterns can all have a negative impact on harvests, making production difficult.
- Diseases and pests can affect jasmine crops, resulting in decreased yield and quality. It can be difficult to manage pests without using a lot of pesticides, which could degrade flower quality.
- Inadequate post-harvest infrastructure, including transportation, storage, and processing facilities, can result in wastage and lower the overall quality of jasmine in the market
- Demand, supply, and outside economic conditions are some of the variables that can cause price swings in the jasmine market. It could be difficult for farmers to anticipate and adjust to these developments.
- Competition for jasmine comes from various flowers and scents. The market share and demand for jasmine may be impacted by the popularity of substitute flowers or artificial perfumes.

- Limited access to market information and pricing data may hinder farmers' ability to make informed decisions. This can result in difficulties in negotiating fair prices for their produce.
- For the purpose of selling their produce, many farmers might rely on middlemen. This reliance may result in problems like unjust pricing and a lack of control over the distribution procedure.

Policy suggestions:

Jasmine growers face lots of constraints in cultivation and marketing of jasmine, so the following suggestions can help to overcome their difficulties

- The government should fix minimum support price for flower crops to protect the farmers when the market face sudden crash of price
- Increasing the market access to the farmers by providing market facilities and transport facilities
- Price incentives and subsidies can be granted for flower growers to boost flower cultivation in the region
- To increase the export potential, reduce tariff on exports and imports for flower growers to strengthen the flower cultivation.
- Subsidies and grants should be given to set up value adding enterprises like Essential oil extraction units, Concrete and absolute jasmine processing, Dry flowers and natural fragrance products
- Subsidized access to High-yielding and disease-resistant jasmine varieties and Organic manures and bio-pesticides.
- Encourage micro-irrigation (drip systems) with higher subsidy rates for small and marginal farmers.
- Designing and implementing crop insurance scheme especially for floriculture industry.
- Provide seasonal labour support schemes during peak harvesting seasons
- Research and new technologies should be developed for flower plucking to reduce labour shortage.
- Investment in cold-chain logistics to reduce post-harvest losses, Low-interest loans for storage, transport vehicles, and packaging units.

BIOLOGICAL CONTROL OF RICE SHEATH BLIGHT DISEASE CAUSED BY *RHIZOCTONIA SOLANI* KUHN

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¹Sheela J.,* ²Rakini R., ²Sabarinathan K., ³Varshini M., ³Syed Mohamed S., ⁴Rajinimala N
and ⁵C. Kannan

¹Professor & Head, ²B. Sc. (Hons.) Agriculture, ³PG Scholars, ⁴Associate Professor,

⁵Assistant Professor, Department of Plant Pathology, VOC AC & RI, Killikulam,

Thoothukudi district, Tamil Nadu-628252, India

*Corresponding Author : Sheela J

Abstract

Rice (*Oryza sativa* L.) is a major staple crop supporting global food security, particularly in Asia. Among the various diseases affecting rice, sheath blight caused by the soil-borne fungal pathogen *Rhizoctonia solani* Kuhn has emerged as one of the most destructive constraints to rice production, especially under intensive cultivation systems. The pathogen survives in soil and crop residues through sclerotia and possesses a wide host range, making its management difficult using chemical fungicides alone. Continuous reliance on chemicals has led to concerns regarding environmental pollution, pesticide residues, and development of resistance in the pathogen. In this context, biological control has gained importance as a sustainable and eco-friendly alternative for managing rice sheath blight. Biological control involves the use of beneficial microorganisms such as fungi, bacteria, and actinomycetes that suppress the pathogen through mechanisms including competition, antibiosis, mycoparasitism, and induction of host plant resistance. Among fungal antagonists, *Trichoderma* spp. has shown consistent effectiveness against *Rhizoctonia solani*, while bacterial agents such as *Pseudomonas fluorescens* and *Bacillus* spp. have also demonstrated strong antagonistic potential. Application of biocontrol agents through seed treatment, seedling root dip, soil application, and foliar spray provides effective disease suppression when integrated with good agronomic practices. Incorporation of biological control within an Integrated Disease Management framework offers a promising approach for

sustainable management of rice sheath blight while reducing dependence on chemical fungicides and improving soil health.

Introduction

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population and serves as the backbone of food security and rural livelihoods across Asia, particularly in India. The crop is cultivated under diverse agro-ecological conditions in tropical and subtropical regions. However, rice productivity is severely constrained by several biotic stresses, including fungal, bacterial, and viral diseases.

Among these, sheath blight has emerged as one of the most destructive diseases of rice and is considered the second most important fungal disease after blast, especially under intensive, high-input production systems. The disease is caused by the soil-borne fungus *Rhizoctonia solani* Kuhn.

It primarily infects the leaf sheath near the waterline and progressively spreads to upper sheaths, leaf blades, and panicles. The disease initially manifests at the tillering stage as elliptical or irregular greenish-grey spots with brown margins on the leaf sheath, often giving a "snake skin" appearance. Severe infections result in poor grain filling, lodging, and yield losses ranging from 20 to 50 per cent, depending on varietal susceptibility, climatic conditions, and crop management practices.



The widespread cultivation of high-yielding semi-dwarf varieties, excessive application of nitrogenous fertilizers, dense planting, and humid microclimates have significantly increased the incidence and severity of sheath blight in recent years.

Nature of the Pathogen and Challenges in Management

Rhizoctonia solani belongs to the class Basidiomycetes and survives in soil and crop residues through the formation of sclerotia, which are hard, resting structures capable of remaining dormant for several years. The pathogen has a very wide host range, infecting many cultivated crops, which further complicates its management.

Because of its soil-borne nature, persistence through sclerotia, and broad host range, effective management of sheath blight using a single fungicide is difficult. Moreover, continuous and indiscriminate use of chemical fungicides leads to environmental pollution, pesticide residues, and development of resistance in the pathogen. These limitations have shifted research and field-level attention towards eco-friendly and sustainable disease management approaches, particularly biological control.

Concept of Biological Control

Biological control refers to the suppression of plant diseases using living organisms, such as beneficial fungi, bacteria, and actinomycetes, which antagonize plant pathogens either directly or indirectly. Biological control has been defined by several scientists:

“Any condition or practice which reduces the survival or activity of a pathogen through the agency of any other living organism, other than man, resulting in reduced disease incidence” (Garrett, 1970).

Stephen Denis Garrett is regarded as the **Father of Biological Control**.

“Biological control is the reduction of inoculum density or disease-producing activities of a pathogen or parasite in its active or dormant state by one or more organisms, accomplished naturally or through manipulation of the environment, host, or antagonist” (Baker and Cook, 1974).

A simplified definition states that biological control is the reduction of pathogen inoculum or disease activity by organisms other than humans (Cook and Baker, 1983).

Unlike chemical fungicides that kill pathogens instantly, biological control agents act gradually and sustainably through multiple mechanisms.

Mechanisms of Action of Biocontrol Agents

Biological control agents suppress *R. solani* by several mechanism of action such as, Competition for space and nutrients, Production of antifungal metabolites, Mycoparasitism and Induction of systemic resistance and enhancement of host immunity.

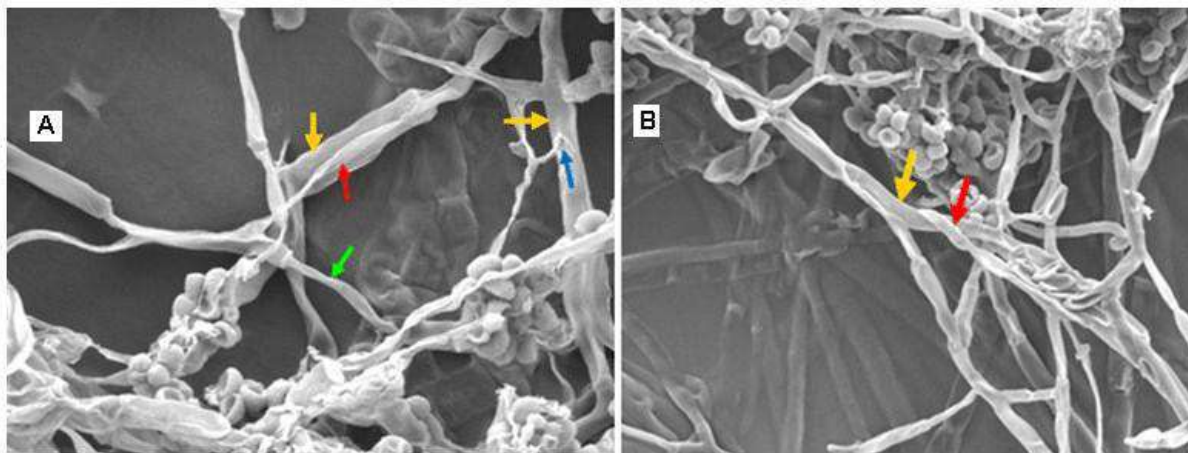
Fungal Biocontrol Agents

Trichoderma spp. – The Frontline Defender

Among the various fungal antagonists, *Trichoderma* species are the most extensively studied and widely used biocontrol agents against *R. solani*. Important species include *Trichoderma harzianum*, *T. viride*, and *T. asperellum*.

Modes of action of *Trichoderma* spp.:

- Mycoparasitism through coiling around pathogen hyphae



- Production of cell wall-degrading enzymes (chitinases, glucanases)
- Secretion of antibiotics and secondary metabolites
- Promotion of plant growth and induction of systemic resistance

Other effective fungal antagonists include *Gliocladium virens* and *Laetisaria arvalis*.

Bacterial Biocontrol Agents

Several beneficial bacteria have shown strong antagonistic activity against rice sheath blight viz., *Pseudomonas fluorescens*, *P. putida*, *Bacillus subtilis*, *Bacillus amyloliquefaciens*, *B. megaterium*, *B. cereus*, *B. polymyxa*, *B. pumilus*, *B. licheniformis*, *Rhizobium radiobacter*, *Serratia marcescens* and *Erwinia herbicola*. Actinomycetes can also be used as biocontrol agents.

Advantages of bacterial biocontrol agents:

- Production of antifungal antibiotics and lipopeptides
- Induction of systemic resistance in rice plants
- Ease of mass multiplication and formulation
- Compatibility with other disease management practices

Other Beneficial Microorganisms

- Actinomycetes such as *Streptomyces griseoviridis* and *S. lydicus* with strong antibiosis
- Endophytic microorganisms that colonize internal plant tissues and provide internal protection against pathogens

Methods of Application of biocontrol agents

Biological control agents are commercially available in TNAU as talc-based formulation and liquid formulations which could be applied through multiple methods:

- **Seed treatment:**

Trichoderma viride @ 4 g kg⁻¹ seed

Pseudomonas fluorescens / *Bacillus subtilis* @ 10 g kg⁻¹ or 10 ml kg⁻¹ seed.

- **Seedling root dip:**

Application involves adding 2.5 kg of a talc-based bacterial formulation (*Pseudomonas fluorescens* / *Bacillus subtilis*) to the stagnated water covering an area of 25 m². Rice seedlings, after being pulled from the nursery, should be immersed in this treated water for root soaking. A minimum soaking period of 30 minutes is essential and longer soaking durations further enhance the efficacy of the treatment.

- **Soil application:**

Trichoderma viride or *Pseudomonas fluorescens* / *Bacillus subtilis* @ 2.5 kg ha⁻¹ mixed with 50 kg well-decomposed FYM and applied 30 days before transplanting.

- **Foliar spray:**

Pseudomonas fluorescens / *Bacillus subtilis* @ 5 g l⁻¹ or 5 ml l⁻¹ during tillering and booting stages

Combined or repeated applications generally provide better and longer-lasting disease suppression.

Advantages of Biological Control

Biological control offers several advantages, as it is environment-friendly and safe to non-target organisms while significantly reducing dependence on chemical fungicides. It helps in improving soil health and enhancing microbial diversity, thereby promoting a more resilient agro-ecosystem. Moreover, biological control is highly compatible with Integrated Disease Management (IDM) strategies and is well suited for organic and natural farming systems.

Biological Control within Integrated Disease Management (IDM)

For effective and sustainable management of sheath blight, biological control agents should be integrated with:

- Use of tolerant or moderately resistant varieties
- Balanced fertilizer application, avoiding excess nitrogen

- Proper plant spacing and water management
- Removal or decomposition of crop residues that harbor sclerotia

Such integration ensures long-term disease suppression rather than short-term control.

Future Prospects

Recent advances in **Nano-biopesticides** are enhancing the efficacy and adoption of biological control strategies. Increased farmer awareness and availability of quality biocontrol products will further strengthen their field-level use.

Conclusion

Biological control offers a promising, eco-friendly, and sustainable approach for managing rice sheath blight caused by *Rhizoctonia solani*. Harnessing beneficial microorganisms not only reduces chemical inputs but also improves soil health and crop resilience. Integrating biological control with sound agronomic practices can pave the way for sustainable and climate-resilient rice production systems.

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EMPOWERING THE GIRL CHILD: SIGNIFICANCE OF NATIONAL GIRL CHILD DAY

Article ID: AG-VO6-I01-65**Rajeshwari Desai*, Geeta Channal**, Sangeeta B D*****

* Senior Scientist, AICRP-WIA, University of Agricultural Sciences, Dharwad-5, Karnataka.

** Professor Dept. of Extension Education & Communication Management, University of Agricultural Sciences, Dharwad-5, Karnataka, India

*** Field Assistant, AICRP-WIA, University of Agricultural Sciences, Dharwad-5, Karnataka.

*Corresponding Author: Rajeshwari Desai

Introduction

National Girl Child Day is observed every year on 24th January in India to raise awareness about the rights, dignity, education, health, and empowerment of the girl child. The day draws national attention to the challenges faced by girls due to gender-based discrimination and social inequalities, while also celebrating their achievements and potential. It emphasizes the importance of providing equal opportunities to girls so that they can grow into confident, healthy, and productive citizens.



In a developing country like India, the empowerment of girls is not merely a social concern but a critical component of sustainable development. Girls constitute nearly half of the population, and neglecting their needs affects not only individual families but also national progress. National Girl Child Day serves as a reminder that investing in girls is essential for building a strong, inclusive, and equitable society.

Historical Background and Need for Observance

National Girl Child Day was initiated in 2008 by the Ministry of Women and Child Development, Government of India. The observance was introduced in response to serious concerns related to the declining child sex ratio, female foeticide, gender discrimination, and unequal access to education and healthcare for girls.

Traditionally, Indian society has been patriarchal, where sons were often preferred over daughters due to cultural norms, inheritance practices, and economic considerations. This preference led to neglect of the girl child even before birth and continued throughout her life in the form of limited education, early marriage, poor nutrition, and restricted decision-making power.

Despite constitutional guarantees of equality and the implementation of several welfare programmes, girls continue to face barriers that prevent them from realizing their full potential. National Girl Child Day was therefore conceptualized as a platform to challenge regressive social attitudes, promote gender equality, and reinforce the value of the girl child in society.

Objectives of National Girl Child Day

The observance of National Girl Child Day aims to achieve the following objectives:

- To create awareness about the importance of the girl child and her rights
- To eliminate gender-based discrimination in education, health, nutrition, and employment
- To promote positive social attitudes towards girls among families and communities
- To encourage education and skill development of girls at all levels
- To prevent harmful practices such as female foeticide, child marriage, and gender-based violence
- To empower girls socially, economically, and politically
- To strengthen the implementation of laws and policies related to women and child welfare

Status of the Girl Child in India

Although India has made significant progress in education, health, and economic development, the girl child still faces multiple challenges that hinder her overall growth and development.

- **Gender Discrimination:** Gender discrimination often begins at birth and continues throughout the life cycle. In some families, girls receive less attention, poorer nutrition, and limited healthcare compared to boys. This unequal treatment affects their physical, cognitive, and emotional development.
- **Education:** While enrolment of girls in primary education has improved due to various government initiatives, dropout rates remain high at the secondary and higher secondary levels.

Poverty, household responsibilities, lack of sanitation facilities, distance to schools, and early marriage are major contributing factors.

- **Health and Nutrition:** Girls are more vulnerable to malnutrition, anemia, and micronutrient deficiencies. Adolescent girls face additional challenges related to menstrual health, reproductive health, and early pregnancy. Poor health during adolescence adversely affects future maternal and child health outcomes.
- **Child Marriage:** Child marriage remains a major social problem in several parts of the country. Early marriage leads to early pregnancy, increased maternal and infant mortality, school dropout, and economic dependency, depriving girls of their childhood and fundamental rights.
- **Safety and Security:** Concerns related to safety, harassment, and violence restrict the mobility and freedom of girls. Fear of insecurity often limits access to education, employment, and social participation, further reinforcing gender inequality.

Importance of Education for the Girl Child

Education is the cornerstone of girl child empowerment. It equips girls with knowledge, skills, confidence, and decision-making abilities. An educated girl is more likely to be aware of her rights, maintain better health and nutrition, marry later, participate in the workforce, and support the education and well-being of her children.

Education has a multiplier effect, benefiting not only the individual girl but also her family, community, and society at large. Promoting education among girls is therefore one of the most effective strategies for breaking the cycle of poverty and inequality.

Health and Nutrition of the Girl Child

Good health and adequate nutrition are essential for the physical and mental development of girls, particularly during critical stages such as infancy, childhood, and adolescence. Adequate nutrition helps prevent stunting, wasting, and anemia, while health education improves hygiene and reproductive health awareness.

Nutrition and health programmes targeting adolescent girls are especially important, as this stage determines future maternal health and the well-being of future generations.

Government Schemes for Empowerment of the Girl Child

These programmes aim to improve survival, education, nutrition, and overall development of girls across the country.

1. Beti Bachao Beti Padhao (BBBP)

Beti Bachao Beti Padhao is a flagship initiative of the Government of India launched in 2015 to address the declining child sex ratio and promote the education and empowerment of the girl child. The scheme focuses on preventing gender-biased sex selection, ensuring survival and protection of the girl child, and encouraging her education. It emphasizes community awareness, behavior change communication, and convergence of efforts from various ministries to improve the status of girls in society.

2. Sukanya Samriddhi Yojana

Sukanya Samriddhi Yojana is a government-backed savings scheme aimed at encouraging parents to build a financial corpus for their daughter's future education and marriage. The scheme allows parents or legal guardians to open an account in the name of a girl child below 10 years of age. It offers attractive interest rates and tax benefits, ensuring long-term financial security for the girl child and promoting a culture of saving for her education and well-being.

3. Kasturba Gandhi Balika Vidyalaya (KGBV)

Kasturba Gandhi Balika Vidyalaya is a scheme that provides residential schooling facilities to girls belonging to disadvantaged groups such as Scheduled Castes, Scheduled Tribes, Other Backward Classes, and minority communities. The scheme aims to improve access to quality education for girls in educationally backward blocks, particularly at the upper primary and secondary levels. It plays a significant role in reducing dropout rates and improving retention of girls in the education system.

4. POSHAN Abhiyaan

POSHAN Abhiyaan (Prime Minister's Overarching Scheme for Holistic Nutrition) is a multi-sectoral nutrition programme aimed at improving the nutritional status of children, adolescent girls, pregnant women, and lactating mothers. The scheme focuses on reducing malnutrition, anemia, and low birth weight through convergence of nutrition-related schemes, community-based interventions, and use of technology for monitoring. It addresses critical nutritional needs of adolescent girls, contributing to better health and future maternal outcomes.

5. Scheme for Adolescent Girls (SAG)

The Scheme for Adolescent Girls aims to improve the nutritional and health status of adolescent girls aged 11–18 years. It focuses on providing supplementary nutrition, health check-

ups, nutrition and health education, life skills training, and vocational guidance. The scheme also promotes awareness on hygiene, reproductive health, and gender equality, enabling adolescent girls to make informed decisions and lead healthy and productive lives.

Role of Family, Community, and Institutions

The empowerment of the girl child requires collective efforts from families, communities, educational institutions, and the media. Parents must provide equal treatment, emotional support, and educational opportunities. Communities and institutions should challenge discriminatory norms and ensure safe and inclusive environments for girls.

Celebration and Activities on National Girl Child Day

National Girl Child Day is celebrated through various activities such as awareness campaigns, seminars, workshops, essay writing and poster competitions, community outreach programmes, and felicitation of girl achievers. These activities help sensitize society and motivate girls to pursue education and leadership roles.

Challenges and the Way Forward

Despite policies and programmes, challenges persist due to deep-rooted social attitudes, poverty, and lack of awareness. Addressing these challenges requires strong implementation of laws, community participation, investment in education and health, and creation of equal opportunities for girls.

Conclusion

National Girl Child Day is a powerful reminder of the importance of valuing and empowering girls. Ensuring equality for the girl child is essential for achieving social justice, economic growth, and sustainable development. When girls are educated, healthy, and empowered, they become catalysts for positive change, contributing to a stronger, more inclusive, and equitable nation.

HEALTH BENEFITS OF BLACK TEA

Article ID: AG-VO6-I01-66**M.Marimuthu**

Krishi Vigyan Kendra, TNAU, Sirugamani, Trichy- 639 115, Tamil Nadu, India

Introduction

India is the largest producer of black tea and hence it is necessary to focus attention on black tea with respect to its health promoting attributes. Black tea is one of the most popular beverages worldwide. Three main types of tea can be produced based on how the leaves of *Camellia sinensis* are processed: Green tea (non-fermented), Oolong tea (partly fermented), and Black tea (fermented). Black tea is commonly consumed in India. Brew prepared from Black tea has a dark brown colour and a sweet aroma. It has stronger flavour than Green and Oolong tea. Black tea without sweeteners or additives contains negligible quantities of calories, protein, sodium and fat. Tea contributes significantly to fluid balance which is vital for physical and mental health. There are numerous scientific evidence showing that black tea can make a significant contribution to a healthy lifestyle.

Constituents of Fresh Tea Leaves

Fresh tea leaves contain approximately 36% polyphenolic compounds, 25% carbohydrates (pectins, glucose, fructose, cellulose), 15% proteins, 6.5% lignin, 5% minerals and trace elements (magnesium, chromium, iron, copper, zinc, sodium, cobalt, potassium, etc.), 4% amino acids (such as theanine [5-N-ethyl-glutamine], glutamic acid, tryptophan, aspartic acid) 2% lipids, 1.5% organic acids, 0.5% chlorophyll as well as carotenoids and ethereal substances below 0.1%, vitamins (B, C, E).⁹ Catechins and other polyphenols have antioxidant properties.¹⁰ They act as chelators and antioxidants under in vitro conditions by sequestering metal ions and by scavenging reactive oxygen and nitrogen species.

Composition of Black Tea

Composition of Black tea solid extract includes: Polyphenolic compounds including catechins in monomeric, dimeric and oligomeric form, other flavonoids (including myricetin,

quercetin and kaempferol, etc.); amino acids (including l-theanine); methylxanthines, carbohydrates, proteins, and minerals.⁹

- Black tea is rich in antioxidants like polyphenols (theaflavins, thearubigins and catechins) that can help prevent several chronic diseases including cancer.
- It keeps one energized it is because of methyl xanthenes.
- It has polyphenols which help protect our cells and DNA against damage.
- Some of the most recent researches have also pointed that antioxidants present in black tea are good for heart health; can lower risks of heart ailments and atherosclerosis (clogging in arteries).
- Regular consumption of black tea is also beneficial to people suffering from diabetes and high blood cholesterol.
- Phytochemicals found in black tea are linked with maintaining healthy bones and prevention of bone related ailments such as osteoporosis.
- Amino acid L-theanine helps in relaxing and enhancing mental concentration .
- It contains alkylamine - an antigen -, that might help in providing natural resistance to microbial infections and perhaps tumors thereby strengthening the immunity.
- More recently, the beneficial properties associated with daily consumption of black tea are getting better recognized.

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IMPACT OF INVASIVE SPECIES IN INDIAN MARINE ECOSYSTEM

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R. Arasi¹, V. Rani² and D. Manimekalai³

^{1,3}Department of Aquatic Environment Management, Fisheries College and Research Institute,
Thoothukudi, 628 008

²Dr.M.C.R. Fisheries College and Research Institute, Thalainayeru, 614712
Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Tamil Nadu, India

*Corresponding Author: R. Arasi

Abstract

The Indian marine ecosystem, encompassing coral reefs, mangroves, estuaries, and open oceans, is highly diverse and ecologically significant. However, it faces growing threats from invasive species introduced through pathways such as ballast water discharge, aquaculture, climate change, and accidental release. Invasive species, unlike exotic species, are non-native organisms that establish, spread rapidly, and cause ecological and economic harm by outcompeting native species, altering habitats, and disrupting ecosystem balance. Case studies such as the invasion of *Kappaphycus alvarezii* on Gulf of Mannar corals and *Mytella strigata* in Tamil Nadu wetlands highlight their detrimental effects on biodiversity and fisheries-dependent livelihoods. Other invasive organisms, including lionfish (*Pterois volitans*), European green crab (*Carcinus maenas*), snowflake coral (*Carijoa riisei*), and barnacles, further exacerbate the problem. India's lack of adoption of the Ballast Water Management Convention increases its vulnerability to marine bioinvasions. Effective management requires integrated strategies including early detection, monitoring, habitat restoration, strict biosecurity measures, public awareness, and regional collaboration. Strengthening policies and implementing sustainable management practices are critical to safeguard marine biodiversity and ensure long-term ecological and economic stability.

Introduction

Indian marine ecosystem - diverse habitats like coral reefs, mangroves, estuaries, and open oceans, is highly productive and ecologically significant (Sharma, 2020). However, the increasing globalization of trade, maritime activities, and climate change has facilitated the movement of non-indigenous species into Indian waters. Invasive species are non-native organisms that cause significant ecological, environmental, or economic harm in their new environments primarily due to human activities such as shipping, aquaculture, and ballast water discharge. These species can be plants, animals, fungi, or even microorganisms, and they often outcompete native species for resources, leading to biodiversity loss and ecosystem disruption. Second largest threat to biodiversity, following habitat degradation and alteration. Out of the 157 species listed by the ZSI, 58 are found on land and in freshwater habitat, while 99 are found in the marine ecosystem. Among invasive marine species, genus *Ascidia* accounts for the maximum number of species (31), followed by *Arthropods* (26), *Annelids* (16), *Cnidarian* (11), *Bryzoans* (6), *Molluscs* (5), *Ctenophora* (3), and *Entoprocta* (1)

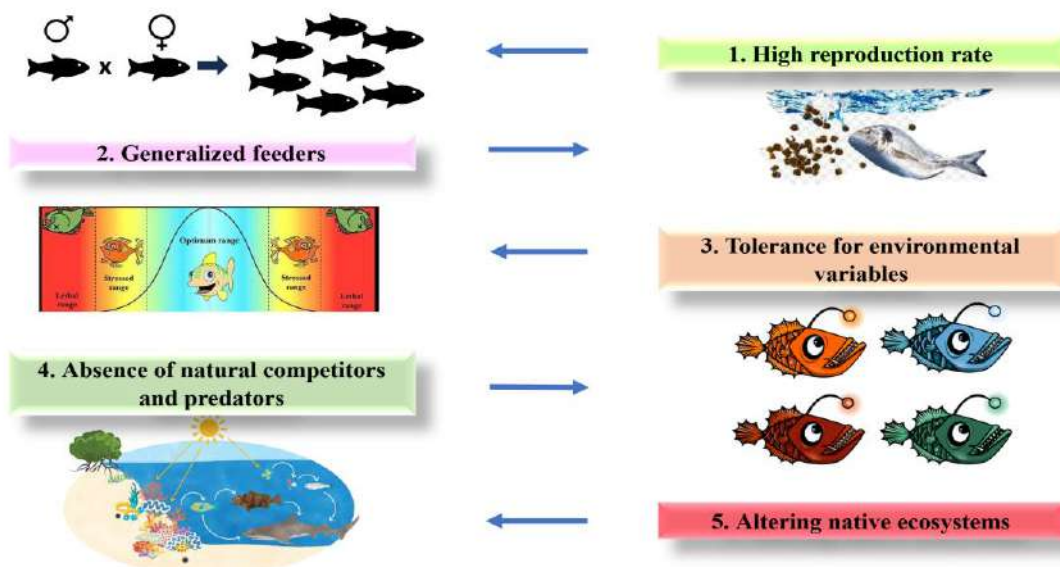
Difference between invasive and exotic species

	Invasive species	Exotic species
Origin	Disrupt the local environment as they are not native to the area	Not native to a specific place but may or may not endanger the local environment.
Impact	Can harm native species and ecosystems by competing for resources and predation.	Exotic species may or may not have a significant impact on native ecosystems, depending on their behavior, reproductive rate
Spread	Can quickly establish populations in new places, outcompeting local species.	Can or cannot spread widely, and their ability to form self-sustaining populations varies.
Management	To prevent ecological	Managed through rules to

	disruption and biodiversity loss	restrict introduction or monitoring programs on native ecosystems.
Regulation	Invasive species face severe rules to prevent importation and control their expansion once established.	Exotic species may be restrictions aimed at preventing potential harm to native ecosystems, but the degree of regulation varies according to the perceived risk.
Example	<i>Pterois volitans</i> (lionfish)	<i>Penaeus vannamei</i>

Characteristics of invasive species:

- **High Rates of Reproduction and Growth:** Several invasive fish species These characteristics enable their populations to grow rapidly and exponentially in a short amount of time. They have an advantage over native species because of this.
- **Generalist Feeders:** The majority of invasive fish are generally generalist feeders, meaning they can survive on a broad range of food sources. This facilitates their emergence and dispersal in novel environments, such as Indian water bodies.
- **Tolerant of a Variety of Environmental Factors:** Wide variations in environmental factors such as salinity, dissolved oxygen, and water temperature are tolerated by invasive species. This facilitates their dispersal throughout India's various aquatic habitats.
- **Absence of Natural Competitors and Predators:** Native American competitors and predators are frequently unable to deal with exotic invasive fish. As a result, their populations explode.
- **Altering Native Ecosystems:** Invasive fish introduce competition for resources, habitat modification, predation, and other factors that affect native fish differences and abundance. It also affects how ecosystems function and how communities are structured



Common invasive species in Indian marine ecosystem:



Pathways of invasion:

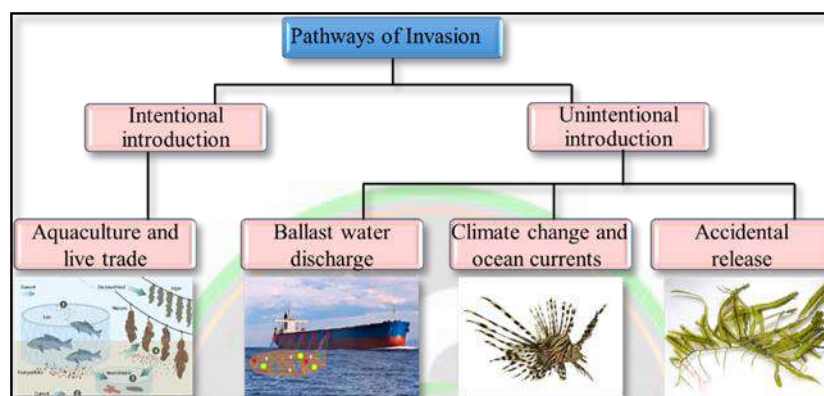
Pathways are the means and routes by which invasive species are introduced into new environments. Pathways can generally be classified as either natural or man-made.

1. Natural pathways include wind, currents (including marine debris), and other forms of natural dispersal that can bring species to a new habitat.

2. Man-made (human assistance) pathways are those which are created or enhanced by human activity. These are characteristically of two types:

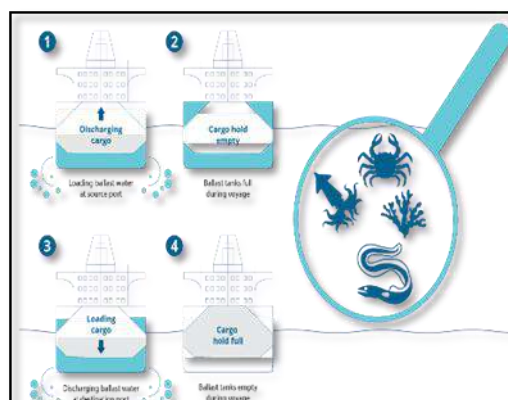
- i. Intentional, which is the result of a deliberate movement of a species by humans outside of its natural range. Examples include the introduction of biological control organisms or the movement of species for the horticultural or pet trade. Intentional introductions as a whole should not be labeled as either good or bad. A specific intentional pathway can only be judged by the positive or negative impact of the specific organisms that are moving along that means.

- ii. Unintentional, which is the inadvertent or accidental movement of species as a byproduct of some other human activity. Examples of unintentional pathways are ballast water discharge (e.g. red-tide organisms), pests and diseases in imported plants, firewood, and other agricultural products (e.g. fire ants), the movement of recreational watercraft (e.g. zebra mussels), and the international movement of people (e.g. pathogens). In these and countless other unintentional pathways, the movement of non-native species is an indirect byproduct of human activities



Ballast water discharge

- * Ballast water discharge severely impacts marine diversity, even more harmful than intentional introductions or natural calamities. Over 80% of global cargo is transferred by ships, carrying about 12 billion tonnes of ballast water annually. **(Indian water portal. com)**. It contains various organisms, from microorganisms to aquatic plants and small animals. Some species survive and adapt to the new environment, becoming invasive over time. These species outcompete native species, disrupt ecological balance, and threaten coastal livelihoods



Climate Change and Ocean Currents

- Rising sea temperatures and shifts in ocean currents allow tropical invasive species, like *Pterois volitans* (lionfish), to expand into many warmed ocean zones and disrupt the native ecosystems
- Lionfish are native to the tropical waters of the western Pacific Ocean and eastern Indian Ocean (Meister *et al.*, 2005)
- Six lionfish reportedly escaped from an aquarium. These escaped individuals reproduced successfully, leading to an invasive population supported by a strong founder effect (Hamner *et al.*, 2007)
- Lionfish compete with commercial fish, affecting the larval recruitment of groupers and snappers, etc.... It not only affect the ecological balance, but it may also impact fisheries
- The free-floating nature of lionfish eggs facilitates their wide dispersal, further contributing to their invasive spread (Freshwater *et al.*, 2009)
- Lionfish in the invasive range can reach populations over five times as large as populations in their native range, thus outnumbering all native fish except for Scamp grouper (*Mycteroperca phenax*) (Arias-González *et al.* 2011)
- Lionfish become more active at higher temperatures (30°C) and feeding rates also increase (Kimball *et al.* 2004)

Accidental release

- ***Caulerpa taxifolia***, also known as "killer algae," is not native to India. It is originally from the tropical waters of the Pacific Ocean, the Indian Ocean, and Caribbean Sea
- The strain of *Caulerpa taxifolia* that has become invasive was initially cultivated for use in aquariums
- The main problem in India is that it can grow quickly, forming dense mats that smother seagrass beds and coral reefs, which are crucial for marine biodiversity
- The presence of this species can lead to a decline in fish populations and negatively impact the overall health of marine environments.
- The accidental release and subsequent establishment of this strain have led to its classification as one of the world's worst invasive species (IUCN database)

European green crab (*Carcinus maenas*)

- European green crab (*Carcinus maenas*) is native to northwestern Europe and Africa.

- It is a widespread invasive species, listed among the 100 of the World's Worst Invasive Species
- Their spread is largely attributed to human activity through increases in the use of live bait, recreational boating, and pet release (Klassen and Locke 2007)
- Climate change is exacerbating the issue, with rising temperatures expected to increase green crab populations
- They threaten coastal ecosystems by destroying eelgrass and shellfish beds, outcompeting native crab species, and through preying on native species.
- Eelgrass provides habitat for invertebrates, waterfowl, seabirds and juvenile fish like pacific herring and salmon
- Economically they pose a threat to shellfish and fishing industries
- It is generalists that feed on a variety of shellfish and other invertebrates. They are known to outcompete native crabs for food and habitat and could pose a serious threat to many other marine species (Klassen and Locke 2007)

Snowflake coral (*Carijoa riisei*)

- *Carijoa riisei* was first reported on 10 May 2009 from the Kundol region of Nicobar Islands by the Zoological Survey of India (ZSI)
- It was subsequently found in **10 islands** (Keelakari and Vembar group) of the Gulf of Mannar Marine National Park area (Padmakumar et al., 2011)
- This coral can establish its colony on a variety of substratum including metal, concrete, plastic, rope and shipwrecks apart from the native corals (Patro et al., 2015)
- It pose a threat to native biodiversity by causing degeneration of coralreefs (Venkataraman et al., 2013)
- It is worth to mention here that the ZSI in collaboration with Andaman and Nicobar Administration, has set up 10 permanent monitoring plots in the major reef areas to continuously monitor the changes in the coral reef ecosystem (Raghunathan et al., 2013)

Invading Barnacles

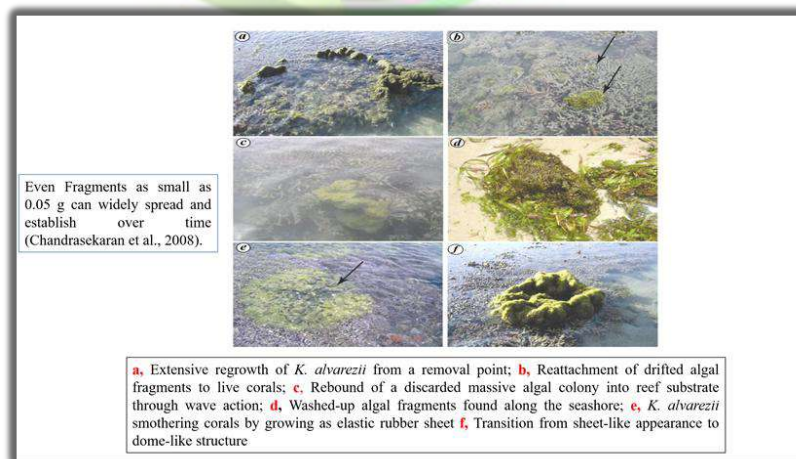
- Barnacles are marine crustaceans that attach to hard surfaces and are spread mainly through shipping and aquaculture
- The warm waters and high nutrient levels in the harbour provide ideal conditions for barnacle growth and reproduction.

- Their presence can cause damage to boats and other structures in the harbour, as well as increase the risk of fouling
- Common species of barnacle causes fouling include *Lepas anserifera*, *Amphibalanus amphitrite*, and *Amphibalanus* sp
- Also, it may introduce invasive species, spread diseases and alter environmental conditions
- This can lead to economic losses and affect local livelihoods

Case studies:

Case study 1: Impact of *Kappaphycus alvarezii* on Indian corals

- *Kappaphycus alvarezii* is a commercially important red macroalga that is widely cultivated around the world. Species are often introduced for aquaculture but escape into local reef ecosystems become invasive and smothering native coral species.
- A native to the Philippines, it has been introduced in more than 30 countries for commercial cultivation. Due to its high plasticity, it is capable of rapid growth and quick biomass increase even after removal, and this is the main reason for its invasiveness.
- It was introduced in GoM in the 1990s with the intention of commercial cultivation. At the time of introduction, the possible damages to corals were not realized. Over time, this species invaded the coral reefs of kurusadi, and smothered native corals, leading to their degradation. Despite its harmful impact, its invasion was overlooked by policymakers due to its high commercial value.



It triggers a decline in the density and diversity of native fish and brings down the species richness and abundance of native macroalgae, coral and other benthic macrofauna

Case study 2: Impact of *Mytella strigata*

- Charru mussels (*Mytella strigata*) are invasive species native to South America locally known as Kakka Aazhi, has become a significant problem in Tamil Nadu, particularly in the Ennore and Pulicat wetlands
- The spread of this species is largely attributed to ballast water discharge from ships, which is not adequately regulated
- The invasion has already affected 11 out of 52 fishing sites in 2015, but the problem began to intensify significantly after the Vardah cyclone in 2016. By 2021, the infestation had spread over two kilometers, but over the past year, it has expanded rapidly, turning into a severe threat
- This invasion has severely impacted local fisheries, especially shrimp fishing, as the mussels have altered the sediment composition, making it difficult for shrimps to thrive in this condition. It also attach to boats and docks and hinder the movement of fishing boats, affecting the livelihoods of local fishermen
- The **National Institute of Ocean Technology (NIOT)** has proposed using chemical methods to control the invasive charru mussel (*Mytella strigata*), particularly in Tamil Nadu's Ennore and Pulicat regions. Collaborative research by Dr. MGR. Fisheries College and Research Institute and Tamil Nadu Dr. J.Jayalalitha Fisheries University has documented the extent of the invasion and its impacts

Laws regulating movement of ballast water**Global regulations**

- * The Ballast Water Management (BWM) Convention started in 2017. It aims to prevent the spread of harmful aquatic organisms and pathogens through ships' ballast water
- * New ships must treat ballast water with chemicals to remove harmful organisms. Older ships must exchange ballast water with clean ocean water during their journey
- * Australia, which frequently handles ballast water due to its role as a major raw material supplier, conducts rigorous checks on ships, especially near sensitive areas like the Great Barrier Reef, to prevent ecological damage

Situation in India

- * As of July 2024, 97 countries have signed the BWM Convention but India is not among them. So, ships at Indian ports aren't required to follow ballast water rules.

- * While Indian ports check for oil pollution, but not for ballast water
- * This could pose a **risk to marine ecosystems** around Indian ports due to possible spread of **invasive species or pathogens**

Control measures for invasive species

i) Restoration of Native Habitats

- Rehabilitate degraded ecosystems like coral reefs and mangroves to strengthen native species resilience.
- Promote marine protected areas (MPAs) to conserve biodiversity hotspots.

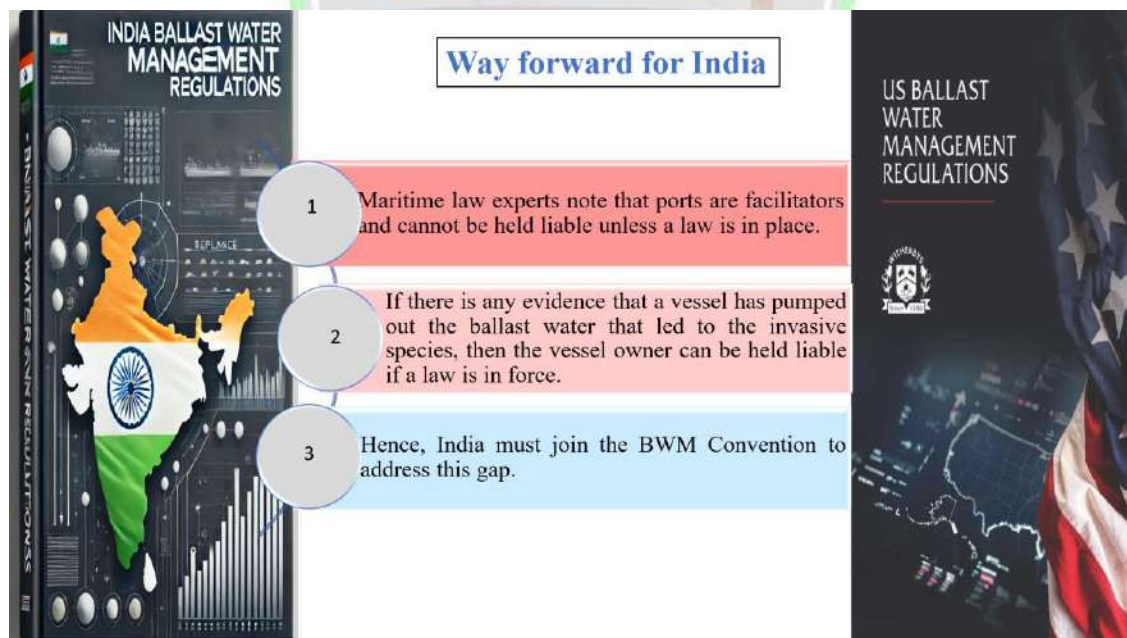
ii) Collaborative Efforts

- Regional cooperation among Indian Ocean countries to monitor and control the spread of invasive species.
- Share knowledge, tools, and technologies to combat marine invasions effectively.

iii) Early Detection and Monitoring

- Regular surveys and monitoring using molecular tools to identify invasive species early.
- Use of citizen science platforms to report sightings.

Way forward for india



iv) Eradication and Management

- Physical removal: For species like *Caulerpa taxifolia*, manual removal can help control spread.

- Biological control: Introduce natural predators or pathogens under controlled conditions (e.g., sea urchins for invasive algae).
- Chemical control: Use herbicides or pesticides judiciously to manage invasive plants or invertebrates.

v) Public Awareness and Community Involvement

- Educate local communities, fishers, and aquaculturists about invasive species and their impacts.
- Promote responsible practices, such as not releasing aquarium species into the wild.

Conclusion

- Invasive species are a big problem for Indian marine ecosystem, harming our native plants and animals
- Ships carrying ballast water are a major way these species get introduced and hurt the fishing industry
- India needs better rules to control invasive species and stop them from spreading
- Effective management through strict biosecurity measures, public awareness, early detection, and policy enforcement is essential. Protecting marine biodiversity requires urgent, coordinated action to ensure ecological balance and long-term sustainability

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ROLE OF BIOTECHNOLOGY AND RNA INTERFERENCE IN PEST MANAGEMENT

Article ID: AG-VO6-I01-68**Ramar Rajendran**

B.Sc.(Hons.) Agri, Dr. M.S.Swaminathan Agricultural College and Research Institute, TNAU,
Eachangkottai, Thanjavur, Tamil Nadu, India

Abstract

Instead of chemical pesticides, use biotechnological approach has emerged as a new era in pest management. RNA interference (RNAi) is a revolutionary pest management approach utilizing double-stranded RNA (dsRNA) to specifically silence essential genes in target insects. The dsRNA, once internalized, triggers the degradation of complementary mRNA, preventing the production of vital proteins and leading to pest mortality or sterility. This method offers unparalleled species-specificity, greatly reducing harm to beneficial organisms and the environment compared to conventional chemicals.

Keywords: RNA interference, Agrobacterium, Dicer, RISC, Pest management

Introduction:

The biotechnological approach is a vital component of integrated pest management worldwide (Kos et al. 2009). It has been developed to generate insect-resistant crops for reducing both yield loss and pesticide utilization (Christou et al. 2006). The first genetically modified plant was produced in 1983, using an antibiotic-resistant tobacco plant. The first genetically modified food approved for release was the Flavr Savr tomato in 1994.

The increasing limitations of conventional chemical insecticides, including the rapid development of pest resistance, negative environmental impacts, and threats to non-target organisms and human health, necessitate the development of novel, highly specific, and sustainable pest management strategies. RNA interference (RNAi), a natural biological process of sequence-specific gene silencing, has emerged as a revolutionary and promising technology for controlling agricultural insect pests.

Central dogma of life



Replication

DNA produce double standard DNA molecules. RNA produce single standard molecule (ssRNA) , but sometimes it produce double standard molecules (dsRNA). The double standard RNA molecules react with Dicer (RNase III) produce,

siRNA(small interference RNA) shRNA(small hair pin RNA) miRNA (micro RNA)

Any one of these RNA react with protein (Slicer and Agronaut) to form a RISC (RNA -Induced Silencing Complex)

RNA Interference in Tobacco nematode management

RNA interference (RNAi) is a powerful, highly specific, and sustainable biotechnological method used to protect tobacco plants from the devastating root-knot nematode, *Meloidogyne incognita*. The process, also known as Host-Induced Gene Silencing (HIGS), leverages the plant's genome to produce the gene-silencing trigger that is then ingested by the parasitic nematode.

1. Selection of Target Gene

The first crucial step is to identify a nematode gene that is essential for parasitism, survival, or reproduction (e.g., genes involved in chitin biosynthesis, esophageal gland secretion, or neuropeptide signaling like Mi-flp genes). The DNA sequence of this target gene from the nematode is required for the subsequent steps.

2. Engineering the Plant Construct

A piece of DNA corresponding to the target nematode gene is designed to produce a double-stranded RNA (dsRNA) molecule within the plant cell.

This is typically achieved by creating a hairpin RNA (hpRNA) construct, where the target gene sequence is inserted twice—once in the sense orientation and once in the antisense orientation—separated by a short spacer sequence.

3. Transgenic Plant Development (Transformation)

The hpRNA construct is introduced into the tobacco plant genome, often using the bacterium

Agrobacterium tumefaciens as a natural delivery vector.

The transformed plant cells are regenerated into whole transgenic tobacco plants that possess the nematode-specific gene construct.

1. dsRNA Production in Plant Cells

When the transgenic tobacco plant grows, the integrated gene construct is transcribed within the plant cells (particularly in the roots) to produce the single-stranded hpRNA.

Due to the complementary sense and antisense sequences, the hpRNA spontaneously folds back on itself to form a double-stranded RNA (dsRNA) molecule

2. Ingestion by Nematode

When the infective juvenile stage (J₂) of the nematode, *M. incognita*, feeds on the roots of the transgenic tobacco plant, it ingests the plant cellular contents, including the nematode-specific dsRNA.

3. Activation of Nematode RNAi Pathway

Once the dsRNA enters the nematode's digestive system and then spreads into its cells, it is recognized as a foreign molecule.

The nematode's natural RNAi machinery, including the Dicer enzyme, cleaves the long dsRNA into shorter, 21–25 nucleotide fragments called small interfering RNAs (siRNAs)

4. Gene Silencing and Resistance

The siRNAs are incorporated into the RNA-Induced Silencing Complex (RISC).

The RISC, guided by the siRNA, binds to the native mRNA of the essential nematode gene (the target).

The Argonaute enzyme within the RISC complex cleaves and degrades the target mRNA, preventing its translation into a functional protein.

The “knockdown” or silencing of this essential gene disrupts the nematode's development, feeding, or reproduction, leading to reduced infectivity, lower egg mass production, and ultimately, effective resistance in the tobacco plant.

Merits

1. High Specificity and Safety

Targeted Action: RNAi is sequence-specific, meaning the dsRNA must be perfectly complementary to the target gene's mRNA. This allows scientists to precisely target essential

genes found only in the pest species (e.g., an insect or nematode) and not in other organisms.

Safety for Non-Targets: This high specificity minimizes adverse effects on beneficial insects (like pollinators and natural enemies), livestock, humans, and other non-target organisms, leading to a much safer ecological profile than broad-spectrum chemicals.

Environmental Benefit: The dsRNA molecules are biodegradable and break down naturally in the environment, reducing long-term environmental accumulation and contamination issues associated with persistent chemical residues.

2. Overcoming Pest Resistance

Novel Mode of Action (MoA): RNAi introduces a fundamentally new mechanism for pest control that is distinct from existing chemical classes. This makes it effective against insect and nematode populations that have already developed resistance to conventional insecticides.

Targeting Essential Genes: By targeting genes critical for basic survival, development, or reproduction, RNAi provides a powerful mechanism that pests are less likely to rapidly overcome through minor genetic mutations.

3. Flexibility and Delivery Options

Versatile Delivery: RNAi can be applied using different methods, enhancing its utility in various agricultural settings:

Host-Induced Gene Silencing (HIGS): Genetically modified (GM) crops express the dsRNA directly in their tissues, providing built-in resistance against pests that feed on the plant (e.g., root-knot nematodes and certain crop-feeding insects).

Exogenous Application: DsRNA can be formulated as a topical spray that is ingested by chewing or sucking insects, allowing for flexible, targeted application similar to conventional pesticides.

4. Reduced Chemical Load and Residues

The implementation of RNAi-based control can significantly reduce the reliance on synthetic chemical insecticides, leading to lower volumes of hazardous materials used on crops.

The absence of persistent chemical residues on harvested produce is a major health and trade advantage.

Conclusion:

RNAi is poised to become an essential tool in integrated pest management (IPM) strategies. While its efficacy has been demonstrated against key agricultural pests (like the Western corn rootworm), its widespread adoption depends on technological advancements in

delivery (e.g., nanotechnology, spray-based formulations) and a deeper understanding of the insect's immune response to dsRNA. Continued research and innovation are essential to overcome existing biological and technical constraints, solidifying RNAi's role in a safer, more sustainable agricultural future.

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AGRI FOOD TOURISM: SHOWCASING LOCAL FOOD SYSTEM

Article ID: AG-VO6-I01-69***¹Bhavana. K. S, ²Dr. Sahana. S, and ³Hariharasudhan. S**¹PG Scholar, ²Professor and Head, ³PG Scholar¹Department of Agricultural Extension Education, ¹KSNUAHS, Iruvakki, Shivammoga, Karnataka, India.***Corresponding Author Email ID: Bhavana. K. S**

I. INTRODUCTION

Agritourism is considered as one of the well-known tourism strategies adopted by many farming communities in rural areas to stimulate their local socio-economic conditions by diversifying agriculture into touristic activities and events (Bachok *et al.*, 2019). Some of the common agriculture based tourism activities are food tourism, farm tours, fruit picking, farm dining and farm stay experience, typically done within an agricultural site such as a working or non-working farm located in the rural areas (Tew and Barbieri, 2012). Agri food tourism could be one of the avenues for the local food system (LFS) to flourish as it can provide additional source of income for farmers, market outlet for local food and as a potential space to connect consumers with their local farmers and food sources.

1.1 THE CONCEPT OF LOCAL FOOD SYSTEM(LFS)

LFS is defined as “foods that are produced, processed and retailed within a defined geographical area” Where “the local is always experienced and understood in relation to larger geographical scales, such as the regional, national or global”, even if “where the local area ends and another scale begins is subjective, depending on context (density of populations, accessibility and rural or urban character) and purpose” (Kneafsey *et al.*, 2013). This means local is the smallest unit used to describe the origin of food and a consumer is at least personally familiar with the place where the food is produced and would recognize a difference between the terms “local” and “regional” when describing the origin of food.

The definition of LFS, therefore, includes spatial distances and personal relationships between the various stages of the food supply chain as well as restrictions to a geographic region in which all activities of the food supply chain from agricultural food production to consumption are located within the same geographic region. This includes the sourcing of agricultural raw material inputs, which will likely reduce the number of intermediary stages in the food supply chain between agricultural food production and consumption. Promoting LFS aims to create more direct links between producers and consumers, aiding sustainability through shorter distances, fewer intermediaries and less industrial processing (Pole and Gray, 2013).

An important dimension of LFS is the presence of short food supply chains (SFSC). The shortening of the supply chain may be interpreted from three different points of view i.e., the reduction of the physical distance between the farmer and final consumer, the reduction of the number of steps that connect the farmer to final consumers and finally, the increase of cultural and social proximity between farmers and consumers. SFSCs aim at reducing the “distance” between agriculture and final consumption, directly re-connecting farmers to consumers and contributing towards the sustainability of food systems.

There are two types of SFSC, namely, direct to consumer (DTC) and direct to retail (DTR). DTC selling arrangements are usually face to face between producers and buyers. It can be in the form of one-off sales with an immediate exchange at current prices. DTR chains, on the other hand, are normally based on formal contracts and do not involve face to face interactions between producers and consumers. Some instances of DTR includes sales through consumer owned food retail cooperatives, local independent retailers (including online retailers), restaurants, caterers and institutions such as schools and hospitals.

Local food production has the capability to generate and support local employment, revitalize local livelihoods, strengthen regional economics and enhance cultural heritage (Hincrichs, 2003). However, conventional agricultural production still dominates the global agri-food system due to economics of scale, agglomeration of profits and bargaining power over LFS. Local food conveys meanings which are strong enough to potentially detach consumers from conventional food networks and attach them to alternative food networks whose impact is more sustainable, equitable and healthy”.

1.2 AGRI FOOD TOURISM AND ITS POTENTIAL CONTRIBUTION TO LOCAL FOOD SYSTEM

Agri food tourism is a functional strategy to improve the economic conditions of local farmers and food producers that goes ‘beyond the boundaries of the economic sphere with a growing emphasis on the exploitation of natural resources and landscape, as well as rediscovery of tangible and intangible resources. This chapter highlights two important contributions of agro-food tourism towards LFS, namely, improving the economic resilience of farms and its implication on heritage construction.

2. AGRO-FOOD TOURISM IN INDIA

In India, agriculture not only sustains the economy but also shapes its rich food heritage. The concept of combining agriculture with tourism gained momentum in 2004 with the Baramati Agri Tourism Center in Maharashtra. Building on this foundation, the Agri-Tourism Development Corporation (ATDC) has since collaborated with hundreds of farmers to establish tourism centers, gradually expanding across states such as Maharashtra, Kerala, Karnataka, Gujarat, Punjab, Haryana and Nagaland. In recent years, farmers have struggled to secure fair prices for their produce, highlighting the need for diversified income streams. **Agro-food tourism** has emerged as a promising solution, offering direct markets for local food, experiential dining and cultural immersion. Notably, the sector is projected to grow rapidly, with estimates indicating a compound annual growth rate (CAGR) of nearly 20.00 per cent during 2023–2028.

The benefits of agro-food tourism are wide-ranging. Economically, it provides supplementary income for farmers, creates rural employment and strengthens local food markets by linking producers directly with consumers. Socially and culturally, it preserves culinary traditions, revives indigenous recipes and fosters cultural exchange between rural and urban communities. Educationally, it exposes visitors to farming methods, food systems, nutrition and sustainable practices. From an environmental perspective, it encourages organic farming, reduces food miles and promotes responsible consumption. In terms of tourism growth, agro-food tourism helps diversify India’s tourism portfolio, reduces pressure on overcrowded urban destinations and promotes regional food products such as spices, fruits, dairy and handicrafts related to food culture.

3. BASIC PRINCIPLES OF AGRI-TOURISM

Agro-food tourism in India encompasses a wide range of activities that appeal to both urban and rural visitors. It offers authentic farm to table dining experiences, culinary trails, cooking demonstrations, food festivals and opportunities to engage with indigenous food

traditions. It offers a chance to escape the stress of urban life, allowing travelers to enjoy both the serenity of rural landscapes and the freshness of traditional foods.

3.1. **Havesomething for visitors to seesuch** as farms, animals, birdsand natural landscapes. In addition, rural culture, traditional dress, festivalsand village games can also spark curiosity and interest among tourists.

3.2. **Have something for visitors to do** activities like participating in farming operations, swimming, bullock cart or camel rides, buffalo rides, cooking local foodand playing rural games allow visitors to actively engage and enjoy themselves.

3.3. **Havesomething for visitors to buy** rural handicrafts, dress materials, farmfresh produceand processed foods provide tourists with memorable souvenirs while also supporting the local economy.

3.4. Showcasing local food systems

3.4.1 FarmtoTable Experiences:Visitors enjoy meals prepared with fresh, locally grown and harvested produce, creating a direct link between farming and dining.

3.4.2 Food Trails and Festivals:Organized tours and events highlight regional specialties such as fruits, spices, winesand traditional recipes.

3.4.3 Demonstrations and Workshops:Activities like pick-your-own fruits, cooking classes with local ingredientsand millet-based recipe workshops (especially popular in Karnataka).

3.4.4 Cultural Integration:Food is connected with folklore, rituals, festivals, and heritage practices, allowing visitors to experience cuisine as part of the local culture and identity.

4. MODELS OF AGRI-FOOD TOURISM IN INDIA

4.1Farm based Tourism:

- Baramati Agri Tourism Centre (Maharashtra): India's first organized agri-tourism model, offering farm stays, bullock cart rides and authentic Maharashtrian meals.
- Punjab Farm Tourism: Wheat and paddy farms near Amritsar attract international tourists seeking "Punjab da pind" experiences with makki di roti and sarson da saag.

4.2Food trails:

- Goa's Feni Trail: Introducing tourists to cashew orchards, distillation and tasting of the local spirit.

4.3Festivals and celebrations:

- Hornbill festival (Nagaland): Combines tribal food with cultural performances.

- International Mango Festival (Delhi): Showcasing the mango varieties.

4.4 Tea and Coffee Tourism:

- Assam and Darjeeling Tea Estates: Colonial era bungalows converted into homestays for tourists.
- Coorg coffee trails (Karnataka): Plantation tours, bean to cup workshops and kodava cuisine.

5. Case Examples from India:

5.1 Spice Routes, Kerala: Tourists walk through plantations and learn about Ayurveda, spice trade history and Keralite cuisine.

5.2 Millet cafes (Karnataka and Telangana): Restaurants and food festivals highlight local grains, encouraging both nutrition awareness and Agri-tourism.

5.3 Punjab Farm Tourism council: Promotes rural hospitality by combining Punjabi cuisine with folk dances, festival and farm experiences.

5.4 Baramati, Maharashtra: Over 100 farmer families are linked with the Agri Tourism Development Corporation (ATDC), offering authentic farm food tourism experiences.

6. Challenges and Constraints in Developing Agri-Food Tourism in India

6.1 Infrastructure Issues

In many parts of Maharashtra and Karnataka, farmers have started small-scale agro-tourism centers, but poor road access and lack of transport facilities often discourage tourists from visiting remote villages.

Example: In rural parts of Coorg (Karnataka), homestays face cancellations during monsoons due to bad road conditions and limited connectivity.

6.2 Limited Marketing Knowledge

Farmers running centers like Baramati Agri-Tourism in Maharashtra reported difficulties in the early years because they relied only on word-of-mouth publicity. Without digital platforms, reaching urban tourists was a big challenge.

6.3 Seasonality

Agro-tourism is often tied to harvest seasons or festivals. For instance, mango farms in Ratnagiri (Maharashtra) attract tourists mainly during summer, while other times see very few visitors.

Similarly, coffee harvest in Coorg or spice tours in Kerala peak only in specific months, limiting year-round income.

6.4 Need for Government & Private Support

Although states like Maharashtra and Kerala have dedicated agro-tourism policies, in many states there is no structured financial or training support.

Farmers in Punjab and Haryana have shown interest in opening agro-tourism farms, but lack of subsidies and training in hospitality has slowed progress.

7. Agritourism Opportunities in India

7.1 Economic Opportunities:

Agritourism offers significant economic benefits, providing supplementary income for farmers and rural communities. It helps buffer the uncertainties of traditional agriculture and enhances rural economies. Yang (2012) suggests that agritourism can contribute to the economic regeneration of rural areas with limited development options. Barbieri (2003) highlights its potential to generate revenue, enhance local economies, create employment opportunities, and stimulate local businesses. Broccardo (2017) discusses various opportunities presented by agritourism, including income enhancement, economic diversification, and seasonal fluctuation mitigation.

7.2 Diverse Experiences and Cultural Preservation:

Ramappa *et al.* (2022) emphasize agritourism's range of experiences, from hands-on farm activities to cultural immersions. It offers tourists opportunities to participate in local festivals, enjoy traditional cuisine, and appreciate rural life.

7.3 Sustainable Tourism

Agritourism aligns with sustainable tourism principles, promoting conservation and organic practices. It encourages sustainable farming and contributes to biodiversity conservation (Mastronardi *et al.*, 2015; Pinto *et al.*, 2017).

7.4 Market Diversification

Agritourism provides rural communities with direct access to urban markets, reducing dependence on intermediaries and fostering market diversification (Ammirato *et al.*, 2020).

7.5 Rural-Urban Linkage

By bridging rural and urban areas, agritourism promotes understanding and collaboration between communities, fostering appreciation for rural lifestyles among urban tourists.

7.6 Education and Awareness Agritourism

Educates urban visitors about agriculture, food production, and sustainability, promoting agricultural literacy and bridging the gap between rural and urban populations (Das and Rainey, 2010).

7.7 Culinary Tourism Agritourism offers farm-to-table experiences, allowing tourists to savor locally sourced organic cuisine, catering to the growing trend of culinary tourism.

7.8 Skill Development, Innovation, and Entrepreneurship Agritourism creates job opportunities for rural youths, encourages innovation, and fosters entrepreneurship among rural communities (Lupi *et al.*, 2017).

8. Future Prospects of Agro-Tourism

The future of agro-tourism in India appears promising with several emerging opportunities. There is growing scope for integration with eco-tourism and wellness tourism, as visitors increasingly seek sustainable and holistic experiences. Digital platforms such as virtual food trails, online booking apps and social media marketing can help farmers and rural entrepreneurs reach a wider audience. Strong policy support for branding regional foods, such as GI-tagged products (e.g., Dharwad Peda, Coorg Orange, Mysore Pak), can further boost the appeal of rural destinations. Additionally, agro-tourism presents significant opportunities for youth and women entrepreneurs, creating employment while reducing migration from villages to cities.

Conclusion

Agro-tourism is more than just an extension of agriculture; it is a celebration of food, culture, sustainability and rural development. By combining authentic rural experiences with modern tourism trends, it can provide economic benefits for farmers while offering visitors unique insights into India's agricultural heritage. With the right mix of policy support, digital innovation and community participation, India and particularly Karnataka has the potential to position itself as a global destination for authentic agri-food experiences.

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WATER: THE CHEAPEST AND MOST EFFECTIVE MEDICINE FOR DAIRY ANIMALS

Article ID: AG-VO6-I01-70***Dr. A. Singaravadivelan, Dr. A. Paramasivam, Dr. C. Mehala, Dr. R. Nithiaselvi**

Veterinary College and Research Institute, TANUVAS, Orathanadu – 614 625, Tamil Nadu

*Corresponding Author: Dr. A. Singaravadivelan

Introduction

Walk into any dairy farm, and you'll find farmers meticulously calculating feed rations, monitoring protein levels and investing thousands in nutritional supplements. Yet ask about water management and you'll often get a shrug. "Water? We just make sure the troughs are full." This casual attitude toward water represents one of the costliest oversights in modern dairy farming.

The scientific evidence is unequivocal: water is not just another nutrient—it's the foundation upon which all other nutrients work. Unlike expensive feed additives or supplements, water is readily available and inexpensive, yet its impact on productivity rivals or exceeds that of far more costly interventions. Research consistently demonstrates that proper water management can increase milk production by 7-30%, prevent numerous health problems and deliver economic returns that make it the single best investment a dairy farmer can make.

By highlighting practical, research backed approaches, this article shows how simple changes in water management can deliver big benefits for both animals and farmers. From smallholder dairy farms to large commercial operations, adopting these strategies can turn water into a strategic resource, boosting milk production, enhancing animal health and improving overall farm profitability.

2. The Science Behind Water's Critical Role

To understand why water deserves to be called "medicine," we need to appreciate its fundamental biological roles. Water isn't simply a beverage—it's the medium in which all life processes occur.

Essential Biological Functions

Water performs multiple critical functions in dairy cattle:

Nutrient Transport and Metabolism: Every nutrient absorbed from feed must be dissolved in water to reach cells throughout the body. Water carries amino acids, glucose, minerals and vitamins through the bloodstream to tissues where they're needed. Without adequate water, even the most expensive feed rations cannot deliver their full nutritional value.

Waste Removal: Metabolic processes generate waste products that must be eliminated. Water dissolves these wastes and carries them through the kidneys for excretion. Insufficient water intake leads to waste accumulation, creating toxic conditions that impair health and performance.

Temperature Regulation: Dairy cows generate enormous amounts of metabolic heat, especially high producing animals. Water is essential for thermoregulation through evaporative cooling (sweating and panting) and heat dissipation through the bloodstream. During heat stress, water requirements can increase by 50% or more.

Milk Synthesis: Perhaps most importantly for dairy farmers, milk is 87% water. Every liter of milk produced requires approximately 2.6 litres of water. This direct relationship means that water availability immediately and directly impacts milk production—there's no way around this biological reality.

Digestive Function: The rumen, that remarkable fermentation vat that allows cattle to convert grass into milk, requires substantial water to function properly. Water maintains the fluid environment necessary for microbial fermentation, nutrient absorption and feed particle movement through the digestive tract.

The Cascade Effect of Water Deprivation

When water intake decreases, a cascade of negative effects follows. Research shows that even modest water restriction triggers multiple problems simultaneously:

- **Reduced feed intake:** Cattle instinctively reduce dry matter consumption when water is limited, as they cannot process feed without adequate water
- **Decreased milk production:** Both the direct effect (less water for milk synthesis) and indirect effect (reduced feed intake) combine to lower yields
- **Impaired nutrient digestion:** Digestive efficiency drops, meaning cattle extract less nutrition from the same amount of feed

- **Compromised immune function:** Dehydration stresses the immune system, increasing disease susceptibility
- **Altered behavior:** Water deprived cattle become stressed, which further impairs production and health

Understanding these interconnected effects helps explain why water management delivers such dramatic returns—it's not addressing just one problem, but preventing an entire cascade of issues.

3. How Much Water Do Dairy Animals Really Need?

One of the most common questions from dairy farmers is: "How much water should my cows be drinking?" The answer is more complex than a single number, as water requirements vary based on multiple factors.

Daily Water Requirements

Research provides clear guidelines for different categories of dairy cattle:

Lactating cows:

- 28 litres of water per day for maintenance
- Additionally, 1.26 litre of water for each 0.5kg of milk produced

Dry Cows:

- 40- 45 litres per day
- Approximately one third the intake of lactating cows, reflecting their lower metabolic demands

Young Stock and Replacements:

- Calves (30 kg): Minimum 3 litres per day (10% of body weight)
- Growing heifers: 30-35 litres per day depending on size and growth rate

Factors Affecting Water Intake

Water consumption isn't static—it varies based on several key factors that farmers must understand to ensure adequate provision:

Milk Production Level: The relationship is direct and predictable. Research shows that water intake increases by approximately 2.52 litres for every additional kilogram of milk produced. A cow producing 15 kg of milk daily requires about 38 kg (litres) of water. This means your highest producers need the most attention to water provision.

Dry Matter Intake: For every kilogram of dry matter consumed, cows need approximately 4.1 litres of water. This relationship is so consistent that you can predict water needs based on feed consumption. When dry matter content in the diet decreases from 50% to 30%, water consumption can drop by 42%, highlighting the importance of diet moisture content.

Environmental Temperature: Heat dramatically increases water requirements. As ambient temperature rises, cows need more water for thermoregulation. During heat stress (Temperature Humidity Index above 78), water requirements can increase by 50% or more. The negative impact of poor water quality on milk yield becomes 1.3 times steeper under heat stress conditions.

Lactation Stage: Early lactation cows have the highest water demands, as they're producing maximum milk while also recovering from calving. Water intake peaks around 60-90 days into lactation, coinciding with peak milk production.

Individual Animal Factors: Breed, body weight, age and social rank all influence water intake.

4. Water Quality: When Good Water Goes Bad

Adequate water quantity alone is not enough. Poor water quality silently reduces feed intake, milk yield, fertility and animal health, often going unnoticed until major losses occur.

Key Water Quality Parameters

1. Total Dissolved Solids (TDS) – the most important indicator

- < 1,000 ppm: Excellent, no effects
- 1,000–3,000 ppm: Safe for livestock
- 3,000–5,000 ppm: Reduced intake and performance
- > 5,000 ppm: Diarrhea, lower milk yield
- > 7,000 ppm: Severe health risk

Above 3,000 ppm, water intake drops by 8–10% and milk yield falls by ~0.6 L/cow/day per 1,000 ppm increase, causing heavy economic losses in large herds.

2. pH

- Optimal: 6.0–8.0
- < 6.0: Acidic—risk of metabolic imbalance
- 8.5: Poor palatability, mineral interference

3. Nitrates

- Safe: < 100 mg/L

- Danger: > 133 mg/L
- Toxic: > 220 mg/L

Nitrates convert to nitrites in the rumen, reducing oxygen delivery and may cause sudden deaths.

4. Sulfates

- Safe: < 500 mg/L
- > 1,000 mg/L: Reduced intake, milk yield, retained placenta
- > 1,500 mg/L: Risk of neurological disorders

5. Fluoride

- Safe: < 1.0 mg/L
- > 1.5 mg/L: Reduced milk fat, lameness, infertility

Milk fat declines by 0.12% for every 1 mg/L increase above safe limits.

6. Microbial Contamination

- Safe: < 1 coliform/100 mL
- Unsafe: > 10 coliforms/100 mL

Contaminated water increases diarrhea and mastitis risk, especially during monsoon.

7. Water Temperature:

Water temperature significantly affects both palatability and physiological function:

- Optimal: 15-17°C - Maximizes intake and milk production
- Acceptable: Up to 26.7°C - Slight reduction in intake
- Problem: Above 28°C - Significant reduction in consumption
- Cold: Below 7°C - Can cause digestive upset and reduced intake

5. The Direct Link Between Water and Milk Production

Water directly affects milk yield, yet many farms underestimate its importance. Even short periods of restricted access can reduce water intake, milk yield and milk fat. Continuous, clean and freely available water is essential for sustaining production.

- ❖ Restricting water to once or twice daily can drop milk production by 1–2%.
- ❖ High TDS, nitrates or fluoride in water can silently reduce milk output over time.
- ❖ Milk is nearly 87% water, so inadequate intake limits milk synthesis.
- ❖ Water shortages also reduce feed intake, rumen efficiency and metabolic performance.
- ❖ High producing cows need extra water to match increased milk output.

6. Water as Preventive Medicine: Protecting Health and Performance

Digestive Health: Adequate and clean water is essential for proper digestion in dairy animals. The rumen works like a living fermentation chamber and requires sufficient water to maintain normal pH, smooth feed movement and healthy microbial activity. When water intake is low or water quality is poor, rumen function is disturbed, leading to acidosis, bloat, poor digestion and reduced feed efficiency.

Metabolic Health: Water plays a vital role in maintaining metabolic balance, especially during early lactation and around calving. Dehydration worsens negative energy balance and increases the risk of metabolic disorders such as ketosis, milk fever, displaced abomasum and fatty liver. Adequate water intake supports calcium metabolism, liver function and normal digestion, helping animals pass smoothly through the transition period with better feed intake and productivity.

Reproductive Performance: Reproductive efficiency is closely linked to both water quality and availability. Poor quality water containing excess salts or fluoride reduces fertility, increases retained placenta and affects fetal development and calf health. Even mild dehydration interferes with hormone function and reduces visible heat signs, delaying conception.

Disease Resistance: Adequate hydration strengthens the animal's immune system, while dehydration weakens disease resistance. Clean drinking water reduces exposure to disease causing organisms and lowers the incidence of mastitis, diarrhoea and respiratory infections. Contaminated water significantly increases mastitis risk, making water hygiene one of the simplest and most effective disease prevention strategies.

7. Practical Management Strategies for Dairy Farmers

- ❖ Provide continuous (24-hour) access to drinking water for all animals.
- ❖ Place water troughs in open and easily reachable areas, close to feeding and resting places.
- ❖ Ensure enough number of water troughs to avoid crowding and competition.
- ❖ Water should refill quickly; slow filling leads to hidden water shortage and milk loss.
- ❖ Never restrict water, even for a short time, as it immediately reduces feed intake and milk yield.
- ❖ Drinking water must be clean, fresh and palatable at all times.
- ❖ Avoid water with bad smell, excess salts or microbial contamination.

- ❖ Clean water troughs regularly, especially during summer, to prevent algae and dirt.
- ❖ Provide cool and shaded water sources during hot weather to improve intake and reduce heat stress.
- ❖ Prevent water from becoming too cold in winter, as it can disturb digestion.
- ❖ Supplying clean water at a comfortable temperature is one of the cheapest and most effective ways to improve animal health and milk production.

8. Special Attention Needed During Heat Stress Periods

Heat stress is one of the most serious challenges in dairy farming, especially during summer months. When temperature and humidity rise, dairy animals struggle to regulate their body heat, resulting in reduced feed intake, lower milk yield and increased health problems. High producing cows and buffaloes are particularly vulnerable because they generate more internal heat. During such periods, water becomes the most effective and immediate tool to protect animals from heat stress and sustain productivity.

Key Water Management Practices During Heat Stress:

- Water requirement increases by 50% or more during hot weather.
- Provide uninterrupted, round the clock access to clean drinking water.
- Ensure adequate number of water troughs with fast refill rates to avoid competition.
- Supply cool, clean and fresh water to encourage higher intake.
- Keep water troughs under shade and clean them frequently during summer.
- Use water based cooling methods such as sprinklers, soakers or misters, preferably along with fans.

Proper attention to water management during heat stress periods helps reduce animal discomfort, prevents production losses and improves overall dairy farm profitability.

9. Drought and Water Scarcity Management

In regions facing water scarcity or drought, efficient water management is critical for the survival and sustainability of dairy farming. Drinking water for animals must always receive the highest priority, as it directly influences health, milk production and survival. Farmers should ensure uninterrupted access to drinking water, promptly repair leaks and use well designed water troughs to avoid wastage. Regular monitoring of water intake also helps detect hidden issues such as blocked pipelines, poor flow rates or early signs of illness in animals.

Key Water Saving Practices During Drought:

- Never compromise drinking water for dairy animals.
- Repair leaks and broken pipelines immediately.
- Use properly designed troughs to reduce spillage.
- Observe daily water intake to identify problems early.
- Reuse water from milk cooling, shed washing or equipment cleaning for irrigation or floor cleaning.
- Adopt efficient, low volume cleaning methods in sheds.
- Maintain equipment regularly to prevent water loss.
- Select low water requiring fodder crops and improve irrigation efficiency.

10. Future-Proofing Your Dairy Operation through Smart Water Management

Preparing for Climate Change: Water management will be one of the most important factors for sustainable dairy farming in the future. Climate change is increasing the frequency of heat waves, droughts and irregular rainfall, all of which raise water demand and reduce availability. Farmers will also face stricter water use regulations. By investing in water storage, developing multiple water sources and adopting water saving practices now, farms can remain resilient during extreme conditions and regulatory changes.

Using Technology and Automation: Modern technology is transforming how water is managed on dairy farms. Automated systems can track water intake, detect quality problems early and alert farmers before losses occur. Precision water delivery including well designed troughs, automated cleaning and temperature-controlled water reduces wastage while improving animal comfort. Data based monitoring helps predict water needs, detect early signs of health issues and optimize overall farm efficiency.

Conclusion

Water is the cheapest yet most powerful input in dairy production. Scientific evidence consistently shows that adequate quantity, quality and continuous access to water directly increase milk yield, improve reproductive performance, reduce disease incidence and enhance animal welfare. With milk being largely water, even small restrictions or quality issues immediately translate into production losses, while proper water provision acts as both a productivity booster and a preventive health measure—far more effective and economical than many therapeutic interventions.



The economic benefits of effective water management are undeniable. Improvements in access, cleanliness, temperature and quality typically repay their costs within weeks, yielding exceptionally high returns through higher milk output, better growth in calves, lower veterinary expenses and improved heat stress resilience. From young stock to high yielding cows, all animals benefit, especially under hot conditions where water becomes the primary defense. In contrast, neglecting water management imposes daily hidden losses, making inaction far more expensive than timely correction.



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REINVENTING TRADITION: CRISPR-CAS ENABLED ENHANCEMENT OF HIGH-YIELDING INDIGENOUS CROP VARIETIES IN INDIA

Article ID: AG-VO6-I01-71***Sivadharsini Devaraj¹ and Santhosh Suryanarayanan²**

¹ICAR-Indian Institute of Agricultural Biotechnology, Ring Road, Garhkhatanga,
Ranchi, Jharkhand (834 003), India

² School of Commerce and Economics, Loyola College, (Autonomous), Chennai- 600034, India

*Corresponding Author: Sivadharsini Devaraj

Abstract

India stands at the threshold of an agricultural revolution powered by genome editing technology. The CRISPR-Cas system represents a paradigm shift in crop improvement, offering unprecedented precision and speed in developing high-yielding varieties from traditional germplasm. This article examines the application of CRISPR-Cas systems in enhancing traditional crop varieties—particularly rice, wheat, and maize—to address food security, climate resilience, and sustainable agricultural development in India. Through targeted genome editing, scientists have achieved remarkable improvements: 42.6% increase in rice grain yield through OsGS2 editing, 143.8% enhancement in drought tolerance via OsDREB1A modification, and 105% improvement in salt resistance in maize edited with ZmNHX1. With India's recent regulatory approval of genome-edited rice varieties (DRR Rice 100 "Kamla" and Pusa DST Rice 1) in January 2026, this technology promises to revolutionize agricultural productivity while maintaining sustainability and public acceptance.

Keywords: CRISPR- Cas9, improved traditional varieties, genome editing, high yield

1. Introduction

Global agricultural systems are facing unprecedented challenges from climate change, expanding populations, and limited arable land. The United Nations projects that the global population will reach 9.7 billion by 2050, necessitating a 70% increase in food production. India, despite being among the world's largest agricultural producers, struggles to feed its 1.4 billion

inhabitants adequately.

The CRISPR-Cas system, derived from bacterial immune mechanisms, has emerged as a revolutionary tool that fundamentally transforms crop improvement strategies currently. Unlike conventional genetic modification techniques that introduce exogenous DNA and require prolonged regulatory scrutiny, CRISPR-Cas enables precise, targeted edits at specific genomic locations without permanently altering the organism's genetic background.

This article explores the multifaceted applications of CRISPR-Cas technology in enhancing traditional crop varieties—particularly those most critical to Indian agriculture and food security.

2. Understanding CRISPR-Cas Technology: Mechanisms and Advantages

2.1 Molecular Mechanisms and System Architecture

The CRISPR-Cas system comprises two key molecular components: the Cas protein (an endonuclease enzyme) and the guide RNA, which directs the Cas protein to specific genomic sequences. The CRISPR-Cas9 variant, derived from the bacterium *Streptococcus pyogenes*, represents the most extensively studied and applied system in agricultural genomics. The mechanism operates through precise three-step process: first, the guide RNA-Cas9 complex scans the plant genome for target sequences; second, upon recognition of the protospacer adjacent motif (PAM) sequence, the Cas9 protein unwinds the DNA double helix; third, the enzyme introduces a double-strand break at the exact target location.

The induced DNA break triggers endogenous repair mechanisms within the plant cell. Non-homologous end joining (NHEJ), the predominant repair pathway, frequently introduces small insertions or deletions (indels) that disrupt gene function. This approach, categorized as SDN-1 (Site Directed Nuclease-1), produces mutations that could theoretically occur through conventional mutagenesis or natural variation, thereby achieving regulatory acceptance in countries like India. Alternative editing approaches, including Cas12a variants offer enhanced precision and expanded targeting capabilities, enabling modifications previously thought impossible.

2.2 Comparative Advantages Over Traditional Breeding and GM Approaches

The advantages of CRISPR-Cas technology in agricultural applications are multifaceted. Traditional breeding, while maintaining genetic diversity and public acceptance, requires extensive time investments spanning multiple generations and remains constrained by reproductive biology and linkage drag—the unwanted inheritance of undesirable traits linked to

desired ones. Conversely, CRISPR-Cas enables heritable modifications in single plant generations, reducing breeding cycles from 10-15 years to 3-5 years.

CRISPR-Cas products, particularly those employing SDN-1 and SDN-2 approaches, contain no exogenous DNA sequences and are indistinguishable from naturally occurring mutations. This distinction proved crucial in India's 2022 regulatory decision exempting SDN-1 and SDN-2 products from the Environment Protection Act's genetically modified organism restrictions[25].

The cost-effectiveness of CRISPR-Cas technology merits emphasis. While initial genome editing costs exceeded \$10,000 per event in the early 2010s, contemporary protocols cost less than \$500, democratizing access to this technology across institutional and national boundaries. This affordability is particularly significant for developing nations like India, enabling indigenous research institutions to conduct advanced crop improvement research without expensive international partnerships.

3. Strategic Gene Targets for Yield Enhancement in Traditional Varieties

3.1 Grain Development and Size Modification

The fundamental thing governing crop yield involves grain number, grain weight, and harvest index. Through CRISPR-Cas9 technology, OsGS2 gene in rice (encodes glutamine synthetase, plays a critical role in nitrogen assimilation and grain filling), expression is enhanced in the Samba Mahsuri variety—a traditional Indian rice cultivar—resulted in a documented 42.6% increase in grain yield. This enhancement manifests through improved nitrogen use efficiency, enabling farmers to maintain productivity while reducing nitrogen fertilizer applications by 30-40%.

Another example, Gn1a gene (encoding cytokinin oxidase 2) Cas12a-mediated editing of the Gn1a locus in Samba Mahsuri rice increased cytokinin concentration in developing panicles, resulting in 19% yield improvement and accelerated maturation by up to 20 days, particularly advantageous in climate-variable regions. Parallel research in wheat identified the *TaQ* gene, modification of which enhanced grain size and weight, contributing to overall yield improvements of 30-38%.

3.2 Photosynthetic Efficiency and Biomass Accumulation

An emerging frontier in CRISPR-based crop improvement involves enhancing photosynthetic efficiency, the fundamental process converting solar radiation into biomass. The

OsSXX1 gene, recently identified through functional genomics approaches, encodes a sucrose transporter critical for carbohydrate distribution in rice tissues. CRISPR editing enhanced the expression of *OsSXX1*, improving translocation of photosynthates to developing grains and increasing grain yield by 25-32%.

These photosynthetic enhancements are particularly valuable for climate adaptation, as improved photosynthetic efficiency partially compensates for water stress and nutrient limitations encountered under adverse environmental conditions.

3.3 Nutrient Use Efficiency and Sustainable Agriculture

The *OsAPL* gene, involved in nucleotide metabolism and nutrient sensing, represents a crucial target for enhancing nutrient use efficiency. CRISPR-edited rice varieties with modified *OsAPL* expression demonstrate 28-35% improvements in nitrogen use efficiency, translating to reduced fertilizer requirements without yield penalties. This advancement addresses twin agricultural challenges: reducing input costs for resource-limited farmers and minimizing environmental impacts from excess nitrogen runoff and greenhouse gas emissions.

Similar approaches targeting phosphate transporters (*OsPT*) and potassium-responsive genes have enhanced efficient nutrient uptake and translocation. These modifications prove especially significant in Indian agricultural contexts, where soil nutrient depletion and fertilizer costs represent critical constraints limiting productivity across smallholder farms.

4. Climate Resilience

4.1 Drought Tolerance Enhancement

Drought represents the most significant abiotic stress limiting agricultural productivity across South Asia. The *OsDREB1A* gene, encoding a dehydration-responsive element binding factor, activates transcriptional cascades essential for drought stress responses. CRISPR-mediated enhancement of *OsDREB1A* expression in rice varieties achieved a remarkable 143.8% improvement in drought tolerance, enabling yield maintenance even during extended dry periods. Field trials of these edited varieties in semi-arid regions of Rajasthan and Maharashtra demonstrated comparable yields to irrigated controls even with 40-50% reduced water availability.

The mechanism underlying this enhancement involves upregulation of genes encoding osmoprotectants, antioxidant enzymes, and root system architecture modifications that enhance water uptake efficiency.

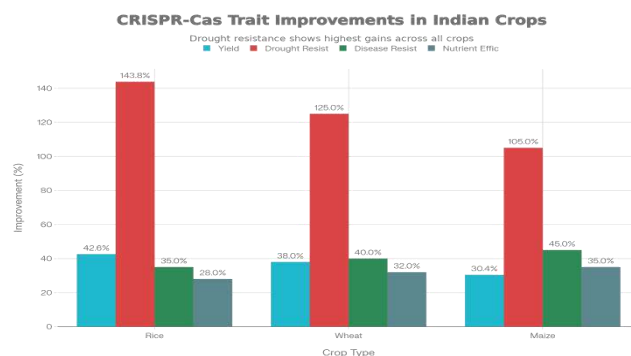


Fig. 1. CRISPR- Cas Trait Improvements in Indian Crops (Drought resistance shows gains across all crops - rice , wheat and maize)

4.2 Salt Tolerance and Saline Soil Adaptation

India's agricultural regions increasingly face soil salinization, affecting approximately 8.5 million hectares of cultivated land. The *ZmNHX1* gene, encoding a sodium-hydrogen antiporter, regulates sodium compartmentalization in vacuoles, preventing toxic sodium accumulation in photosynthetically active tissues. CRISPR editing of *ZmNHX1* in maize, with parallel modifications in wheat, achieved a 105% improvement in salt tolerance. Edited varieties maintained 80-90% of normal yield even when cultivated in soils with electrical conductivity exceeding 8 dS/m, compared to 30-40% yield retention in unedited controls.

These developments are transformative for coastal regions and command areas affected by saline groundwater, potentially bringing millions of hectares of currently unproductive land into productive cultivation.

5. Disease Resistance: Strategy for Biotic Stress Management

Plant-pathogenic bacteria and fungi cause approximately 15-20% crop losses annually in India, with certain diseases destroying entire harvests under favorable conditions. The *R* genes encoding resistance proteins initiate hypersensitive responses to pathogen perception. Editing the *OsXA21* gene enhanced recognition of *Xanthomonas oryzae* pv. *oryzae*, the causal agent of bacterial leaf blight affecting over 2 million hectares annually in India.

Traditional introgression of these resistance genes from wild relatives requires 8-12 generations of backcrossing, often introducing undesired traits. CRISPR editing achieves similar or superior resistance levels in single generations, preserving the genetic background of high-yielding varieties.

6. Regulatory Framework and Public Acceptance in India

6.1 India's Progressive Regulatory Approach

India's regulatory framework governing genome-edited crops represents a balanced approach recognizing scientific reality while maintaining biosafety oversight. In April 2022, the Ministry of Environment, Forest & Climate Change exempted SDN-1 and SDN-2 products from comprehensive biosafety assessment requirements, transferring regulatory jurisdiction from the Genetic Engineering Appraisal Committee (GEAC) to the Institutional Biosafety Committee, which simply confirms the absence of exogenous DNA. This streamlined pathway reduces approval timelines from 8-10 years to approximately 2-3 years.

The landmark January 2026 approval of DRR Rice 100 (Kamla) and Pusa DST Rice 1 developed using CRISPR-Cas12a editing of the *OsCKX2* gene, exhibited no foreign DNA and demonstrated safety equivalent to conventional breeding. This precedent accelerates approvals for additional varieties currently in advanced field trials, including salt-tolerant MTU-1010 and drought-resistant Basmati variants.

6.2 Public Perception and Consumer Acceptance

Distinguishing CRISPR products from transgenic crops proves essential for public acceptance in India, where public opposition to genetically modified crops significantly impeded Bt Brinjal commercialization. The critical distinction—CRISPR products contain no permanent foreign DNA, while transgenic crops retain exogenous genes indefinitely—resonates with informed publics. Agricultural economist surveys indicate 72-78% public acceptance of CRISPR-edited crops with clearly demonstrated benefits for yields, affordability, and environmental sustainability.

Farmer perception studies conducted across rice-growing regions of Punjab, Odisha, and Tamil Nadu showed 65-75% acceptance of CRISPR-edited varieties, particularly when associated with reduced fertilizer requirements and improved climate resilience.

7. Case Studies: Demonstrable Impact on Traditional Varieties

7.1 Samba Mahsuri Rice Enhancement Programme

Samba Mahsuri, cultivated across 8.5 million hectares of South Indian rice fields, represents the quintessential example of a traditional high-quality, medium-grain rice variety with excellent culinary characteristics. Despite these advantages, moderate yields (4.5-5.2 tons/hectare) and sensitivity to drought limit farmer profitability. CRISPR editing targeting the

Gn1a locus increased grain number per panicle by 25-32%, while simultaneous OsDREB1A enhancement improved drought tolerance by 144%. Field trials across three rainy seasons (2023-2025) demonstrated that the edited Samba Mahsuri variety achieved 5.9-6.3 tons/hectare productivity while requiring 40% less irrigation, with grain quality parameters remaining unchanged. Farmer-participatory trials indicated 82% adoption intention among pilot participants.

7.2 MTU-1010 Salt-Tolerant Rice Development

MTU-1010, India's most widely cultivated long-grain rice variety, occupies 12 million hectares primarily in coastal regions and command areas produce inferior grain quality and lower yield due to soil salinization. Recognizing this constraint, researchers applied CRISPR-Cas9 to edit the NHX1 gene in MTU-1010, maintaining its agronomic superiority while conferring salt tolerance. Modified MTU-1010 varieties, field-tested in coastal Odisha and Gujarat, retained 85-90% productivity even in soils with electrical conductivity of 8-10 dS/m, compared to 35-40% retention in control plants. This advancement opens approximately 2.3 million hectares of currently unproductive saline soils to cultivating India's most preferred

8. Future Perspectives: Beyond Simple Trait Enhancement

8.1 Multiplexing and Stacked Traits

The next frontier in CRISPR-based crop improvement involves simultaneously editing multiple genes to stack beneficial traits—enhanced yield combined with drought tolerance, disease resistance, and improved nutritional content. Proof-of-concept demonstrations in rice have successfully pyramided five simultaneously edited loci affecting yield, drought tolerance, and disease resistance.

8.2 Nutritional Biofortification

Iron-deficiency anemia affects 53% of Indian women and 33% of children, frequently resulting from inadequate micronutrient intake. CRISPR editing of rice genes controlling iron translocation and bioavailability could increase grain iron concentration by 3-5 fold. Similarly, vitamin A biofortification through editing pathway-regulating genes offers potential solutions to vitamin deficiency diseases affecting millions.

9. Challenges and Mitigation Strategies

9.1 Technical Challenges

Off-target mutations—unintended edits at genomic regions with sequence similarity to

targets—represent the primary technical concern. High-fidelity Cas9 variants and validated design algorithms reduce off-target frequencies to <0.1%, acceptable for regulatory purposes.

9.2 Regulatory and Acceptance Challenges

Despite progress, inconsistent global regulatory frameworks complicate international seed trade and research collaboration. Some countries maintain requirements treating CRISPR products equivalently to transgenic crops, despite scientific consensus distinguishing their risk profiles. India's progressive approach positions it as a model for harmonized, evidence-based regulation.

Conclusion

Traditional Indian crop varieties—developed through centuries of farmer selection and cultural integration—possess immense genetic diversity and adaptation. CRISPR technology enables preserving these valuable genetic backgrounds while introducing targeted, high-impact improvements in yield, stress tolerance, and nutritional content. Unlike complete variety replacement, genome editing enhances familiar varieties, likely facilitating farmer adoption and integration into existing agricultural systems. The convergence of compelling scientific evidence, supportive regulatory frameworks, demonstrated field-level benefits, and alignment with farmer priorities suggests that CRISPR-improved traditional varieties will become prominent components of India's agricultural landscape within the next 5-10 years. India stands positioned to leverage CRISPR-Cas technology to fundamentally enhance agricultural sustainability and productivity, exemplifying how developing nations can harness cutting-edge biotechnology for inclusive development and food security.

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CROP YIELD GAP IN INDIAN AGRICULTURE: CONCEPT, MAGNITUDE, CAUSES AND IMPLICATIONS

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Nanda K. P.^{1*} and Makvana S. R.²

^{1*}Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh 362001, Gujarat, India.

²Junior Fellow, National Innovation Foundation - India, Gandhinagar 382650, Gujarat, India.

*Corresponding Author: Nanda K. P

1. Introduction

Indian agriculture is currently at a critical juncture. Rapid population growth, increasing per capita food consumption and evolving dietary preferences are placing unprecedented pressure on agricultural production systems. Simultaneously, the availability of cultivable land is steadily declining due to urbanization, industrial expansion, infrastructure development and progressive environmental degradation. Under these conditions, future food security in India cannot depend on expanding agricultural land but must rely primarily on increasing productivity per unit area. This fundamental constraint makes the analysis of unrealized yield potential within existing farming systems particularly important.

This situation reflects a broader global challenge. Projections summarized by Lobell, Cassman and Field indicate that global cereal demand for food and animal feed is expected to reach approximately **2.8 billion tonnes per year by 2030**, representing an increase of nearly **50% compared to the year 2000** (Lobell *et al.*, 2009). Meeting this demand through cropland expansion would require large scale conversion of forests and grasslands, leading to severe biodiversity loss, increased greenhouse gas emissions and longterm environmental instability. Consequently, enhancing yields on existing farmland has become a central objective of both national and global agricultural strategies.

The Green Revolution of the mid to late twentieth century demonstrated the effectiveness of yield based growth in addressing food shortages. The widespread adoption of high yielding

wheat and rice varieties, coupled with irrigation development, increased fertilizer use, mechanization and strong public sector investment in agricultural research, resulted in substantial increases in food production in India and other developing countries. Importantly, these gains were achieved largely without expanding cultivated area, highlighting the power of productivity led growth (Lobell *et al.*, 2009). However, recent evidence suggests that yield growth rates for major cereals have slowed or plateaued in several regions, including South Asia, raising serious concerns about the future capacity of agriculture to meet rising demand.

This renewed concern has shifted scientific and policy attention toward understanding why average farm yields remain significantly below what is biologically achievable. In this context, the concept of the **crop yield gap**, defined as the difference between potential yield and actual farm yield, has emerged as a central analytical framework for diagnosing productivity constraints and identifying opportunities for sustainable intensification.

2. Concept and Definition of Crop Yield Gap

The crop yield gap is defined as the difference between the **yield potential** of a crop and the **average yield achieved by farmers under actual field conditions**. Yield potential is rigorously defined as the yield of an adapted crop variety or hybrid grown under optimal agronomic management, without limitations from nutrients, water, pests or diseases and is primarily determined by solar radiation, temperature and crop physiological characteristics (Lobell *et al.*, 2009).

Fischer (2014) further refined yield related terminology by distinguishing among **potential yield (PY)**, **water limited potential yield (PY_w)**, **actual farm yield (FY)** and **economic yield**. He emphasized that yield gap refers specifically to the difference between PY (or PY_w in rainfed systems) and FY under the same environmental conditions. This distinction is critical because it establishes yield gap as a system level outcome rather than a direct indicator of varietal performance.

In irrigated systems, yield potential assumes an adequate water supply throughout the crop growth period, whereas in rainfed systems, water limited yield potential is a more appropriate benchmark due to frequent seasonal or episodic water stress. In both cases, yield potential is location specific and influenced by climate, cropping system context, sowing time and cultivar duration, but it remains independent of farmers' actual management decisions (van Ittersum *et al.*, 2013).

Importantly, yield gap analysis does not imply that farmers should or can realistically achieve 100% of yield potential. As emphasized by Lobell *et al.* (2009), yields approaching **80-85% of potential** already represent highly optimized systems and further gains become increasingly constrained by climatic uncertainty and economic risk. Thus, the yield gap concept is best understood as a diagnostic tool for identifying **exploitable yield gaps** rather than as an idealized production target.

3. Methods Used to Estimate Yield Gaps

Estimating yield gaps requires robust assessment of yield potential, which can be achieved through several methodological approaches. These include crop simulation models, controlled field experiments, boundary yield functions derived from top performing farms and farmer based yield distributions. Each method produces different estimates of yield potential, leading to variability in reported yield gap magnitudes.

Model based approaches generally generate the highest estimates of yield potential because they assume near ideal growing conditions and rely on mechanistic representations of crop growth processes. Experiment based approaches use yields from research stations or well managed field trials, while farmer based approaches often define attainable yield using the upper percentiles (commonly the 90th or 95th percentile) of observed farm yields (Lobell *et al.*, 2009). Lobell *et al.* demonstrated that yield gap estimates typically follow the relationship:

$$\text{Farmer-based} \leq \text{Experiment-based} \leq \text{Model-based}$$

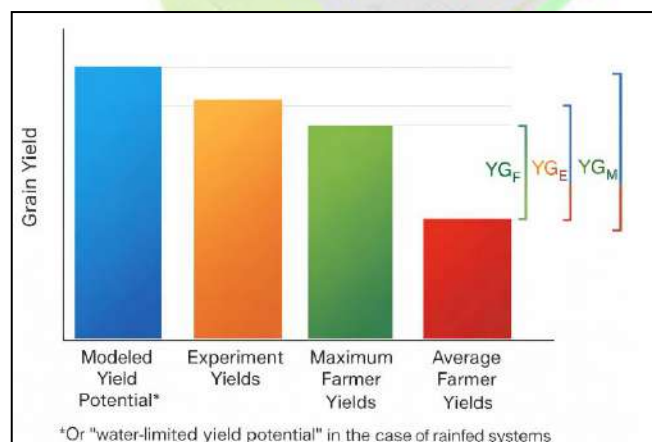


Fig. 1. Conceptual framework showing the relative magnitude of model based yield potential, experimental yield, maximum farmer yield and average farmer yield and the corresponding definitions of yield gaps. Adapted from Lobell *et al.* (2009).

This pattern highlights the strong influence of methodological choice on yield gap magnitude. van Ittersum *et al.* (2013) further emphasized the importance of transparent, spatially explicit and agronomically relevant protocols to ensure meaningful comparison of yield gap estimates across crops, regions and scales.

In the Indian context, yield gap estimates vary widely depending on the estimation method, crop type and agro ecological zone. Studies cited by Lobell *et al.* and Aggarwal *et al.* report substantial differences between simulated potential yields and farmer yields for crops such as wheat, rice, maize and sorghum, reflecting both methodological uncertainty and genuine heterogeneity in production environments.

4. Magnitude of Yield Gaps Across Crops and Regions

Global syntheses indicate that yield gaps differ widely across crops, regions and production systems. In highly intensified and irrigated systems such as wheat and rice systems in northwest India, Japan and parts of China average yields commonly reach **70-80% of yield potential**, suggesting relatively narrow exploitable yield gaps (Lobell *et al.*, 2009). In contrast, rainfed systems, particularly in tropical and semi arid regions, often achieve only **20-50% of yield potential**, indicating substantial unrealized production capacity.

Lobell *et al.* reported that average yields in rainfed cereal systems frequently remain below 50% of yield potential, whereas irrigated systems rarely exceed 80% of potential yield on a sustained basis. These patterns are consistent across major cereals, including rice, wheat and maize and reflect fundamental differences in water availability, management intensity and climatic risk.

Table 1. Average yield gap estimates for selected crops in India computed using simulated yield potential, experimental yield potential and on farm yield benchmarks. Data compiled from Lobell *et al.* (2009).

Crop	Simulated potential	Experimental potential	On farm potential	Average
Cotton	1117	635	549	767
Mustard	856	149	376	460
Rice	2556	1478	973	1669
Wheat	14	0	196	70

In India, national and sub national assessments consistently report yield gaps ranging from **30-60%** for major cereals when research station or simulated yields are compared with average farmer yields. The persistence of these gaps, even in regions where improved varieties are widely adopted, indicates that genetic availability alone has not translated into proportional yield gains at the farm level.

5. Causes of Crop Yield Gaps

Yield gaps arise from complex interactions among biophysical, management and socio economic factors. Key biophysical constraints include nutrient deficiencies, water stress, pest and disease pressure, suboptimal planting dates, inadequate plant population, soil degradation and climatic extremes during critical crop growth stages. Management related factors such as delayed sowing, imbalanced fertilizer application, inefficient irrigation practices and insufficient crop protection further widen the gap between potential and actual yields.



Nutrient Deficiencies



Water Stress



Pest And Disease Pressure



Inadequate Plant Population



Soil Degradation



Extreme Climatic

Socio economic constraints are equally important. Limited access to credit, high input costs, labor shortages, risk aversion and lack of timely agronomic information often prevent farmers from adopting yield enhancing practices. On farm studies reviewed by Lobell *et al.* (2009) showed that even when improved inputs were applied, yield responses were highly

variable and sometimes economically unattractive under prevailing market and climatic conditions.

Yield gaps therefore cannot be attributed to a single factor. Instead, they represent systemic constraints that limit the effective translation of genetic yield potential into realized farm level productivity.

6. Implications for Indian Agriculture

Persistently large yield gaps have serious implications for Indian agriculture, food security and environmental sustainability. When yield gaps remain unaddressed, pressure increases to expand cultivated land, accelerating deforestation, land degradation and depletion of natural resources. This trajectory is particularly concerning for India, where land and water resources are already under severe stress.

From a farmer's perspective, yield gaps translate directly into lower income, higher production risk and reduced resilience to climate variability. Many yield reducing factors such as delayed sowing, inefficient nutrient use or untimely irrigation are often perceived as routine farming challenges and therefore ignored. However, yield gap research demonstrates that these seemingly "normal" practices collectively result in substantial and persistent yield losses.

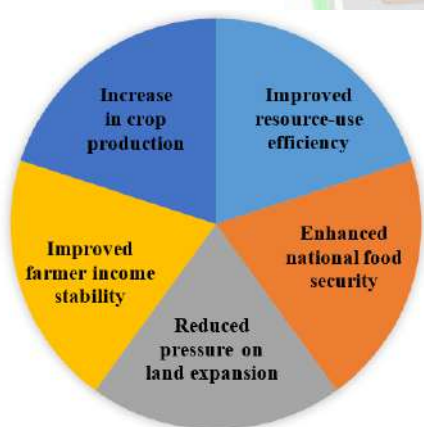


Fig. 2. Conceptual representation of major impacts associated with reduction of exploitable crop yield gaps, synthesized from yield gap literature.

For policymakers and researchers, yield gap analysis provides a powerful tool for prioritizing interventions. Rather than focusing exclusively on varietal replacement, it highlights the need for targeted investment in agronomy, extension services, irrigation infrastructure and risk management mechanisms. Addressing yield gaps also aligns with national goals of sustainable intensification, as it enables increased production without expanding cultivated area or increasing environmental damage.

In the Indian context, where smallholder farming dominates, reducing yield gaps through improved management and knowledge transfer offers one of the most practical and scalable pathways to enhance

productivity, stabilize farm incomes and strengthen national food security.

7. Conclusion

Crop yield gaps represent one of the most significant challenges and opportunities for Indian agriculture. Extensive scientific evidence shows that modern crop varieties already possess high yield potential, yet a large share of this potential remains unrealized in farmers' fields. Yield gap analysis provides a rigorous framework for understanding why this gap persists and how it can be reduced.

Addressing yield gaps is not merely a technical exercise but a strategic priority for ensuring food security, improving farmer livelihoods and achieving sustainable agricultural intensification. Recognizing yield gaps as a serious and systemic problem rather than a routine farming issue is a critical first step toward closing them effectively.

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ALTERNATE WETTING AND DRYING (AWD) IN RICE - A WATER SAVING TECHNIQUE

Article ID: AG-VO6-I01-73**Uma Maheshwari S**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Rice (*Oryza sativa* L.) is one of the most water-intensive cereal crops, traditionally cultivated under continuous flooding conditions. Increasing pressure on freshwater resources, rising irrigation costs, and concerns over greenhouse gas emissions necessitate the adoption of sustainable water management practices. Alternate Wetting and Drying (AWD) is an innovative irrigation technique that reduces water use while maintaining grain yield and improving environmental performance. This article discusses the principles, agronomic benefits, water-saving potential, climate change mitigation effects, and field-level application of AWD in rice cultivation, drawing evidence from authorised research institutions and peer-reviewed studies.

Key words: AWD, rice irrigation, water use efficiency, methane emission, climate-smart agriculture

Introduction

Rice is the staple food for more than 50 per cent of the world's population and plays a vital role in food security, particularly in Asia. Conventional rice cultivation involves maintaining standing water throughout the crop growth period, which requires large quantities of irrigation water. On average, 2,000–2,500 litres of water are used to produce one kilogram of rice grain under continuous flooding systems.

However, increasing water scarcity, declining groundwater levels, and climate variability have made traditional irrigation practices unsustainable. Moreover, continuously flooded rice fields are a major source of methane (CH_4), a potent greenhouse gas. In this context, **Alternate Wetting and Drying (AWD)** has emerged as a

- promising water-saving and climate-smart irrigation technology promoted by institutions such as the
- International Rice Research Institute (IRRI) and CGIAR. Alternate Wetting and Drying (AWD) is a water- saving technology that farmers can apply to reduce their irrigation water consumption in rice fields without
- decreasing its yield. In AWD, irrigation water is applied a few days after the disappearance of the ponded water. Hence, the field gets alternately flooded and non-flooded. The number of days of non-flooded soil between
- irrigations can vary from 1 to more than 10 days depending on the number of factors such as soil type, weather, and crop growth stage.

Concept of Alternate Wetting and Drying (AWD)

Alternate Wetting and Drying is a controlled irrigation practice in which rice fields are not kept continuously flooded. Instead, irrigation is applied only after the soil water level drops to a predefined threshold. This technique allows periodic drying of the soil while avoiding moisture stress during critical crop growth stages. AWD is commonly implemented using a **field water tube (Pani pipe)** inserted into the soil to monitor the depth of the water table below the soil surface. Irrigation is usually applied when the water level reaches about **15 cm below ground level**.



Figure 1. Field water tube used for observation of water levels by farmers. The ability to observe the level of the water table below the soil helps build confidence in AWD. (Photo: IRRI)

Water Saving and Water Use Efficiency

Several field studies have confirmed that AWD can reduce irrigation water use by **15–35 per cent** compared to continuous flooding. Improved **water use efficiency (WUE)** and **irrigation water productivity (IWP)** have been consistently reported across different agro-ecological regions.

A global meta-analysis reported that AWD saved nearly one-third of irrigation water while maintaining comparable rice yields under proper management. This makes AWD particularly suitable for water-scarce regions and command areas with limited irrigation supply.

Effect of AWD on Rice Yield

The impact of AWD on grain yield depends on soil type, variety, and management practices. When AWD is properly scheduled and severe moisture stress is avoided during sensitive stages such as tillering and flowering, yields are generally maintained or slightly increased.

Studies from South and Southeast Asia reported grain yields ranging from **5–10 per cent higher** under AWD compared to continuously flooded fields. Improved root growth, enhanced nutrient uptake, and better tiller development contribute to this positive response.

Impact on Greenhouse Gas Emissions

Flooded rice ecosystems are major sources of methane due to anaerobic decomposition of organic matter. AWD significantly reduces **methane emissions** by **30–70 per cent** by introducing aerobic soil conditions during drying periods.

Although AWD may increase nitrous oxide (N_2O) emissions during re-wetting phases, the overall **global warming potential (GWP)** remains lower than that of conventional flooding systems. Thus, AWD is recognised as an effective **climate change mitigation strategy** in rice production.

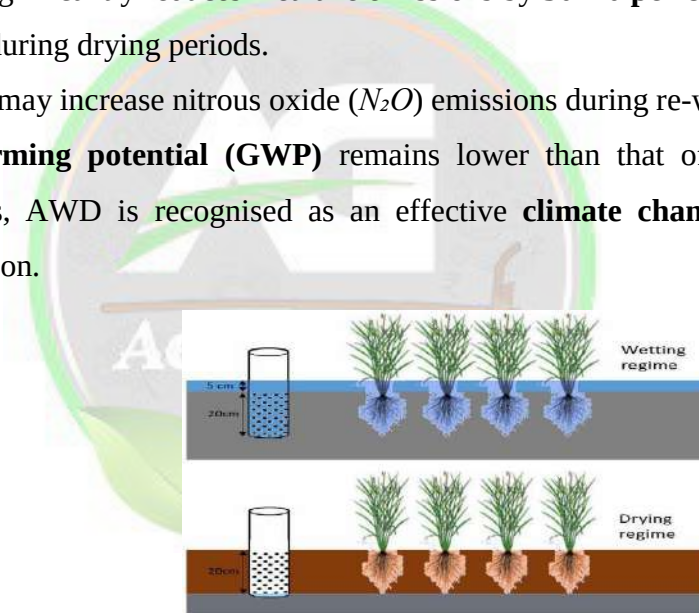


Figure 2. Using Pani pipe (Field water tube) to Monitor water level.

Field-Level Application of AWD

For effective implementation of AWD at the farmer's field level, the following steps are recommended:

- Install a perforated PVC or bamboo tube in the field to monitor water level.
- Allow water to recede naturally after irrigation.
- Re-irrigate when the water table reaches 15 cm below the soil surface.
- Avoid drying during critical growth stages such as flowering.
- Integrate AWD with proper weed management and nutrient scheduling.

Training farmers on water level monitoring and irrigation timing is crucial for successful adoption.

Constraints and Limitations

Despite its advantages, AWD adoption faces certain challenges. Increased weed pressure during drying periods may require additional weed control measures. Farmers' perception that rice requires standing water also limits acceptance. In heavy clay soils, prolonged drying may lead to soil cracking, while in sandy soils, water stress may occur if AWD is not carefully managed.

Conclusion

Alternate Wetting and Drying is a scientifically proven, economically viable, and environmentally sustainable irrigation practice for rice cultivation. It enhances water productivity, reduces irrigation costs, mitigates greenhouse gas emissions, and supports climate-smart agriculture goals. With proper training, monitoring, and institutional support, AWD can play a crucial role in sustainable rice production systems, particularly under increasing water scarcity conditions.

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COLOSTRUM – A LIQUID GOLD FOR NEWBORN CALVES

Article ID: AG-VO6-I01-74***V.Ramakrishna and L.Vimalendran**

Assistant Professor, Tamil Nadu Veterinary and Animal Sciences University –
Krishi Vigyan Kendra Kundrakudi – 630 206 Sivaganga District, Tamil Nadu

*Corresponding Author: V.Ramakrishna

Introduction

Calf rearing is the cornerstone of sustainable and profitable dairy farming. Every calf born on a dairy farm represents not only the genetic future of the herd but also the economic security of the farmer. A healthy calf grows into a productive cow, contributes to higher milk yield, and ensures continuity of the dairy enterprise. However, despite advances in veterinary medicine, nutrition, and breeding technologies, calf mortality during the early days of life remains a persistent challenge in many dairy farms across India. The majority of these losses occur within the first week after birth and are often preventable through simple but timely management practices. Among all management interventions in calf rearing, colostrum feeding occupies the most critical position. The first few hours after birth are biologically the most decisive period in a calf's life, determining its ability to survive, resist disease, and perform efficiently in the future. Unfortunately, colostrum management is frequently neglected, misunderstood, or improperly practiced at the field level. Many farmers focus heavily on feeding, breeding, and milking of adult animals, while newborn calves receive comparatively less attention. This imbalance in management priorities results in weak calves, frequent illness, slow growth, and poor lifetime productivity.

Colostrum is a unique biological secretion produced by the dam immediately after calving, specifically designed by nature to protect the newborn. It is not merely the first milk but a complex mixture of antibodies, nutrients, enzymes, hormones, and growth-promoting factors. In dairy farming, colostrum is often referred to as “liquid gold” because of its priceless value in

safeguarding calf health. Yet, paradoxically, this most valuable resource is sometimes discarded, diluted, or fed late, resulting in irreversible damage to the calf's immune system. A fundamental biological fact that underscores the importance of colostrum is that calves are born without immunity. Unlike human infants, calves do not receive antibodies from their mothers during pregnancy due to the structure of the bovine placenta. This means that at the moment of birth, the calf is completely defenseless against bacteria, viruses, and other pathogens present in the environment. Colostrum serves as the only source of early immunity, providing ready-made antibodies that protect the calf during its most vulnerable phase of life. Failure to provide adequate colostrum leads to a condition known as failure of passive transfer of immunity, which is directly associated with increased calf mortality and morbidity.

In traditional dairy systems, it was common practice to allow the calf to remain with the dam and suckle naturally. While this system worked reasonably well under extensive management conditions, modern dairy farming practices often involve early separation of calf and cow, machine milking, and stall-fed systems. Under such conditions, relying solely on natural suckling without supervision is risky. Many calves fail to suckle adequately due to weakness, cold stress, difficult calving, or poor teat accessibility. As a result, calves may ingest very little colostrum during the critical absorption window, even though colostrum is available. Another important issue is the lack of awareness regarding the correct timing, quantity, and quality of colostrum feeding. Some farmers believe that feeding colostrum at any time during the first day is sufficient, while others assume that small quantities are adequate. In reality, the calf's intestine can absorb antibodies efficiently only during the first few hours after birth, and this ability declines rapidly thereafter. Delayed feeding or insufficient quantity results in poor antibody absorption, even if good-quality colostrum is provided later.

The consequences of poor colostrum management extend far beyond early calfhood. Calves that suffer from inadequate colostrum intake are more prone to neonatal diarrhea, pneumonia, navel ill, and septicemia. These calves require repeated veterinary interventions, incur higher treatment costs, and often exhibit stunted growth. Even if they survive to adulthood, such animals tend to have delayed age at first calving, lower milk yield, and reduced reproductive efficiency. Thus, the impact of colostrum feeding is not limited to calf survival alone but influences the entire productive life of the animal. From an economic perspective, colostrum feeding is one of the most cost-effective investments a dairy farmer can make. Unlike

expensive feed supplements or medicines, colostrum is a naturally available resource that requires no additional cost if managed properly. The benefits, however, are immense, including reduced calf mortality, lower veterinary expenses, improved growth rates, and higher lifetime milk production. In contrast, neglecting colostrum feeding leads to hidden losses that accumulate over time and significantly reduce farm profitability. In recent years, scientific research has strongly reinforced the traditional knowledge surrounding colostrum. Numerous studies have demonstrated a direct relationship between successful colostrum feeding and improved calf health, immunity, and productivity. These findings highlight the need to treat colostrum management as a non-negotiable practice in dairy farming. Extension agencies, veterinarians, and dairy development programmes increasingly emphasize colostrum feeding as a key intervention for improving livestock productivity and farmer income.

Therefore, understanding the importance of colostrum, its biological role, and correct feeding practices is essential for every dairy farmer. Proper colostrum management does not require sophisticated equipment or high investment, but it demands awareness, discipline, and timely action. By giving due importance to colostrum, farmers can ensure healthy calves, strong future cows, and a sustainable and profitable dairy enterprise.

WHAT IS COLOSTRUM?

Colostrum is the thick, yellowish, sticky milk produced by the cow immediately after calving and secreted for the first three to five days, with the highest biological value present in the very first milking. It is a unique and irreplaceable secretion that differs fundamentally from normal milk in its appearance, chemical composition, and biological function. While normal milk is primarily designed to meet the nutritional needs of the growing calf, colostrum is specially meant to ensure survival during the earliest and most vulnerable stage of life. Nature has designed colostrum as a complete protective package that equips the newborn calf to face a world full of disease-causing organisms. Colostrum is exceptionally rich in immunoglobulins, particularly Immunoglobulin G (IgG), which are responsible for providing passive immunity to the calf. In addition to antibodies, colostrum contains high levels of proteins, fats, fat-soluble vitamins, minerals, enzymes, hormones, and growth-promoting factors. These components work together to protect the calf against infections, support rapid energy supply, stimulate organ development, and enhance overall vitality. The concentration of these protective components is highest in the first milking after calving and declines rapidly with subsequent milkings, which

explains why early feeding of colostrum is so critical.

The characteristic yellow colour and thick consistency of colostrum are primarily due to its high concentration of antibodies, fat, carotenoids, and vitamins, especially vitamin A. This dense nature distinguishes colostrum from normal milk and serves as a visual indicator of its superior quality. The richness of colostrum provides the calf with immediate energy, helping it maintain body temperature, especially under cold or stressful conditions. This early energy support is vital for newborn calves, which are born with limited fat reserves. Beyond immunity and nutrition, colostrum plays a crucial role in establishing a healthy digestive system. It acts as a natural laxative, enabling the calf to pass meconium, the dark, sticky fecal material accumulated in the intestines during fetal life. Removal of meconium cleanses the digestive tract, prevents constipation, and prepares the intestine for efficient digestion and absorption of nutrients from subsequent milk feedings. Failure to pass meconium often leads to digestive disturbances and discomfort in young calves.

Colostrum also contains enzymes and beneficial bioactive compounds that support the development of the intestinal lining. Growth factors present in colostrum stimulate rapid maturation of the gut, increasing its surface area and absorptive capacity. This early development improves feed efficiency and nutrient utilization, contributing to better growth rates during the pre-weaning period. A well-developed digestive system in early life has long-term benefits, including improved health and productivity in adulthood. Another important but often overlooked function of colostrum is its role in establishing a healthy microbial balance in the calf's gut. Colostrum promotes the growth of beneficial microorganisms while suppressing harmful bacteria. This early microbial colonization strengthens gut health and reduces the risk of neonatal diarrhoea, which is one of the leading causes of calf mortality. Thus, colostrum not only provides passive immunity but also supports the calf's own developing immune system.

In essence, colostrum is far more than just the first milk. It is a biologically active fluid that serves as the calf's first vaccine, first nutrition, and first protective shield against disease. No artificial feed, milk replacer, or supplement can replicate the complex combination of immune and growth-promoting factors present in natural colostrum. Understanding what colostrum is and recognizing its unmatched value is the first step toward ensuring healthy calves and successful dairy farming.

WHY COLOSTRUM IS VITAL FOR CALF SURVIVAL

A newborn calf enters the world in a highly vulnerable state. Unlike human infants, calves are born completely devoid of protective antibodies because the bovine placenta does not allow the transfer of maternal immunoglobulins during pregnancy. This biological limitation means that at the moment of birth, the calf has no immunity against bacteria, viruses, or other disease-causing organisms present in the environment. Immediately after birth, the calf is exposed to pathogens from the dam, bedding material, air, soil, utensils, and handlers. Without timely immune protection, the calf is at extremely high risk of infection during the first few days of life.

Colostrum serves as the sole and irreplaceable source of early immunity for the newborn calf. Through colostrum feeding, the dam transfers ready-made antibodies to the calf, a process known as passive transfer of immunity. These antibodies represent the cumulative immune experience of the mother against diseases prevalent in the farm and surrounding environment. By ingesting colostrum, the calf instantaneously acquires this protective shield without having to fight infections on its own. In the absence of colostrum, or when colostrum feeding is delayed or inadequate, the calf suffers from failure of passive transfer, a condition strongly associated with increased sickness and mortality. The antibodies present in colostrum are absorbed intact through the intestinal lining of the calf during the first few hours after birth. Specialized intestinal cells allow these large antibody molecules to pass directly into the bloodstream. Once absorbed, these antibodies circulate throughout the body and provide immediate systemic protection. They neutralize invading pathogens, prevent bacterial multiplication, and reduce the severity of infections. This early immune defense is particularly critical during the first two to three weeks of life, when the calf's own immune system is still immature and incapable of mounting an effective response.

Adequate colostrum intake significantly reduces the incidence of major neonatal diseases such as diarrhea, pneumonia, septicemia, and navel ill. Neonatal diarrhea alone accounts for a large proportion of calf deaths in dairy farms, and studies have consistently shown that calves receiving insufficient colostrum are several times more likely to develop severe diarrhea. Similarly, respiratory infections are far more common in calves with poor passive immunity. Thus, colostrum feeding directly determines not only survival but also the overall health status of the calf during early life. Beyond immediate disease protection, colostrum plays a crucial role in

supporting growth and vitality. Calves that receive adequate colostrum are more alert, stand earlier, suckle better, and show improved appetite. They grow faster, utilize feed more efficiently, and maintain better body condition. These calves also respond more effectively to vaccinations later in life because their immune system develops in a healthier and more balanced manner. In contrast, colostrum-deprived calves often remain weak, show poor growth, and require repeated veterinary interventions.

The importance of colostrum extends far beyond the neonatal period and influences the entire productive life of the animal. Research has clearly demonstrated that calves with successful passive transfer of immunity reach puberty earlier, calve at a younger age, and produce more milk during their first and subsequent lactations. Studies have reported significantly higher lifetime milk yield in cows that received adequate colostrum as calves compared to those that did not. Thus, colostrum feeding is not merely a calf survival strategy but a long-term investment in herd productivity. Colostrum also plays a preventive role by reducing the need for antibiotic treatment in young calves. Calves with strong passive immunity experience fewer infections and therefore require fewer medications. This not only reduces treatment costs but also contributes to responsible antibiotic use and control of antimicrobial resistance. In this way, colostrum feeding supports both animal health and public health goals. In summary, colostrum is vital for calf survival because it provides immediate immunity, protects against life-threatening infections, supports growth and development, enhances vaccine response, and improves lifetime productivity. A calf that receives timely and adequate colostrum is biologically better equipped to survive the challenges of early life and to perform efficiently as an adult animal. Ensuring proper colostrum feeding is therefore the single most important step in safeguarding calf survival and building a healthy, productive dairy herd.

TIMING OF COLOSTRUM FEEDING – THE GOLDEN WINDOW

The timing of colostrum feeding is the single most critical factor determining the success of immunity transfer in newborn calves. Although the quantity and quality of colostrum are important, they cannot compensate for delayed feeding. The digestive system of the newborn calf is uniquely adapted immediately after birth to absorb large antibody molecules directly into the bloodstream. This special ability exists only for a very short period and declines rapidly with time. Therefore, colostrum feeding is a race against time, where every hour of delay reduces the immune protection received by the calf. Maximum absorption of antibodies occurs during the

first one to two hours after birth. During this period, the intestinal cells are highly permeable and allow immunoglobulins to pass intact into the circulation. By six hours after birth, the efficiency of antibody absorption is reduced by nearly fifty percent. By twelve hours, absorption becomes minimal, and by twenty-four hours, the intestinal lining undergoes a process known as “gut closure,” after which antibodies can no longer be absorbed into the bloodstream. At this stage, colostrum can still provide local gut immunity and nutrition but cannot offer systemic protection.



Field observation of newborn calves during the critical colostrum feeding period

Delayed colostrum feeding is the most common and costly management error observed in dairy farms. Many calves appear normal at birth and are therefore left unattended, while attention is focused on the dam. Such calves may receive colostrum only after several hours, by which time the opportunity for effective immunity transfer has already passed. This delay often results in failure of passive transfer of immunity, predisposing the calf to infections during the first few weeks of life. Studies have shown that calves fed colostrum within two hours of birth have significantly lower disease incidence and mortality compared to those fed later. Ideally, colostrum should be fed within the first one hour after birth and must be administered within two hours under all circumstances. If the calf does not suckle on its own within this period, assisted feeding through bottle or stomach tube becomes essential. Treating the first two hours of life as a “golden window” and prioritizing colostrum feeding during this period can dramatically improve calf survival and long-term performance.

HOW MUCH COLOSTRUM SHOULD BE FED?

While timely feeding is crucial, the quantity of colostrum fed also plays a vital role in ensuring adequate immunity transfer. The amount of colostrum required by a calf depends

primarily on its body weight and the antibody concentration of the colostrum. As a general rule, a newborn calf should receive colostrum equivalent to at least ten percent of its body weight within the first six hours of life. This ensures that sufficient antibodies are available for absorption during the limited window of intestinal permeability. For an average calf weighing around thirty kilograms, this translates to approximately three litres of colostrum within the first two hours after birth. An additional two litres should be fed within the next six to eight hours, bringing the total colostrum intake on the first day to around four to five litres. Larger calves or calves born under stressful conditions such as difficult calving, cold weather, or twin births may require slightly higher quantities to achieve adequate immunity levels.

Feeding smaller volumes of colostrum is a common mistake that leads to partial immunity transfer. Even if colostrum is fed on time, insufficient quantity results in inadequate antibody intake, leaving the calf partially protected. Such calves may survive initially but often show poor growth, frequent illness, and reduced performance later in life. Therefore, both timing and quantity must be considered together for successful colostrum management. Colostrum feeding should not be limited to the first day alone. Feeding colostrum for at least three days, and preferably up to five days, provides additional benefits beyond immunity transfer. Although systemic absorption of antibodies stops after gut closure, continued colostrum feeding supplies local gut immunity, growth factors, enzymes, and nutrients that support intestinal health, improve digestion, and enhance resistance to enteric infections.

METHODS OF COLOSTRUM FEEDING

The method of colostrum feeding plays a crucial role in ensuring that the calf receives the required quantity at the correct time under hygienic conditions. Colostrum can be fed through natural suckling, bottle feeding, or stomach tube feeding, each method having its own advantages and limitations. However, reliance on natural suckling alone is often unreliable in modern dairy farming systems. Natural suckling may be allowed only under close supervision, as many calves fail to suckle adequately due to weakness, cold stress, difficult birth, or poor teat accessibility. Even when calves appear to suckle, the actual volume consumed is often much less than required. Moreover, delayed suckling results in loss of valuable time during the golden window for antibody absorption. Therefore, unsupervised natural suckling should not be considered a dependable method of colostrum delivery.

Bottle feeding is widely recommended as the preferred method of colostrum feeding. It allows accurate measurement of colostrum volume, ensures timely administration, and promotes hygienic feeding practices. Bottle feeding also stimulates the natural sucking reflex, aiding closure of the esophageal groove and directing colostrum to the abomasum for proper digestion. Farmers can easily monitor intake and ensure that the calf receives the full required quantity within the critical time frame. In weak, sick, or non-suckling calves, stomach tube feeding becomes a life-saving intervention. Although some farmers hesitate to use this method due to fear of injury, stomach tubing performed by trained personnel is safe and highly effective. It ensures that colostrum is delivered directly into the stomach when the calf is unable to suckle on its own. Delaying feeding in such calves often leads to severe immunity failure and high mortality. Therefore, timely tube feeding **should be viewed** as a protective measure rather than a last resort. Regardless of the feeding method used, hygiene is of paramount importance. Feeding bottles, nipples, and tubes must be thoroughly cleaned and disinfected to prevent introducing pathogens into the calf's digestive system. Colostrum should be fed warm, at body temperature, as cold colostrum may reduce intake and digestion efficiency.

COMPOSITION AND NUTRITIONAL VALUE OF COLOSTRUM

Colostrum is nutritionally superior to normal milk in every aspect. It contains several times more protein, fat, vitamins, minerals, and antibodies than normal milk. This rich composition supports immunity, energy supply, organ development, and early growth.

Table 1. Comparison of Colostrum and Normal Milk

Component	Colostrum (First Milking)	Normal Milk
Total solids	23–25%	12–13%
Protein	14–16%	3.0–3.5%
Immunoglobulins	Very high	Very low
Fat	6–7%	3–4%
Vitamin A	5–10× higher	Normal
Minerals	High	Normal
Growth factors	Present	Absent

Not all colostrum is of equal quality. Good-quality colostrum is thick, creamy, yellowish, and obtained from healthy, well-fed, vaccinated cows. Colostrum from second and later parity cows is usually superior to that from first-calving heifers. Poor-quality colostrum is often seen in cows with mastitis, malnutrition, metabolic disorders, or premature milking. Colostrum quality

can be assessed using a Brix refractometer, where readings of twenty-two percent or above indicate good antibody concentration.

ARTIFICIAL COLOSTRUM – EMERGENCY MANAGEMENT

In certain situations such as death of the dam, agalactia, or mastitis-affected colostrum, artificial colostrum may be used as an emergency measure. Artificial colostrum does not fully replace natural colostrum but provides temporary nutritional and immune support

Table 2. Composition of Homemade Artificial Colostrum

Ingredient	Quantity	Purpose
Cow milk	1 litre	Base nutrition
Egg yolk	1	Protein and fat
Glucose/sugar	20–25 g	Energy
Castor/vegetable oil	1 teaspoon	Laxative & energy
Vitamin-mineral mix (optional)	As advised	Immunity support

Artificial colostrum should be used only when natural colostrum is unavailable. Commercial colostrum replacers with guaranteed immunoglobulin content are preferable whenever available. Common field-level mistakes include delayed feeding, insufficient quantity, dilution with water or milk, feeding cold colostrum, poor hygiene of feeding equipment, and assuming that natural suckling is sufficient. Each of these mistakes reduces immunity transfer and increases calf mortality and disease incidence.

CONCLUSION

Colostrum is rightly regarded as liquid gold for newborn calves because its value far exceeds that of any commercial feed, medicine, or supplement available in dairy farming. It is the calf's first vaccine, first feed, and first protective shield against disease, delivered naturally by the dam at the most critical moment of life. The importance of colostrum does not lie merely in its nutritional richness but in its unique ability to transfer immunity, support early organ development, and prepare the calf to survive in a disease-rich environment. No artificial intervention can replicate the complex biological functions of natural colostrum.

Proper colostrum management determines whether a calf merely survives or thrives. Timely feeding within the golden window, adequate quantity based on body weight, good-quality colostrum, and hygienic feeding practices together ensure successful passive transfer of immunity. Failure in any one of these aspects results in partial or complete failure of immunity

transfer, leading to weak calves that are prone to diarrhea, pneumonia, septicemia, and high mortality. Such calves often require repeated veterinary interventions, increasing treatment costs and antibiotic use, while still performing poorly in the long run. The benefits of proper colostrum feeding extend far beyond the neonatal period. Calves that receive sufficient high-quality colostrum grow faster, utilize feed more efficiently, and show improved resistance to disease throughout the rearing period. These calves reach puberty earlier, calve at a younger age, and produce higher quantities of milk during their productive life. Thus, colostrum feeding is not merely a calf management practice but a long-term investment in herd productivity and genetic potential.

From an economic perspective, colostrum management is one of the most cost-effective interventions available to dairy farmers. It requires no additional financial input, yet it significantly reduces calf mortality, lowers veterinary expenses, minimizes medicine usage, and improves lifetime milk yield. In contrast, neglecting colostrum feeding results in hidden economic losses that accumulate over time through poor growth, delayed maturity, reduced milk production, and premature culling. Therefore, the financial success of a dairy farm begins not in the milking parlour, but in the calf pen, during the first few hours of life. Colostrum feeding also has broader implications for sustainable and responsible dairy farming. Healthy calves with strong passive immunity require fewer antibiotics, thereby contributing to reduced antimicrobial use and supporting efforts to control antimicrobial resistance. In this way, colostrum management aligns with One Health principles by protecting animal health, human health, and the environment simultaneously.

Despite its proven benefits, colostrum remains underutilized or mismanaged in many dairy farms due to lack of awareness, improper timing, or misconceptions regarding natural suckling. This highlights the need for continuous education and extension efforts by veterinarians, livestock extension officers, KVKs, and dairy development agencies. Farmers must be trained to recognize colostrum as a biological asset that must be harvested, stored, and utilized with the same care as valuable farm inputs. In conclusion, colostrum is not an optional feed but a non-negotiable requirement for every newborn calf. Ensuring timely, adequate, and hygienic colostrum feeding is the simplest and most powerful step toward reducing calf mortality, improving herd health, and enhancing farm profitability. Every dairy farmer must treat colostrum with the respect it deserves and ensure that no calf is deprived of this life-saving first

feed. Investing attention in colostrum management today guarantees healthier cows and a more sustainable dairy enterprise tomorrow.

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CLIMATE CHANGE AND AGRICULTURE: A GROWING CHALLENGE FOR FOOD SECURITY

Article ID: AG-VO6-I01-75**Divya Vasundhara A**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Climate change has emerged as one of the most serious global challenges of the twenty-first century, with agriculture being one of the most vulnerable sectors. Changes in temperature, rainfall patterns, and the increasing frequency of extreme weather events such as droughts, floods, and cyclones have significantly affected crop production, livestock health, soil fertility, and water availability. These changes pose a serious threat to food security and farmer livelihoods, particularly in developing countries like India where a large population depends on agriculture. This article discusses the concept of climate change, its major causes, and its direct and indirect impacts on agriculture. It highlights how rising temperatures, irregular monsoons, increased pest and disease incidence, and soil degradation are reducing agricultural productivity. The article also explains the consequences of climate change on food security and rural livelihoods. Further, the importance of mitigation and adaptation strategies in agriculture is emphasized. Climate-smart agricultural practices, efficient water management, crop diversification, and the development of climate-resilient crop varieties are discussed as key solutions. The roles of farmers, government, and students in addressing climate change are also outlined. Overall, the article concludes that although climate change poses a serious threat to agriculture, its negative impacts can be reduced through sustainable farming practices, strong policies, scientific innovation, and public awareness. Understanding the link between climate change and agriculture is essential for building a food-secure and sustainable future.

Introduction

Agriculture is highly dependent on climate. Temperature, rainfall, sunlight, and seasonal patterns directly influence crop growth, livestock health, and overall farm productivity. In recent decades, climate change has emerged as a serious threat to agriculture across the world. Rising temperatures, irregular rainfall, frequent droughts and floods, and extreme weather events are already affecting food production and farmer livelihoods.

For a country like India, where a large population depends on agriculture, climate change is not just an environmental issue but also a socio-economic challenge. Understanding the relationship between climate change and agriculture is essential for students and the general public to ensure future food security and sustainable development.

What is Climate Change?

Climate change refers to long-term changes in average weather conditions such as temperature, rainfall, and wind patterns. Although natural climate variations exist, the current changes are mainly caused by human activities that increase greenhouse gas concentrations in the atmosphere.

The burning of fossil fuels, deforestation, industrial activities, and modern agricultural practices release gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). These gases trap heat in the atmosphere and lead to global warming, which in turn alters climate patterns.

Why Agriculture is Highly Vulnerable to Climate Change

Agriculture is one of the most climate-sensitive sectors. Even small changes in temperature and rainfall can significantly affect crop yields.

- Crops require specific temperature ranges and water levels for optimal growth.
- Livestock are sensitive to heat stress and water scarcity.
- Soil moisture and fertility depend on rainfall and temperature.

Therefore, climate change directly threatens food production systems.

Major Impacts of Climate Change on Agriculture

1. Rising Temperatures

Increasing temperatures reduce crop growth duration and accelerate crop maturity, resulting in lower yields. Heat stress affects crops like wheat, rice, and maize and reduces milk production in dairy animals.

2. Irregular Rainfall and Droughts

Unpredictable monsoon patterns lead to delayed sowing, crop failures, and reduced groundwater recharge. Drought-prone regions face frequent crop losses.

3. Floods and Cyclones

Heavy rainfall and cyclones damage standing crops, wash away fertile topsoil, and destroy irrigation infrastructure.

4. Increased Pest and Disease Incidence

Warmer temperatures and high humidity favor the multiplication of insect pests, weeds, and plant diseases.

5. Soil Degradation

Extreme weather events and higher temperatures reduce soil organic matter and increase soil erosion.

Impact on Food Security and Farmer Livelihoods

Climate change threatens food availability, accessibility, and affordability.

- Reduced crop yields increase food prices.
- Small and marginal farmers suffer income losses.
- Livestock mortality increases during heat waves and droughts.

This increases rural poverty and food insecurity.

Climate Change and Indian Agriculture (Examples)

- Irregular monsoons affect rice and pulse production.
- Heat waves reduce wheat yields in North India.
- Droughts in Maharashtra and Karnataka affect sugarcane and millet.
- Cyclones damage paddy and coconut crops in coastal regions.

Mitigation Strategies in Agriculture

Mitigation aims to reduce greenhouse gas emissions from agriculture.

- Use of renewable energy on farms.
- Reduced chemical fertilizer use and adoption of organic manures.
- Improved manure management in livestock farming.
- Promotion of agroforestry and tree planting.

Adaptation Strategies in Agriculture

Adaptation helps farmers adjust to climate change impacts.

- Development of drought- and heat-tolerant crop varieties.
- Efficient irrigation methods such as drip and sprinkler systems.
- Crop diversification and mixed farming.
- Climate-smart agricultural practices.

Role of Farmers, Government, and Students

Role of Farmers

- Adopting sustainable farming practices.
- Conserving water and soil.
- Using weather-based advisory services.

Role of Government

- Providing crop insurance and financial support.
- Investing in climate-resilient agriculture.
- Strengthening extension services.

Role of Students

- Spreading awareness about climate change.
- Supporting environmental conservation.
- Promoting sustainable lifestyles.

Conclusion

Climate change poses a serious threat to agriculture and food security. Its impacts are already visible in the form of declining crop yields, increased pest attacks, frequent droughts and floods, and farmer distress.

However, through climate-smart agricultural practices, supportive government policies, scientific research, and public awareness, it is possible to reduce the negative impacts of climate change on agriculture.

For students and the general public, understanding climate change and agriculture is the first step toward building a sustainable and food-secure future.

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INTEGRATED PEST MANAGEMENT OF YELLOW STEM BORER IN RICE

Article ID: AG-VO6-I01-76**Gogul. B**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Rice is a major staple food crop in India, and its production is greatly affected by insect pests, especially the yellow stem borer (*Scirpophaga incertulas*). This pest damages the crop from seedling stage to maturity and causes serious yield loss through dead heart and white ear symptoms. Farmers often depend on chemical pesticides for its control, which leads to problems like pest resistance, destruction of natural enemies, higher cultivation cost, and environmental pollution. To address these issues, Integrated Pest Management (IPM) provides a safe and sustainable approach for managing yellow stem borer in rice. This article explains the importance, identification, life cycle, and damage symptoms of yellow stem borer, along with various IPM practices such as cultural, mechanical, biological, host plant resistance, and need-based chemical control. IPM helps in reducing pesticide use, protecting beneficial organisms, and maintaining ecological balance. Adoption of IPM practices is essential for effective management of yellow stem borer and for achieving sustainable rice production.

Introduction

Rice is one of the most important food crops in India and serves as the staple diet for millions of people. A large percentage of farmers depend on rice cultivation for their livelihood. Even though rice can be grown under different agro-climatic conditions, its production is greatly affected by insect pests. Among the various insect pests attacking rice, the yellow stem borer (*Scirpophaga incertulas*) is considered one of the most destructive and economically important pests.

The yellow stem borer damages the crop from seedling stage to maturity and causes serious yield loss if not managed properly. Many farmers rely heavily on chemical pesticides to control this pest, which often leads to problems such as pest resistance, destruction of natural enemies, increased cost of cultivation, and environmental pollution. To overcome these issues, Integrated Pest Management (IPM) is recommended. IPM is a balanced and eco-friendly approach that combines different pest control methods in a practical and sustainable way.

Importance of Yellow Stem Borer in Rice

The yellow stem borer is the most dominant stem borer species found in Indian rice fields. It is present throughout the year due to continuous rice cultivation. The pest is more severe in irrigated and lowland rice ecosystems. Late transplanted crops and fields with excessive nitrogen fertilizer usually suffer higher infestation.

Yield loss due to yellow stem borer can vary depending on crop stage, variety, and management practices. In severe cases, yield loss can be very high, especially when white ear damage occurs during the reproductive stage. Therefore, timely identification and proper management of this pest are very important for successful rice production.

Identification and Life Cycle

The adult yellow stem borer is a small moth. The female moth is yellowish in colour with a black spot on each forewing and a tuft of yellow hairs at the tip of the abdomen. The male moth is smaller and pale in colour. The moths are mostly active during night and are attracted to light. The female lays eggs in masses on the upper surface of rice leaves, usually near the leaf tip. The eggs are covered with buff-coloured hairs. After 5–8 days, the eggs hatch into larvae.

The young larvae move to nearby plants and bore into the stem.



Egg



Larva



Adult



Only one larva is usually found inside a tiller. The larval stage lasts for about 30–40 days.

Pupation occurs inside the stem near the base of the plant, and adult moths emerge after about a week.

Nature and Symptoms of Damage

The larva is the damaging stage of the yellow stem borer. It feeds inside the rice stem and damages the growing tissues.

At the vegetative stage, the larva damages the growing point, resulting in drying and death of the central shoot. This symptom is known as **dead heart**. Dead heart can be easily pulled out and shows feeding damage near the base.

At the reproductive stage, the larva damages the stem below the panicle, resulting in complete drying of the ear head. This symptom is called **white ear** or **white head**. The panicle becomes white and produces no grains. White ear damage causes direct yield loss and cannot be compensated.



Dead Heart at Vegetative stage



White Ear at Reproductive Stage

Concept of Integrated Pest Management (IPM)

Integrated Pest Management is an approach that uses a combination of different pest control methods to keep pest populations below economic threshold levels. The main aim of IPM is not to completely eliminate the pest, but to manage it in a safe, economical, and environmentally friendly manner.

IPM emphasizes the use of cultural, mechanical, biological, and host plant resistance methods first. Chemical pesticides are used only as a last option when pest population exceeds economic threshold levels.

IPM Practices for Yellow Stem Borer

1. Cultural Practices

1. Cultural methods are preventive measures that help in reducing pest incidence naturally.
2. Early and synchronized planting helps escape peak moth activity.

Avoid excessive application of nitrogen fertilizers, as lush growth attracts stem borer

moths.

Maintain recommended plant spacing to avoid dense crop canopy. Clip the tips of seedlings before transplanting to remove egg masses present on leaves.

3. Remove and destroy rice stubbles after harvest to kill larvae and pupae.

Ploughing and flooding the field after harvest helps reduce carryover of the pest.

Remove and destroy infested tillers showing dead heart symptoms.

2. Mechanical and Physical Methods

Mechanical control methods are simple and can be practiced easily by farmers.

- Hand collection and destruction of egg masses from leaves.
- Removal of dead heart tillers at early stages of infestation.
- Installation of light traps (one per hectare) to attract and kill adult moths.
- Use of pheromone traps (about five per acre) for monitoring and mass trapping of moths.

3. Biological Control

Biological control plays a major role in IPM and helps maintain ecological balance.

- Release of egg parasitoid *Trichogramma japonicum* during the egg-laying period at recommended intervals.
- Conservation of natural enemies such as spiders, predatory beetles, and parasitoids by avoiding unnecessary pesticide sprays.
- Application of biopesticides like *Bacillus thuringiensis* and neem seed kernel extract to reduce larval population and egg laying.

4. Host Plant Resistance

Growing resistant or tolerant rice varieties is an effective and economical method of pest management.

Rice varieties such as Ratna, Jaya, IR-20, IR-26, IR-36, IR-50 and other locally recommended varieties show tolerance to yellow stem borer damage. Cultivation of such varieties reduces the need for chemical control.

5. Chemical Control

Chemical control should be adopted only when pest population crosses the economic threshold level.

- Economic threshold level is about 10% dead hearts at vegetative stage or 2% white ears at reproductive stage.

- Selective insecticides should be used at recommended doses and proper timing.
 - Chemicals should always be used as a part of IPM and not as the sole control method.
- Judicious use of pesticides helps in effective control while protecting beneficial organisms.

Advantages of IPM in Rice

- Reduces excessive use of chemical pesticides
- Lowers cost of cultivation
- Protects natural enemies and beneficial insects
- Reduces environmental pollution
- Ensures sustainable rice production

Conclusion

The yellow stem borer is one of the most serious insect pests of rice and causes significant yield loss if not managed properly. Integrated Pest Management offers a practical and sustainable solution to manage this pest effectively. By combining cultural practices, mechanical methods, biological control, resistant varieties, and need-based chemical control, yellow stem borer infestation can be kept under control. Adoption of IPM practices not only reduces crop loss but also helps in protecting the environment and maintaining ecological balance. As future agriculture professionals, it is our responsibility to promote and implement IPM strategies for sustainable rice production and farmer welfare.

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SOLAR LIGHT TRAP – AN ECO-FRIENDLY PEST MANAGEMENT TOOL IN AGRICULTURE

Article ID: AG-VO6-I01-77**Ishwarya. R**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Insect pests cause heavy damage to crops and reduce yield. Farmers mostly use chemical pesticides to control these pests, but continuous use creates problems like pollution, health issues, and pest resistance. To overcome these problems, eco-friendly pest control methods are needed. Solar light traps are a simple and safe method used in Integrated Pest Management. These traps use solar energy to attract and trap night-flying insects. They help in reducing pest population and also in monitoring pest activity in the field. Solar light traps are easy to use, cost-effective, and suitable for areas without electricity. They are mainly effective against pests like stem borers, moths, and beetles. When used along with other IPM practices, solar light traps support sustainable farming and reduce dependence on chemical pesticides.

Introduction

Insect pests are one of the major problems faced by farmers in crop production. They cause heavy yield losses every year, especially in crops like rice, pulses, vegetables, cotton, and oilseeds. To control these pests, farmers mostly depend on chemical pesticides. Though pesticides give quick results, their continuous and excessive use has created many problems such as pest resistance, killing of beneficial insects, environmental pollution, and health hazards to farmers and consumers.

In recent years, there has been growing awareness about eco-friendly and sustainable pest management practices. Integrated Pest Management (IPM) promotes the use of mechanical, cultural, biological, and need-based chemical methods to manage pests safely. Among the mechanical methods, the **solar light trap** is an important and farmer-friendly tool. It helps in monitoring and controlling insect pests without harming the environment. This article discusses

the concept, working principle, importance, advantages, and field application of solar light traps in simple terms.

What is a Solar Light Trap?

A solar light trap is a pest management device that uses light to attract insects and trap them. It operates using solar energy collected during the daytime and works automatically at night. Many insect pests are naturally attracted to light, especially during night hours. The solar light trap makes use of this behavior to attract harmful insects and trap or kill them.

Unlike traditional electric light traps, solar light traps do not require electricity from power lines. This makes them suitable for use in remote villages and agricultural fields where power supply is irregular or not available.



Solar Light Trap

Components of a Solar Light Trap

A solar light trap mainly consists of the following parts:

1. **Solar Panel** – This is fixed on the top of the structure and collects sunlight during the day. The collected energy is converted into electrical energy.
2. **Battery** – The battery stores the energy generated by the solar panel and supplies power to the light during night time.
3. **Light Source** – Usually LED or UV light is used. This light attracts insects during the night.
4. **Trap or Collection Chamber** – Below the light, a funnel or container is placed where insects fall after being attracted. Water mixed with a small quantity of soap or kerosene is often used to prevent insects from escaping.

5. **Support Structure** – The entire unit is mounted on bamboo poles or iron stands at a suitable height in the field.

Working Principle of Solar Light Trap

The working of a solar light trap is simple and easy to understand. During daytime, the solar panel absorbs sunlight and charges the battery. At night, the stored energy is used to automatically switch on the light.

Many insect pests such as stem borers, leaf folders, hoppers, moths, beetles, and grasshoppers are attracted towards light. When they fly near the light, they either fall into the collection container or get trapped near the light source. In this way, the population of harmful insects is reduced in the field.

Solar light traps mainly work during night hours, which is the active period for most insect pests. This helps in early monitoring and control of pests before they cause serious damage to crops.

Importance of Solar Light Trap in Agriculture

Solar light traps play an important role in modern agriculture, especially under IPM practices. Their importance can be explained as follows:

- They help in **early detection of pest population**, allowing farmers to take timely control measures.
- They reduce the **dependence on chemical pesticides**, thus lowering production costs.
- They help in maintaining **ecological balance** by reducing pesticide pollution.
- They are useful for **community-based pest management**, where traps are installed over a large area.

In crops like rice, solar light traps are effective against pests such as yellow stem borer, leaf folder, gall midge, and rice bugs.

Installation and Field Use

Solar light traps should be installed at the correct height for effective performance. Generally, the trap is fixed at about 1 to 1.5 meters above ground level. One trap can cover an area of approximately one acre depending on crop and pest intensity.

The traps should be installed at the center or along the borders of the field. They are usually operated from evening to early morning. Regular cleaning of the collection container is important to ensure proper functioning. Farmers should observe the trapped insects daily. This

helps in identifying the major pests present in the field and deciding whether further control measures are needed.

Advantages of Solar Light Trap

Solar light traps have many advantages which make them suitable for farmers:

- **Eco-friendly:** No chemical use, safe for humans, animals, and environment.
- **Cost-effective:** After installation, running cost is very low.
- **Energy saving:** Uses renewable solar energy.
- **Easy to use:** Simple design and low maintenance.
- **Useful in remote areas:** Works without electricity connection.
- **Reduces pesticide residues** in food and soil.



Limitations of Solar Light Trap

Though solar light traps are very useful, they also have some limitations:

- They may attract both harmful and beneficial insects.
- They are more effective against night-flying insects only.
- Initial installation cost may be slightly high for small farmers.
- Effectiveness depends on weather conditions and proper maintenance.

Hence, solar light traps should be used as a part of IPM, not as the only control method.

Role of Solar Light Trap in Integrated Pest Management

Under Integrated Pest Management, solar light traps act as a **monitoring and mechanical control tool**. They help in reducing pest population naturally and guide farmers in deciding the need for other control measures. When used along with cultural practices like proper field sanitation, resistant varieties, balanced fertilizer use, and biological control methods,

solar light traps give better results. This approach leads to sustainable crop production with minimum environmental impact.

Conclusion

Solar light traps are an effective, eco-friendly, and farmer-friendly tool for pest management in agriculture. They help in reducing insect pest population, minimizing pesticide use, and protecting the environment. With increasing focus on sustainable farming, solar light traps can play a major role in Integrated Pest Management programs. For a developing country like India, where many farmers face power shortages and rising input costs, solar light traps offer a practical solution. With proper awareness and support from agricultural departments, the adoption of solar light traps can improve crop protection and contribute to safe and sustainable agriculture.

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ACCELERATING AGRI-TECH STARTUPS ECOSYSTEM IN INDIA AND RAJASTHAN

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Dr. Seema Tyagi and Dr. Vasupriya Parashar****

*Assistant Professor, Directorate of Prioritization, Monitoring & Evaluation and

**Ph.D., Extension Education and Communication Management,

Swami Keshwanand Rajasthan Agricultural University, Bikaner-334006 (Rajasthan), India

*Corresponding Author: Dr. Seema Tyagi

Abstract

Agri-tech startups have emerged as a energetic rift that leverages cutting-edge technologies like AI, IoT, data analytics, and robotics to transform traditional agriculture to enhance productivity, efficiency, and profitability in agriculture. This study explores the evolving landscape of agritech in India, highlighting its role in transforming traditional agriculture through technology-driven innovations. With rising internet penetration, increased investment, and government support, agritech startups are addressing critical issues such as inefficient supply chains, post-harvest losses, and lack of timely inputs. However, challenges like low digital literacy, small landholdings, infrastructure deficits, and regional disparities—particularly in Rajasthan—continue to hinder large-scale adoption. The study analysis the need for integrated policy support and localized solutions to ensure inclusive and sustainable agricultural growth through Agri-Tech Startups.

Introduction

In recent years, the concept of startups has gained immense momentum globally, with a significant rise in innovation-driven ventures. Startups are commonly defined as newly established businesses, often driven by unique solutions to pressing market needs. Among them, **agri-tech startups** have emerged as a dynamic subset that leverages cutting-edge technologies like AI, IoT, data analytics, and robotics to transform traditional agriculture. These ventures aim to enhance productivity, efficiency, and profitability in agriculture while addressing challenges

such as diminishing arable land and supply chain inefficiencies. Globally, the agri-tech market is experiencing rapid growth, with regions like North America and Asia leading the way. India, too, is witnessing a surge in agri-tech entrepreneurship, backed by government initiatives such as Startup India and RKVY-RAFTAAR. With over 2,000 agri-tech startups and a market potential of US \$24 billion, India's agri-tech ecosystem is becoming a hub of innovation. State-level efforts, especially in Rajasthan through policies like the **Rajasthan Startup Policy 2022**, are further accelerating this growth. These policy frameworks offer financial incentives, mentorship, infrastructure support, and capacity building, creating a fertile ground for innovation-led agricultural transformation. This research explores the evolving landscape of agri-tech startups, their ecosystem enablers, and the socio-economic impact they are poised to deliver.

Agri-Tech Startups

Startups are ventures that focus on a unique product or service and are often managed by few founders. According to Forbes, startups are the young companies rooted in innovation with an intent to solve a problem or to create an entire category of new goods and services. The Department for Promotion of Industry and Internal Trade (DPIIT), Government of India defines a startup as an entity whose period of existence is less than 10 years and has not exceeded an annual turnover of US \$ 13 million (Rs. 100 crores) during any financial year since its operations. The entity to be called as startup should be incorporated as a Private Limited Company or a Registered Partnership Firm or a Limited Partnership. The entity to be called as startup should not have been formed by reconstruction of an already existing business.

The word '**agri-tech**' can be defined as utilization of technology for improving agricultural output productivity, profitability and efficiency. Apart from agriculture, agri-tech also finds its application in horticulture, forestry, aquaculture and viticulture. Agri-tech includes application of internet, automation technologies, Internet of Things (IoT) data science, Artificial Intelligence (AI) and Machine Learning (ML). Automated irrigation, precision farming, weather forecasting, IoT-based sensors, satellite imaging, remote sensing, drone technology etc. are a part of agri-tech.

An '**Agri-tech Startup**' is a venture aimed at creating products or services that improve agricultural output using the latest technological advancements. Agri-tech startups are the entrepreneurial initiatives taken by the tech-driven startups to change the status-quo of the agricultural sector. Agri-tech startups also aim to increase farmers' income by elimination middle

men from their business operations (procurement or sourcing). Some agri-tech startups are making the agricultural supply chain more efficient using modern technologies. Agri-tech startups are the pioneers of agricultural transformation through digitalization. Agri-tech has the potential of increasing agricultural performance improving farmers' lives. Numerous agri-tech startups have emerged at the national level that are reaping the benefits of innovative disruption in the field of agriculture and providing solutions for supply chain inefficiencies either in the upstream side or the downstream side of agricultural production.

Different Categories of Agri-tech Startups

Emerging technologies like computer vision, blockchain, robotics, IoT devices and Artificial Intelligence (AI) can accelerate the rate of innovation and scale of adoption of existing agritech (**Jammanahalli, 2022**) The agri-tech sector itself is an ecosystem of companies working towards making the occupation of farming more profitable by leveraging technologies like data analytics, SaaS (Software as a Service), Artificial Intelligence (AI) and Machine Learning (ML). As per **Sharma and Mathur in year 2019**, agri-tech startups are using technology and digitization to revolutionize traditional farming practices. These startups are developing innovative solutions that make farming more efficient, profitable, and sustainable. Following are the broad categories that are globally used to classify the agri-tech startups:

Table 1: Categories of agri-tech startups

Categories	Description	Examples
Upstream Supply chain Technology	These startups focus on improving input access for farmers through digitalization of the input supply chains, as in, e-commerce in seeds, fertilizers, pesticides	BigHaat, Unnati, Krishify, DeHaat AgroStar, Gramophone
Downstream Supply Chain Technology	Startups in this category deploy technology-led solutions to optimize output supply chains and create linkages at various levels of aggregation and with end consumers.	BigBasket, Gramophone, Ninjacart, WayCool, DeHaat, FreshVnF, Bijak, Captain Fresh, Otipy, Jumnotail, Reshamandi
Agriculture Finance and	Startups in this space	Samunnati, Jai Kisan,

Insurance Technology (Agri-FinTech)	explore novel credit solutions and leverage farm and value chain data to enable financing and insurance, offering them through traditional and novel distribution channels.	Gram Cover,DGV, Samaaru
Precision Agriculture	This category covers digital platformsthat provide crop advisory, weather modelling, drones, machine-learning-led grading solutions, and solutions foroptimal resource usage	CropIn, Stellapps, Absolute, IntelloLabs, Fasal, BharatAgri, Fyllo, Euruvaka Technologies, IoTechWorld, General Aeronautics
Robotics and Mechanization	Startup developing novel tools or farming systems for the sector, e.g., small farmmechanization tools, cold chain solutions, hydroponicequipment, etc	Tessol, Ecozen, Carnot, Eeki Foods, Kheyti, TartanSense, Gourmet Garden
Agriculture Infrastructure Technology: Warehousing and Logistics	This segment primarily refers to warehousing solutionsoffered for agri-produce and does not include broad-based logistics start-ups that may also serve the agriculture sector.	Arya Collateral, Origo Commodities, Ergos, NCML, StarAgri
Agriculture Biotechnology and Biomaterials	This category includes all biotech and biomaterials innovations for agriculture such as bio-inputs, food preservation tech	String Bio, Sea6 Energy, BioPrime Solutions,

Source: Think Ag: Ag-Tech in India – Investment Landscape Report 2022

Agri-tech Startup Ecosystem at a Global Level

An agri-tech startup ecosystem consists of agri-tech startups at different stages, organizations and people associated with the startups. Organizations include incubators, funding organizations, accelerators, universities etc. People in this definition includes founders, investors,

advisors, industry experts etc. **As per Spherical Insights report (2020)**, the global agri-tech market was valued at US\$ 19,542.7 million in 2021 and is projected to grow at a CAGR of 17.3 per cent to US\$ 46,372.5 million by 2030. As per the ‘Research and Markets’ report North America dominated the global agri-tech market with a revenue share of 38.59 per cent in 2019 followed by Asia-Pacific (29.68 per cent). The Asian agri-food industry has been valued close to US\$ 5 trillion and the scope of agri-tech is projected to widen in the decade.

The Global Startup Ecosystem Report 2022 (Agtech and New Food Edition) has divided the global agri-tech startup ecosystem into seven regions namely North America, Latin America, Europe, MENA (Middle East and North Africa), Africa, Asia, and Oceania. The top 5 agri-tech startup (Agtech and New food) ecosystems are as follows –

- I. Silicon Valley
- II. New York City
- III. London
- IV. Tel Aviv-Jerusalem
- V. Denver-Boulder

Among the regional agri-tech startup ecosystems, North America and Asia account for 48 per cent and 20 per cent of the top 25 Agtech and New Food startups, respectively. The top global startup incubators and accelerators include Y Combinator, EIT Food, Yield Lab, Astralabs and Indie Bio. Top investors and Venture Capital (VC) firms include Matrix Partners China, Alumni Ventures, CPT Capital, Ag Funder etc. Brinc, Antler, Viligro, and India’s Indigram Labs Foundation are among the top startup incubators in Asia. IDG Capital, Zhen Fund, K2VC, Plum Ventures and Sequoia Capital are the top Venture Capital (VC) firms of Asia. Indian agri-tech startups are capable of resolving inherent challenges in Indian agriculture. India is competing with the United States and China in the global agri startup domain. Agri e-commerce, IoT, big data, nano technology, post-harvest technology, precision farming, agri-fintech, smart machinery and FaaS (Farming-as-a-Service) as the biggest opportunities for agri-tech startups in India. (Adhya and Sahoo, 2022)

Agri-tech Startup Ecosystem in India

As per the **Pahwa (2020)** the market potential of Indian agri-tech sector has been estimated to be close to US \$ 24 billion and the market size of Indian agri-tech sector was US \$ 204 million in 2019-20. This shows that market penetration of Indian agri-tech startups

combined in that year was close to 1 per cent. Agri fintech and output market linkage startups jointly comprise of around 65 per cent of the agri-tech market potential. Agri-tech ecosystem in India is witnessing unprecedented adoption of technology across all key areas such as precision farming, farmer platforms, credit and financing, agri-biotech, food processing, quality and traceability and agri infrastructure - storage and logistics. **(Narayanan *et al.*, 2021).**

Around 2,028 agri-tech startups are operational in India. Investments in agri-tech startups (agri and food tech combined) doubled to \$ 4.6 billion during the Financial Year (FY) 2022 which is 119 percent more than that of Financial Year 2021. More than 1000 agri-tech startups have emerged over the last six years in India. The agri-tech startup ecosystem has become one of the fastest growing startup ecosystems in India with 9.4 times increase in institutional funding in the past 5 years says Post Covid Agritech Landscape Report 2021 by **Accel and Omnivore**. India's agri-tech sector is expected to surge ahead due to increasing rural internet penetration, rapid digital transformation due to COVID-19, together with increased interest from investor community. Agri-tech sector has shown lot of resilience and growth during the pandemic **(Narayanan and Dublish, 2021)**. As per the **National Academy of Agricultural Sciences (NAAS)** Policy Paper of year 2022, there were 1485 agri-tech startups recognized by the DPIIT in 2021. Karnataka and Maharashtra account for half of the total agri-tech startups in India. Bengaluru is biggest established startup ecosystem of India followed by Mumbai and Delhi. According to **Wong *et al.*** in the year 2021, total of 700 agri-tech startups were operational in India as of mid-2021. Approximately 40 percent of them are located in Karnataka and Maharashtra and around 64 percent of the total agri-tech investments have been made in startups based in Karnataka. The investments have been focused on startups related to agri-commodity trading platforms, farm-inputs, processing and transportation. **As per DPIIT**, Rajasthan stands at the 10th place among the highest number of agri-startups (as of 10th November, 2021).

Accelerators and Incubators are a crucial component of any startup ecosystem. They provide the best possible technical support to the startups to reduce their gestation period. Here, gestation period means the time between investing in the business and making the very first profit. An accelerator (or startup accelerator) speeds up the growth of existing startups that have already developed a business model. An accelerator provides valuable mentorship and other resources essential for the startup's growth. On the other hand, an incubator (or startup incubator) helps the early-stage startups in developing a business model that can earn profits. An

incubator helps the startups in getting angel investors, venture capitalists and industrial expertise for entering the market. Around 32.17 per cent of the total number of agribusiness startups incubated under CCS NIAM Business Incubator were related to Food Processing IoT, ICT and AI in Agriculture and 27.83 % had their business models based on farming and agricultural supply chain as highlighted by **Mittal *et al.* (2021)**

Some of the key accelerators and incubators of agri-tech startups in India are –

- a) **CIIE (IIM Ahmedabad)** – The Centre for Innovation Incubation and Entrepreneurship (CIIE) at the Indian Institute of Management (IIM), Ahmedabad is an academic incubator that primarily focuses on entrepreneurship and innovation.
- b) **a-IDEA (ICAR-NAARM)** – Association for Innovation Development of Entrepreneurship in Agriculture (a-IDEA) is a business incubator that mainly focuses on technological innovations in agriculture. It is under the aegis of Centre for Agri-Innovation at the National Academy of Agricultural Research and Management, Hyderabad (ICAR-NAARM).
- c) **iHub (ICRISAT)** – The Innovation Hub (iHub) has been developed as an agribusiness incubator by the joint efforts of International Crop Research Institute for Semi-Arid Tropics (ICRISAT) and the Department of Science and Technology, Govt. of India. The iHub also provides a platform where agri-tech entrepreneurs can collaboratively work together with scientists and technology industry experts for bringing innovations to the entire agricultural value chain.
- d) **Agri-Tech Start-up Accelerator (MANAGE)** – The ‘Agri-Tech Start-up Accelerator’ has been jointly established by the National Institute of Agricultural Extension and Management (MANAGE), Hyderabad and Indian Institute of Information Technology (IIIT), Hyderabad to identify, and support the startups at ideation stage to build a profitable business model with the help of technology.

Government of India launched its flagship initiative ‘**Startup India**’ in 2016, to encourage the youth to establish their startup in the country and create wider scope of employment in the country. Agriculture is also among the thrust areas of this flagship initiative. Under the Startup India initiative, a platform named ‘**Startup India Hub**’ has also been established by the Department for Promotion of Industry and Internal Trade (DPIIT) to facilitate startups in reaching out to angel investors, venture capitalists and industry experts. Government of India is

forming a high-level steering committee under the chairmanship of Union Minister of Agriculture and Farmers' Welfare Shri Narendra Singh Tomar to develop an accelerator programme specially for the agri startups. The outlay of the accelerator programme is ₹ 500 crore which will be a part of central government's policy initiative for agri startups in India.

An angel investment has a crucial role in providing an initial thrust to the early stage startups. They provide early risk financing to the startups in exchange for equity. Angel investors identify passionate and committed co-founders and invest on their ideas and the bigger market opportunities that will be tapped by their startups. Some of the top angel investors for agri-tech startups are Sandeep Singhal, Sanjiv Rangrass, Jitendra Gupta and Binny Bansal. A venture capital is type of investment made in private businesses that are in their growth or maturity stage in exchange for equity of the company. **Venture capitalists** are capital investment companies that invest in a startup's future growth prospects. Some of the top venture capitalists for agri-tech startups are Omnivore, Ankur Capital, Aavishkaar Venture Capital, Better Capital and Orios Venture Partners. An angel investor invests in early-stage startups and also provide mentorship to the startup founders whereas venture capitalists invest in startups that are in their growth or maturity stage.

Besides this, the Ministry of Agriculture and Farmers' Welfare is also running its flagship Rashtriya Krishi Vikas Yojana - Remunerative Approaches for Agriculture and Allied Sectors Rejuvenation (RKVY-RAFTAAR) scheme to support Indian agricultural startup ecosystem as a whole through which the agri-tech startups are also being supported under this scheme (**Pal et al., 2021**).

Agri-tech Startup Ecosystem of Rajasthan

Rajasthan has 92 DPIIT-recognized agri-tech startups, out of which 39 are headquartered in the capital city, Jaipur. Rajasthan is one of the states that has imbibed innovation and technology as the core agendas for economic development. The state has been working hand-in-hand with the central government for developing an ecosystem for the startups. Government of Rajasthan introduced the '**Rajasthan Startup Policy 2015**' to kick start the initiatives towards making the state a start-up hub. The objective of the policy was to establish institutions and incubators for incubating and supporting Rajasthan-based startups and stimulate innovation in the state. The policy was implemented for a total period of 5 years starting from 9th October, 2015. Government of Rajasthan launched its flagship startup initiative '**iStart**' in 2017. The state

government also launched ‘**Challenge for Change**’ platform as a part of iStart in alignment with the ‘**Startup India Hub**’ platform for the stakeholders of Rajasthan’s startup ecosystem. The flagship startup program has been instrumental in fostering the growth of more than 2000 affiliated startups. It is now among the most widely recognized state-run startup ecosystems in the country.

Following this momentum, the Government of Rajasthan introduced the ‘**Rajasthan Startup Policy 2022**’ a revamped and updated version of the 2015 policy. It has been designed to make Rajasthan, the most vibrant startup ecosystem in India and to make the state the trendsetter in terms of disruptive innovation in areas like agriculture, rural development, fintech, environment, healthcare and education in the next 5 years. The policy aims to stimulate job creation and foster skill development among the youth of Rajasthan. It is encouraging the budding entrepreneurs to utilize the recent technological advancements to transform their dreams into reality. The main highlights of Rajasthan Startup Policy 2022 are –

- a) Rajasthan Startup Fund** – The ‘Rajasthan Startup Fund’ is mainly utilized to support the startups, operate and maintain physical and digital infrastructure, organize workshops, operate startup training centers, organize mentorship programs and support academic institutes. The physical infrastructure working space within government incubation centers, testing laboratories and digital infrastructure includes payment platforms, APIs (Application Programming Interfaces), cloud storage, SMS and email services and ‘Rajasthan Stack’.
- b) Incentives for startups** – Young entrepreneurs have the access to low-cost capital, attractive incentives and financial boosters to further progress from ideation stage to growth stage. Startups registered under the ‘iStart Rajasthan’ program are eligible to avail funding incentives, additional financial initiatives and enabling support.
 - i. Funding Incentives** – The startups are funded on the basis of their stage (Pre-Seed & Seed and Growth Stage) in the startup lifecycle. The startup’s credit worthiness and potential are assessed on their ‘QRate Startup Rating’. The ‘Ideation Grant’ is given to the startups in their ‘Pre-Seed’ stage. A sum of ₹ 2,40,000 is provided if their idea is approved by the Evaluation Committee. The ‘Viability Grant’ is given to the startups at ‘Seed’ stage. The startups can avail up to ₹ 10 lakh under the Non-QRate category. Startups with a QRate score of 1-50 (Bronze) may avail grants ranging from ₹ 20 to ₹ 40 lakh (based on QRate Score). Startups with a QRate Score above 50 (Silver) can avail grants up to ₹ 60 lakh.

Startups in their ‘Growth’ stage can avail up to a maximum of 50 per cent of the total funds raised under the ‘Scale up Fund’. Incentives range from ₹ 1 crore to ₹ 2 crore based on their QRate category (Bronze, Silver, Gold, Platinum and Signature). Alternative Investment Fund (AIF) provides funding to the ‘Growth’ stage startups in the form of matching equity. It means that the government will pay the equal amount of fund raised by the startup up to a maximum of ₹ 5 crore. The ‘Growth’ stage startups can only choose one from ‘Scale up Fund’ and ‘Alternative Investment Fund’.

- ii. **Boosters and Additional Financial Incentives** – Additional boosters (Performance, Employment and other boosters) are given to the eligible startups for creating employment and promoting innovation. Additional financial incentives include investment subsidy, intellectual property incentives, quality certification incentive, exemptions etc.
- iii. **Enabling Support** – Startups are supported by providing awareness and outreach (exposure visits, networking events and corporate partnerships). The startups are supported in their marketing. Skill development of the entrepreneurs is done under the ‘iStart Spotlight’ program. Upskilling takes place at the Rajasthan Institute of Advanced Learning, Rajiv Gandhi Fintech Digital Institute and Rajiv Gandhi Center of Advanced Technology (R-CAT). Capacity building of startups takes place at ‘iStart Nest’ incubators, Techno Hub, Rajiv Gandhi Knowledge Service and Innovation Hub. In order to facilitate smooth business operations, the policy also includes ‘Ease of doing business’ measures. It comprises of self-certification (to bypass numerous approvals and inspections), plug and play incubation facilities, Patent Information Centre (to protect intellectual property of startup founders) etc. Besides this, public procurement option is also offered to the startups.
- c) **Support to academic institutions and startup incubators** – As a part of the Rajasthan Startup Policy 2022, the academic institutions and the incubators are now being encouraged to promote entrepreneurship in the state. Incubators can avail grants up to ₹ 35 lakh for running Accelerator Programs in the state. The only condition here is that at least 30 per cent of the participants must be from Rajasthan-based startups. Government colleges and schools can avail grants up to ₹ 15 lakh for establishing an Entrepreneurship

Cell within their campus. In order to encourage collaboration with premier global institutions, Government of Rajasthan has allocated a budget of ₹ 5 crore per year.

Drawbacks of Agri-tech Startups

The agri-tech startup ecosystem in India is rapidly expanding, driven by increased internet penetration, supportive government policies, and a growing need for climate-resilient agricultural solutions. Nationally, startups are addressing challenges across the agricultural value chain, including input access, credit availability, crop advisory, and post-harvest infrastructure. Despite this progress, the sector faces persistent issues such as traditional farming practices, lack of commercial expertise, infrastructural deficits, and long gestation periods that deter investor interest. Moreover, the widespread nature of small landholdings and low digital literacy among farmers continue to hinder large-scale adoption of agri-tech solutions.

In contrast, Rajasthan's agri-tech ecosystem presents a unique set of challenges influenced by the state's geographic and socio-economic conditions. While the state has actively promoted innovation through initiatives like the Rajasthan Startup Policy and iStart program, agri-tech startups here struggle with issues like low awareness of technological solutions, slow digital adoption, and limited affordability among the rural population. The prevalence of small and scattered landholdings makes it difficult to implement cost-effective farm gate procurement models. Additionally, the shortage of skilled manpower, difficulty in talent retention, and lack of localized infrastructure for grading, storage, and transport further restrict the growth and impact of agri-tech startups in the state. Despite these barriers, Rajasthan is making steady progress toward fostering a more inclusive and technology-driven agricultural sector.

Way forward to prevail over the failures

The role played by agri-tech startups in solving some of the inherent problems of the agricultural supply chain and creating jobs in the agriculture sector are now being widely recognized by both government as well as the investors. The following are the ways to foster a conducive environment for agri-tech startups in Rajasthan, enabling their growth, addressing critical gaps and overcoming challenges to unlock the full potential of the agri-tech sector in the state –

- The Government of Rajasthan should continue to implement and promote the Rajasthan Startup Policy 2022. The government should also ensure that agri-tech startups receive the necessary support, incentives, and training to foster their growth and success.

- The government should highlight initiatives like iStart Spotlight and ‘Ease of Doing Business’ measures on its online platforms so that the startups can easily get to know about them and avail benefits out of them. Moreover, the nodal officers of the iStart Rajasthan should create a community / group on commonly used social media platforms like Facebook, Whatsapp, LinkedIn for agri-tech startups of different stages. This will ensure timely flow of information related to incentives, workshops, trainings, tax waivers etc. on a regular basis.
- Exclusive information counters for agri-tech startups can be setup at various district, state as well as national level trade fairs and exhibitions organized by the government where the founders of agri-tech startups can get information regarding incentives, financial assistance, training programs offered by the government.
- For sustained growth and survival, the co-founders of agri-tech startups should also be fully aware about each and every part of the policy to gain maximum benefits out of it. The government can also ensure an enhanced handholding support to the agri-tech startups by providing 1-on-1 assistance to them.
- The agri-tech startups should develop remunerative business plans on phygital marketplace models, real-time data driven farm advisory platforms, Farm-to-Market models, post-harvest management technology platforms, produce aggregation technology platforms and decentralized farm storage models. They can seek help from the business incubators associated with Rajasthan Startup Policy 2022.
- Capacity building programs and training campaigns can be implemented by the government and NGOs in the rural areas to overcome the challenges like slow digital technology adoption, poor awareness on agri-tech solutions, digital literacy issues etc. Access to financial and technical assistance for digital technology adoption may be extended to the rural areas by the stakeholders of the agri-tech sector.
- The government should also ensure proper road connectivity between the rural areas and the trade hubs in the state to facilitate movement of agricultural goods and provide better infrastructural support to the agri-tech startups.
- Tech-savvy rural youth can be incentivized for providing training on handling digital technologies to the farmers under Corporate Social Responsibility (CSR) and University Social Responsibility (USR) initiatives.

Conclusion

The growth of agritech in India reflects a transformative shift toward digital and data-driven agriculture, addressing long-standing issues like low productivity, market inefficiencies, and climate vulnerabilities. Startups across the country are leveraging innovations in AI, IoT, and mobile technology to empower farmers and streamline supply chains. Despite promising developments, challenges such as digital illiteracy, fragmented landholdings, and infrastructure gaps remain significant, especially in regions like Rajasthan. Government support, increased investment, and targeted policy implementation are crucial to sustaining this momentum. If these barriers are addressed effectively, agritech can revolutionize Indian agriculture, ensuring food security and economic sustainability for rural communities.

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EXPENSIVE MUGA SILK: FROM FOREST REARING TO GLOBAL MARKETS

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***Lokesh Kumar P., Basavaraj Somalingappa Purad., Sabiya Sulthana M., Utchimahali T.,
Pavithra N and Padmapriya R**

Department of Sericulture, Forest College and Research Institute, TNAU, Mettupalayam
Tamil Nadu, India

*Corresponding Author: Lokesh Kumar P

Introduction

Muga silk occupies a unique position among the world's natural fibers due to its rarity, ecological specificity, and deep cultural roots. Produced exclusively by the silkworm *Antheraea assamensis*, Muga silk is endemic to the Brahmaputra valley and adjoining regions of North-East India. Unlike mulberry silk, which is produced under controlled and highly standardized conditions, Muga silk is obtained through an open, forest-based rearing system that remains closely tied to natural ecosystems and seasonal rhythms. Its characteristic natural golden hue, exceptional durability, and resistance to fading have earned it recognition as a luxury and heritage textile. However, these same biological and ecological constraints that confer uniqueness also limit production, making Muga silk one of the most expensive silks in the global market. Understanding why Muga silk commands such a high price requires examining the entire value chain—from silkworm biology and host plant ecology to labor inputs, cultural protection, and global demand dynamics.

Endemic Silkworm and Biological Constraints

Muga silk production is inseparably linked to *Antheraea assamensis*, a silkworm species that is only semi-domesticated and biologically fragile compared to *Bombyx mori*. Over evolutionary time, this species has adapted to very specific ecological niches characterized by stable humidity, moderate temperature, and forest-based microclimates. Unlike mulberry silkworms, Muga silkworms show poor performance under artificial rearing conditions, and

attempts at complete indoor domestication have had limited success. Their physiological processes, including feeding rhythm, moulting, and cocoon spinning, are synchronized with natural photoperiod and seasonal cues. This strong ecological dependence restricts genetic manipulation, selective breeding, and geographic relocation, creating an inherently low and inflexible production base that drives scarcity and high cost.

Dependence on Forest-Grown Host Plants

The primary host plants of Muga silkworm, Som (*Persea bombycina*) and Soalu (*Litsea polyantha*), are forest tree species with long gestation periods and complex nutritional profiles. Unlike mulberry, which can be intensively cultivated and harvested multiple times a year, these host plants require years to establish and are highly sensitive to soil degradation, moisture stress, and pest infestation. Leaf biochemical composition—particularly protein content, secondary metabolites, and moisture level—directly affects larval growth rate, cocoon shell ratio, and filament quality. Seasonal variation in leaf quality further introduces inconsistency in cocoon yield. Maintaining productive host plantations therefore demands sustained ecological management, land availability, and delayed economic returns, all of which add significantly to the cost of Muga silk production.

Outdoor Rearing and High-Risk Exposure

Muga silkworm rearing is carried out entirely in open, outdoor conditions, exposing the larvae to a wide range of biotic and abiotic stress factors. Predation by ants, birds, spiders, and parasitoids is common, while microbial infections such as virosis, bacteriosis, and fungal diseases frequently spread uncontrollably due to the absence of physical barriers. Climatic extremes—including heavy rainfall, sudden temperature drops, or prolonged heat—can disrupt larval feeding and cocoon spinning. Unlike indoor systems, there is minimal scope for quarantine, disinfection, or environmental regulation. Consequently, mortality rates are high and unpredictable, often exceeding economically acceptable thresholds. This elevated production risk increases the cost of successful cocoons, as losses must be compensated through higher market prices.

Seasonal and Limited Crop Cycles

Muga silk production follows a multivoltine pattern with several crops per year, but these crops are not equal in economic value. Certain seasons produce cocoons with superior filament strength, color, and reeling performance, while others are maintained primarily to sustain seed

continuity. Seasonal variations in temperature, rainfall, and host plant physiology strongly influence larval metabolism and cocoon structure. Moreover, adverse weather during critical stages such as late larval instars or spinning can drastically reduce output. Because production is biologically timed rather than market-driven, supply remains irregular and cannot respond quickly to demand fluctuations. This seasonal rigidity contributes to market instability and reinforces the premium nature of high-quality Muga silk.

Low Cocoon Productivity and Silk Recovery

From a production efficiency perspective, Muga silkworms are inherently less productive than mulberry silkworms. The number of cocoons harvested per unit of rearing effort is lower, and cocoon uniformity is poor due to environmental variability. Although Muga cocoons are relatively heavy, their filament structure is **coarse and uneven**, resulting in frequent breaks during reeling. The effective silk recovery rate is therefore **low**, meaning that a larger quantity of cocoons is required to obtain a kilogram of raw silk. This low conversion efficiency directly inflates the cost of yarn production and reduces profitability unless compensated by higher selling prices.

Labor-Intensive and Skill-Dependent Processing

Muga silk production remains deeply reliant on human skill and manual labor at every stage of the value chain. Rearing requires continuous vigilance to protect larvae from predators and environmental stress, while cocoon harvesting must be carefully timed to preserve filament quality. Reeling Muga silk is particularly demanding because of irregular filament thickness and limited reelability, requiring experienced artisans to minimize wastage. Mechanization is technically challenging and economically unviable at small scales. The slow pace of production, combined with the scarcity of skilled labor and the time required for training, significantly raises labor costs and contributes to the high price of Muga silk.

Natural Golden Color and Exceptional Durability

One of the most distinctive features of Muga silk is its natural golden-yellow hue, which arises from specific pigments and structural characteristics of the silk protein. This color is intrinsic to the fiber and does not require chemical dyeing, reducing processing steps while enhancing ecological appeal. Unlike dyed silks that fade with time, Muga silk develops a deeper luster as it ages, increasing its aesthetic and heirloom value. Structurally, the fiber exhibits higher tensile strength and resistance to wear, making Muga silk garments exceptionally durable.

Cultural Heritage and GI Protection

Muga silk is inseparable from the cultural identity of Assam, where it is traditionally associated with rituals, ceremonies, and social status. Garments woven from Muga silk are often preserved as family heirlooms, reinforcing their symbolic value beyond mere utility. The Geographical Indication (GI) status legally protects Muga silk by restricting its production to defined regions and traditional methods. While this safeguards authenticity and prevents dilution of quality, it also constrains expansion and standardization. The combination of cultural reverence, legal protection, and limited production volume contributes significantly to its elevated market price.

Limited Supply and Growing Global Demand

In recent years, global textile markets have shown increasing interest in sustainable, ethically sourced, and naturally colored fibers. Muga silk aligns closely with these values, attracting designers and consumers in high-end and niche markets. However, production remains constrained by biological, ecological, and cultural factors that prevent rapid scaling. This persistent mismatch between limited supply and rising demand creates a strong price premium. Unlike synthetic or mass-produced natural fibers, Muga silk cannot respond elastically to market signals, reinforcing its exclusivity and high valuation.

Hidden Costs of Conservation and Sustainability

Beyond visible production expenses, Muga silk carries significant hidden costs related to conservation and sustainability. Maintaining viable silkworm populations requires preservation of genetic diversity and prevention of inbreeding depression. Host plant ecosystems must be protected from deforestation and degradation, often at the expense of alternative land uses. Additionally, traditional knowledge related to rearing, reeling, and weaving must be transmitted across generations, requiring social and institutional support. These ecological and cultural investments are not directly priced at the farm level but are implicitly embedded in the final cost of Muga silk, distinguishing it fundamentally from industrial textiles.

Subtopic	Scientific / Technical Basis	How It Increases Cost
Endemic silkworm (<i>Antheraea assamensis</i>)	Semi-domesticated species with strict ecological requirements and limited adaptability	Restricts production to a narrow geographic region; supply cannot be expanded

Forest-grown host plants (Som & Soalu)	Perennial tree species with long establishment period and seasonal leaf quality variation	High land requirement, delayed returns, and inconsistent leaf availability
Outdoor rearing system	Larvae exposed to predators, pathogens, and climatic fluctuations	High mortality rates and frequent crop losses raise production risk
Seasonal crop cycles	Only specific seasons produce high-quality commercial cocoons	Irregular supply and unstable output increase market price
Low cocoon productivity	Fewer cocoons per rearing cycle and poor uniformity	More input required per unit of output
Low silk recovery rate	Thick, uneven filament reduces reeling efficiency	Larger quantity of cocoons needed for the same amount of silk yarn
Labor-intensive rearing	Continuous manual monitoring and protection required	High labor input with low mechanization
Skill-dependent reeling	Frequent filament breaks demand experienced artisans	Low productivity per worker and higher labor cost
Natural golden color	Pigments intrinsic to fibroin; no chemical dyeing needed	Enhances luxury value and market premium
Exceptional durability	High tensile strength and long service life	Positions Muga silk as a high-value, heirloom textile
Cultural significance	Traditional use in rituals and heritage garments	Increases perceived and symbolic value
GI protection	Legal restriction on production area and methods	Prevents mass production and imitation
Limited global supply	Biological and ecological constraints on scaling	Persistent demand–supply gap
Growing international demand	Preference for sustainable and natural luxury textiles	Drives premium pricing in export markets
Conservation requirements	Protection of silkworm biodiversity and host plant ecosystems	Hidden ecological and social costs embedded in price

Conclusion

The high cost of Muga silk is the cumulative outcome of biological rarity, ecological dependence, labor-intensive production, and cultural protection rather than simple market speculation. Every stage of its production is constrained by natural factors that resist industrial scaling, from the semi-domesticated nature of the silkworm and forest-grown host plants to outdoor rearing and low silk recovery rates. Added to this are the intrinsic material advantages of Muga silk—its natural golden color, exceptional strength, and longevity—which elevate it to the status of a luxury and heirloom fiber.

Cultural significance, reinforced by Geographical Indication protection, further restricts expansion while enhancing value. In an era of increasing demand for sustainable and ethically produced textiles, Muga silk stands as a premium product whose price reflects not only the fiber itself, but also the conservation of biodiversity, traditional knowledge, and forest-based livelihoods.

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GANODERMA FREE COCONUT FARM

Article ID: AG-VO6-I01-80**R.Aswini, R.K.Ajitha Sweety* and M.Brindha**

Undergraduate Student of B.Sc. (Hons.)Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

*Corresponding Author: R.K.Ajitha Sweety

Abstract

Ganoderma disease,also known as Basal stem rot or Thanjavur wilt,is a lethal,Soil-borne fungal disease of coconut palms caused primarily by *Ganoderma lucidum*.The symptoms of this disease was root rot,trunk decay,leaf yellowing,and eventual tree death.This fungus infects the bottom 122-152 centimeters(4-5 feet) of the plant.It is primarily spread through airborne spores from the fungus fruiting bodies that infect wounds on the trees,but also via direct root contact with infected stumps or soil,with vectors like wind,water,insects and animals helping disperse spores,leading to internal decay,especially in stressed palms like oil palms,where it's a silent killer.The integrated approach of this disease was immediately remove the destroy infected palms,di isolation trenches,apply biocontrol agents.

Introduction

Coconut palm (*Cocos nucifera*, L.) is an important plantation crop of india and often described as “ Kalpavriksha” because of the multifarious use of every part of it in the commercial sector.Coconut is grown in almost 94 countries in the world of which 90% of the production comes from Asian and Pacific countries.Andhra Pradesh occupies fourth position in coconut growing area and production(1.15 lakh ha;1378 million nuts). Coconut palms are normally affected by various insect pests and diseases resulting into reduction in yields. Among the various fungal diseases affecting coconut palm, basal stem rot (BSR) or wilt or root rot caused by *Ganoderma* spp. viz., *G. lucidum*, *G. boninense*, *G. applanatum* etc., is the most destructive. *Ganoderma* spp. has a wide host range attacking a variety of palms and several

forest, avenue and fruit trees. According to Naidu et al., (1986), hosts belonging to 19 families, 36 genera and 48 species have been reported to be affected by *Ganoderma* spp. Coconut palms in the age group of 10–30 years are easily attacked by the pathogen.

Symptoms:

- The trees in the age group of 10-30 years are easily attacked by the pathogen.
- The most usual symptoms are yellowing, withering and drooping of the outer fronds which remain hanging around the trunk for several months before shedding.
- The new fronds produced become successively smaller and yellowish in colour which do not unfold properly.
- The wilting plants also show bleeding patches near the base of the trunk.
- A brown gummy liquid oozes out from the cracks in the tree which slowly result in the death of outer tissues.
- In the advanced stages of infection, the fungus produces fruiting body (Bracket) along the side of the basal trunk.
- The roots of wilting trees show discoloration and severe rotting.

**(a)****(b)****(c)****Pathogenic character:**

The fungus produces a semi circular basidiocarp (bracket), which is attached to the tree with a stalk. The bracket is very big about 10-12 cm diameter and woody. The upper surface is almost black with concentric furrows. The lower surface is white and soft with numerous minute pores. Basidiospores are oval, brown and thick walled.

Mode of spread and survival:

- *Ganoderma* disease (Basal Stem Rot) spreads mainly through root-to-root contact, infected soil or water, and old stumps, with the pathogen surviving long-term in soil

via tough chlamydospores.

- It thrives in sandy soils, during drought/water stagnation, and affects older palms (10-30 years), requiring removal of infected trees and preventing water flow between healthy/sick areas for control.

Management:

Cultural method:

- Remove and destroy all affected palms.
- Green manure crops must be raised and ploughed in situ before flowering.

Biological method:

- Apply *Pseudomonas fluorescens* (Pf-1) @ 200g/palm + *Trichoderma viride* @ 200g/palm/year.
- Apply FYM 50kg + neem cake 5 Kg once in 6 months along with fertilizers.

Chemical method:

- Root feeding with Tridemorph 2ml or Hexaconazole 1 ml with 100 ml of water (3 times at 3 months interval).
- Forty litres of 1% Bordeaux mixture should be applied as soil drench around the trunk in a radius of 1.5m.

Conclusion

Ganoderma disease poses a serious threat to coconut plantations, causing root and basal stem rot that can lead to significant yield loss and tree death. Effective management requires an integrated approach—combining cultural practices like proper sanitation and soil health improvement, use of resistant varieties, biological control agents, and timely chemical treatments. Early detection and continuous monitoring are key to preventing spread. By adopting these strategies, farmers can protect their coconut palms, sustain productivity, and reduce economic losses caused by Ganoderma infection.

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FROST MANAGEMENT IN HILL VEGETABLES: TRADITIONAL WISDOM MEETS MODERN SCIENCE

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***P. Jaisridhar, P. Raja, S. Manivasakan, R. Shanmugam, B. Vinoth Kumar, S. Thenmozhi
& M. Vijayakumar**

ICAR – Krishi Vigyan Kendra, Tamil Nadu Agricultural University, The Nilgiris, India

*Corresponding Author: P. Jaisridhar

Introduction

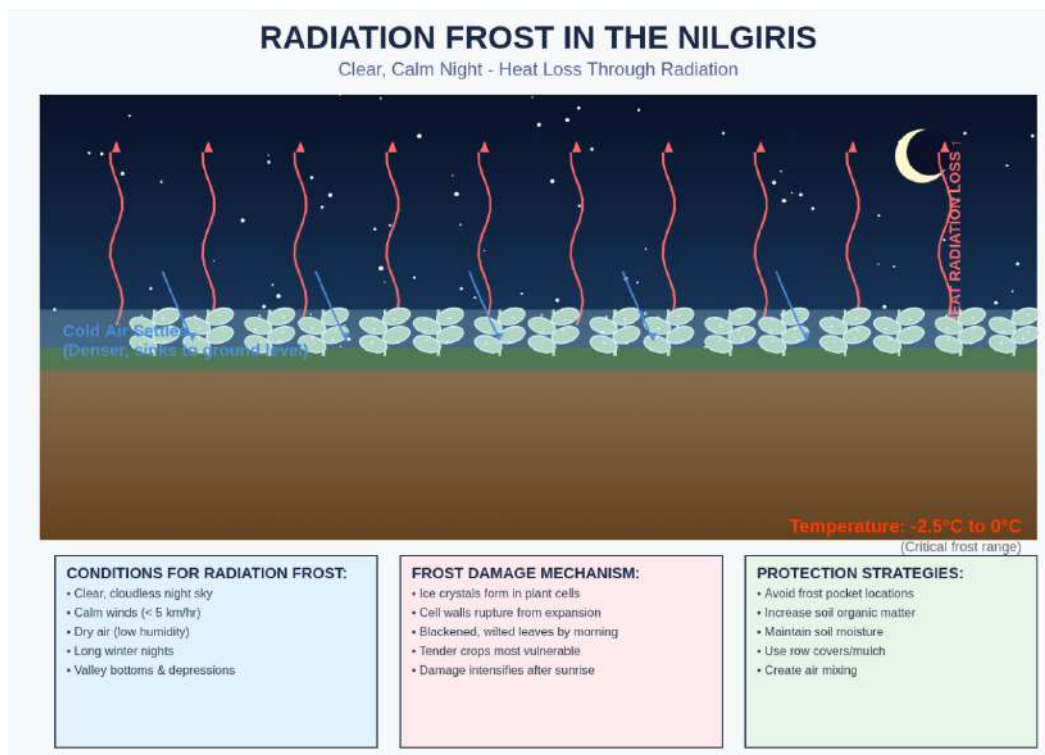
The morning of January 2025 brought an unwelcome surprise to the Nilgiris - temperatures plummeting to -2.5°C , the coldest recorded in recent memory. Across the undulating hills, vegetable farmers watched helplessly as frost painted their carefully tended crops white, leaving behind blackened, wilted leaves by mid-morning. What was once an occasional winter challenge has now become an unpredictable threat, striking earlier, lasting longer, and occurring with greater intensity than our grandparents ever experienced?

Yet, amid this climate chaos, there exists a reservoir of time-tested wisdom. The indigenous Toda and Badaga communities have cultivated these hills for centuries, developing ingenious strategies to protect their crops from frost's icy grip. Today, as climate variability intensifies, the fusion of this traditional ecological knowledge with modern agricultural science offers our best hope for resilient hill vegetable production.

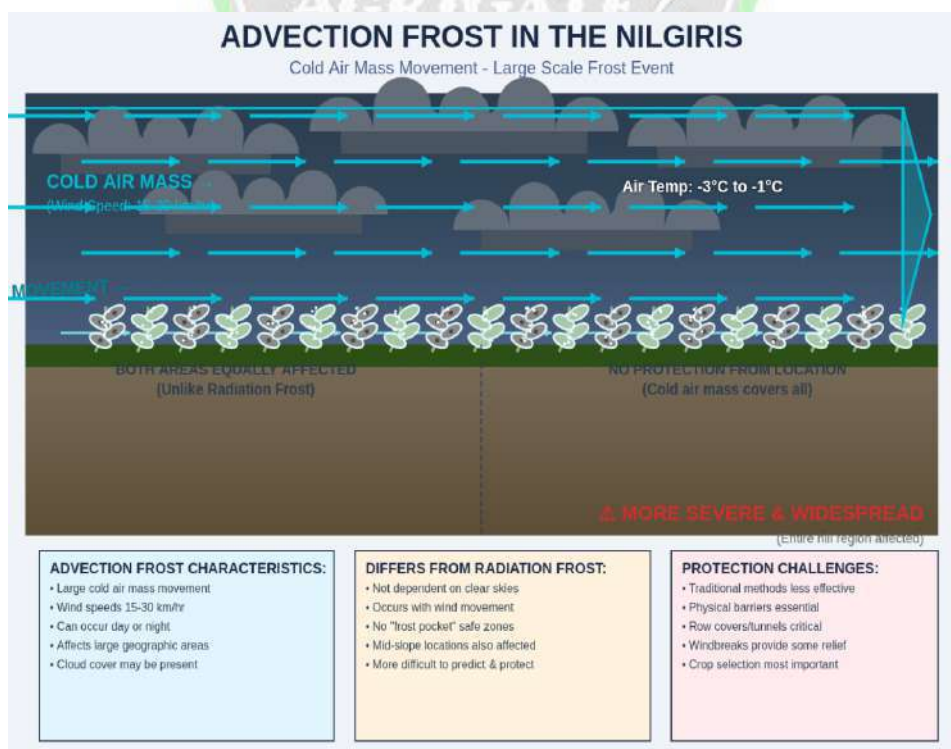
Understanding Frost in the Nilgiris Context

Frost occurs when surface temperatures drop below 0°C , causing ice crystals to form on plant tissues. In the Nilgiris, two types of frost predominately affect our crops:

Radiation frost develops on clear, calm nights when heat radiates rapidly from the soil surface. This is the most common type in our region, particularly in valley bottoms and depressions where cold air settles - what meteorologists call "frost pockets."



Advection frost results from large cold air masses moving into the region, often accompanied by wind. While less common, these events can be more devastating as they affect larger areas and are harder to protect against.



The damage mechanism is straightforward yet cruel: ice crystals form inside plant cells, rupturing cell walls and causing the characteristic blackening and wilting we observe. Tender crops like tomatoes, beans, and leafy vegetables are particularly vulnerable, while cabbage, cauliflower, and root vegetables show greater tolerance.

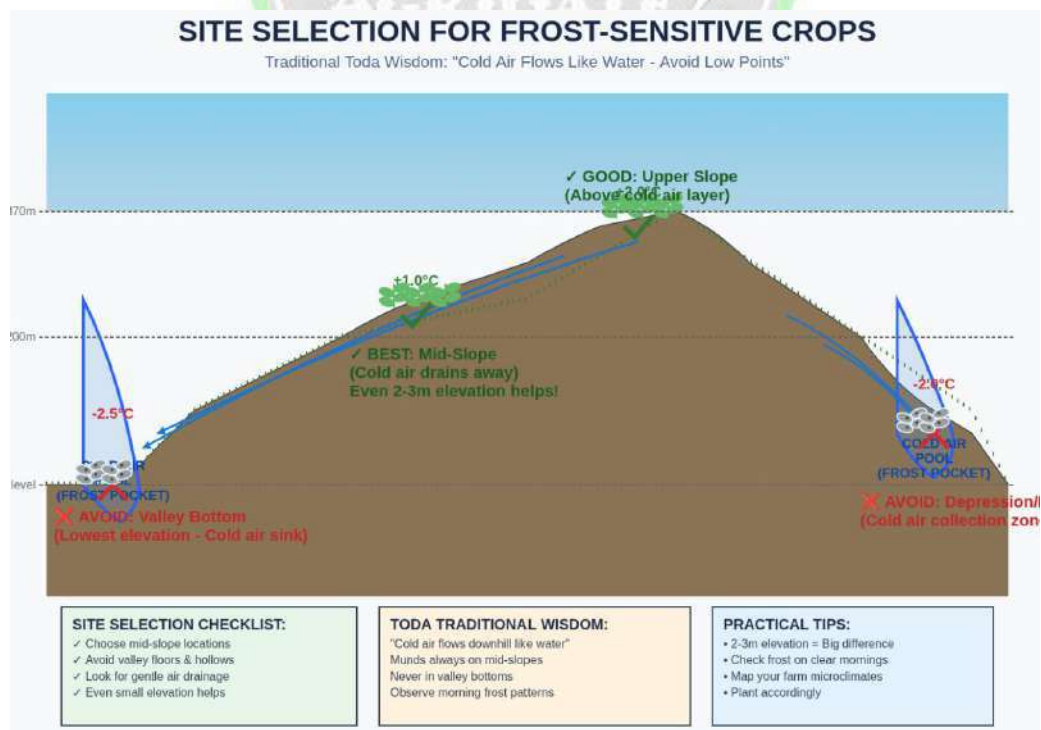
Traditional Toda Wisdom: Lessons from the Mandu Keepers

The Todas, pastoral guardians of the Nilgiris for over a millennium, have developed sophisticated frost management strategies centered around their sacred buffalo-rearing traditions. Their approach offers profound insights for modern vegetable cultivation.

Landscape Reading and Microsite Selection

Toda settlements, or munds, are never located in valley bottoms. As elder Kuttan of Karkada mund explains, "Cold air flows like water - it seeks the lowest point." This indigenous understanding of cold air drainage perfectly aligns with modern micrometeorology. Toda communities establish their munds and cultivation areas on gentle mid-slopes where cold air flows away rather than pooling.

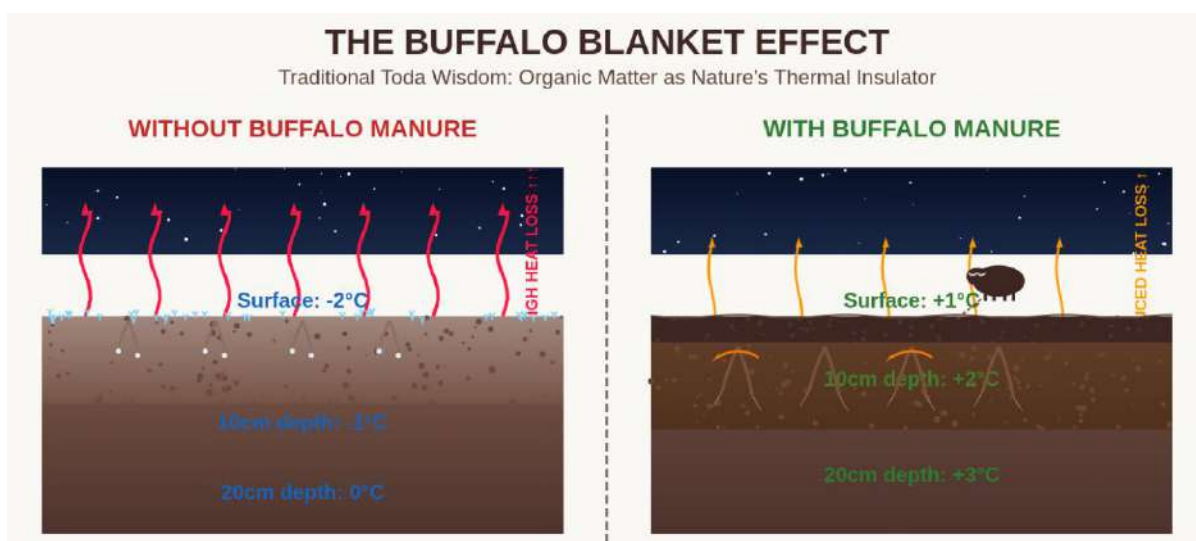
For vegetable farmers, this translates to a critical site selection principle: *avoid depressions and valley bottoms for frost-sensitive crops*. Even a 2-3 meter elevation difference can mean the difference between crop survival and loss during frost events.



The Buffalo Blanket Effect

Around Toda settlements, buffalo manure is systematically applied to cultivated areas throughout winter. Beyond its nutritional value, the Todas have observed that manured soils remain warmer. Modern science confirms this: organic matter increases soil heat capacity and improves thermal conductivity, helping soil retain and release heat more gradually. Buffalo dung mulches also create a physical barrier, reducing radiative heat loss from the soil surface.

Practical Application: Apply well-decomposed farmyard manure (5-7 tons/acre) to vegetable beds 2-3 weeks before expected frost periods. The dark color absorbs more solar radiation during the day, while the organic matter buffers temperature fluctuations.



Windbreak Wisdom

Traditional Toda munds are surrounded by stone walls and strategically positioned vegetation. While primarily for livestock management, these structures serve a secondary frost protection function by disrupting cold air flow and creating calmer microclimates. The Todas intuitively understood that gentle air mixing prevents extreme temperature drops.

Badaga Agricultural Practices: Centuries of Crop Protection

The Badaga community, the Nilgiris' predominant agricultural tribe, has refined frost management techniques through generations of vegetable and millet cultivation.

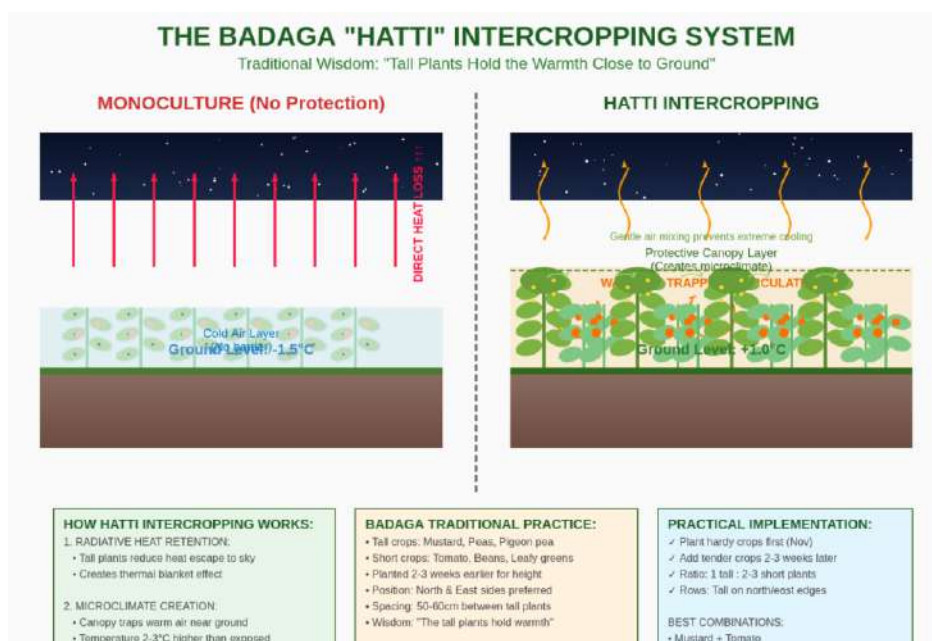
The 'Hatti' System of Intercropping

Traditional Badaga vegetable gardens, called hattis, employ dense intercropping patterns that modern agronomists are only now fully appreciating. Taller crops like pigeon pea or maize are

planted alongside shorter vegetables in specific patterns. As Rama from Kotagiri explains, "The tall plants hold the warmth close to the ground during cold nights."

Scientific explanation: The taller crops create a modified microclimate by reducing radiative heat loss from the soil surface. They also induce slight air turbulence that prevents extreme temperature stratification near the ground.

Practical Application: Intercrop frost-sensitive vegetables like tomatoes and beans with hardy plants like mustard or peas planted 2-3 weeks earlier. The taller companion crops should be positioned on the northern and eastern sides to avoid shading while providing frost protection.



Smoke Generation Traditions

During extreme cold nights, Badaga farmers traditionally light uppu (green branch fires) at field edges. The smoke serves dual purposes: it creates a physical barrier reducing radiative cooling, and the particles act as condensation nuclei, encouraging dew formation rather than frost crystallization at higher temperatures.

While effective, traditional smoke generation has environmental drawbacks. Modern adaptations using cleaner methods can preserve the principle while reducing air pollution.

Mulching with Native Materials

Badaga farmers have long used shambe (bracken fern) and forest litter as mulch materials. Applied thickly around vegetable plants before winter, these materials insulate the soil surface and protect root zones.

The practice also suppresses weeds and gradually improves soil organic matter.

Practical Application: Apply 5-7 cm thick mulch of locally available materials (dried grass, shredded leaves, or rice straw) around vegetable plants by late November. Ensure mulch doesn't directly contact plant stems to prevent fungal diseases.

Modern Scientific Frost Protection Methods

Contemporary agricultural science offers additional tools that can complement traditional practices:

Row Covers and Low Tunnels

Non-woven agricultural fabric (spunbond) or perforated plastic covers supported by bamboo hoops can create a 2-4°C temperature buffer. These are particularly effective for crops like tomatoes, capsicum, and beans.

Implementation: Install low tunnels (60-90 cm height) over raised beds. Remove or vent covers during warm days to prevent excessive heat buildup and ensure pollination access.

Overhead Sprinkler Irrigation

A counterintuitive but highly effective method involves continuous sprinkling when temperatures drop below 2°C. As water freezes on plant surfaces, it releases latent heat, maintaining leaf temperature at 0°C rather than dropping further. This method requires significant water availability and careful monitoring.

Suitability for Nilgiris: Limited to farmers with reliable water sources and electricity. Best suited for high-value crops like strawberries or specialty vegetables.

Anti-Transpirant Application

Foliar sprays containing film-forming polymers or kaolin clay create a physical barrier on leaf surfaces, reducing ice crystal formation and water loss. Products like "Vapor Gard" have shown 30-40% frost damage reduction in trials.

Application protocol: Spray 3-5 days before anticipated frost events, preferably in late afternoon. Reapply after heavy rains or every 2-3 weeks during high-risk periods.

Soil Moisture Management

Moist soils have higher heat capacity than dry soils and release more heat during cold nights. Strategic irrigation 1-2 days before predicted frost events can provide 1-2°C temperature buffering at ground level.

Critical consideration: Avoid waterlogging, which can exacerbate frost damage by creating conditions for ice formation around root zones.

Integrated Frost Management Strategy for Nilgiris Farmers

The most resilient approach combines traditional wisdom with modern science:

Pre-Season Planning (October-November)

1. **Site selection:** Choose mid-slope locations; avoid frost pockets
2. **Soil preparation:** Incorporate 5-7 tons FYM per acre
3. **Cultivar selection:** Prefer frost-tolerant varieties when available
4. **Planting schedule:** Stagger plantings to spread risk
5. **Windbreak establishment:** Plant hedgerows of hardy species on northern boundaries

Season-Long Practices (November-March)

1. **Mulching:** Apply 5-7 cm organic mulch by late November
2. **Intercropping:** Integrate taller hardy crops with frost-sensitive vegetables
3. **Soil moisture:** Maintain moderate moisture; irrigate 1-2 days before predicted frost
4. **Canopy management:** Avoid excessive pruning that exposes fruits/stems

Frost Event Response (When frost is predicted)

1. **Immediate protection:** Deploy row covers or low tunnels
2. **Smoke/heat:** Use clean-burning materials in extreme cases (charcoal briquettes better than green wood)
3. **Sprinkler irrigation:** If facilities available and temperatures $> -2^{\circ}\text{C}$
4. **Anti-transpirant spray:** If applied 3-5 days prior

Post-Frost Recovery

1. **Delay pruning:** Wait 3-5 days to assess actual damage
2. **Gentle irrigation:** Prevent additional stress from desiccation
3. **Foliar nutrition:** Apply water-soluble fertilizers to support recovery
4. **Disease prevention:** Monitor for secondary fungal infections

Looking Ahead: Adapting to Increasing Climate Variability

The -2.5°C event of January 2025 may be a harbinger of more extreme and unpredictable weather patterns. To build resilience, Nilgiris vegetable farmers must adopt a multi-pronged adaptation strategy:

1. Crop Diversification with Heritage Varieties

Beyond mainstream vegetables, revive cultivation of indigenous frost-hardy crops that our grandparents grew - heritage radishes, turnips, local carrot varieties, and traditional leafy greens. These crops co-evolved with Nilgiris' climate and carry genetic resilience we desperately need.

2. Protected Cultivation Systems

Invest incrementally in protective structures. Begin with simple low tunnels for high-value crops, gradually expanding to walk-in poly-tunnels or shade-net structures. While capital-intensive, these provide year-round production stability and can buffer both frost and excess rainfall extremes.

3. Community-Based Frost Warning Systems

Establish village-level frost monitoring networks using affordable digital thermometers with min-max memory. Share observations via WhatsApp groups to provide advance warning to neighboring farmers. Link with IMD Agro-met advisories for broader weather pattern awareness.

4. Indigenous Knowledge Documentation and Sharing

Systematically document Toda and Badaga frost management practices through participatory research. Organize inter-generational knowledge exchange programs where elders share traditional wisdom with younger farmers, bridging the gap between ancestral knowledge and modern techniques.

5. Carbon-Positive Farming Systems

Embrace agroforestry and organic matter building as both climate change mitigation and adaptation. Higher soil organic carbon improves frost resilience while contributing to global climate solutions. Every ton of additional soil organic matter is both a frost buffer and a climate action.

6. Market Linkages for Climate-Resilient Production

Develop premium markets for organically produced, frost-protected vegetables. Consumer awareness of climate challenges can translate into price premiums that justify protective investments. Certification as "climate-resilient produce" could open new market opportunities.

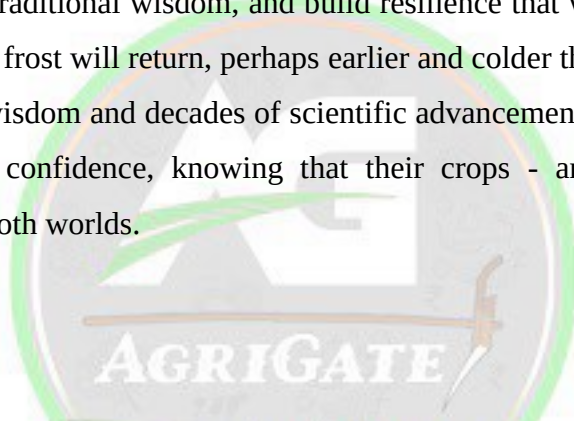
7. Weather-Indexed Insurance

Advocate for and participate in weather-indexed crop insurance specifically designed for hill agriculture. Such schemes can provide financial safety nets when protective measures fail during extreme events.

Conclusion

As we stand at the intersection of accelerating climate change and rich indigenous heritage, the path forward for Nilgiris vegetable farming is neither purely traditional nor exclusively modern - it is intelligently integrated. The Todas teaching us to read landscapes, the Badagas showing us the value of intercropping and mulching, and modern science providing protective technologies - together these form a robust shield against frost's increasing unpredictability.

The -2.5°C morning of January 2025 was harsh, but it need not be devastating. With informed site selection, soil building, timely protection measures, and community solidarity, our hill vegetable farmers can transform this climate challenge into an opportunity - an opportunity to farm smarter, honour traditional wisdom, and build resilience that will sustain the Nilgiris for generations to come. The frost will return, perhaps earlier and colder than before. But armed with centuries of indigenous wisdom and decades of scientific advancement, Nilgiris farmers can face each frozen dawn with confidence, knowing that their crops - and their livelihoods - are protected by the best of both worlds.



FUSARIUM WILT IN BANANA: THEIR MANAGEMENT

Article ID: AG-VO6-I01-82**A.Ananthapriya**

Undergraduate Student of B.Sc. (Hons.)Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Fusarium wilt of banana, caused by *Fusarium oxysporum* f. sp. *cubense*, is a major disease that seriously affects banana production. The disease spreads through infected planting material, soil, water, and farm tools, and can survive in soil for many years. In India, it causes heavy yield losses, especially in susceptible varieties like Rasthali and Karpuravalli. Common symptoms include yellowing and wilting of leaves, vascular discoloration, and plant death. Effective control mainly depends on using resistant varieties, clean planting material, good field sanitation, and integrated management practices to reduce disease spread.

Introduction

Banana is the world's most important fruit in terms of production ,volume and trade and among the world's top 10 staple foods. Although fruits of the wild banana plants (*Musa* spp.) have large, hard seeds, most edible bananas are seedless. Banana plants are therefore propagated asexually from offshoots. Because these rhizomes are usually free of symptoms even when the plant is infected by *Fusarium oxysporum* f.sp. *cubense* , they are a common means by which this pathogen is disseminated. It can also be spread in soil and running water, on farm implements or machinery.The disease was first reported in Australia in 1874.In Asia, the disease was first recorded in 1911 in West Bengal, India, and the disease now is widespread and destructive in almost all the banana growing states in India, causing disease incidence of 30% in the plant crop and up to 85% in the ratoon crop. The cultivars ‘Rasthali’ ,‘Karpuravalli’, ‘Monthan’ and ‘Virupakshi’ are severely affected by fusarium wilt disease.This disease is considered one of the most destructive disease in banana . In the mid-twentieth century Fusarium wilt also known as

"Panama disease". Panama disease affects a wide range of banana cultivars; however, it is best known for the damage it caused to a single cultivar in the early export plantations.

Taxonomic position:

Kingdom: Fungi

Phylum: Ascomycota

Class: Sordariomycetes

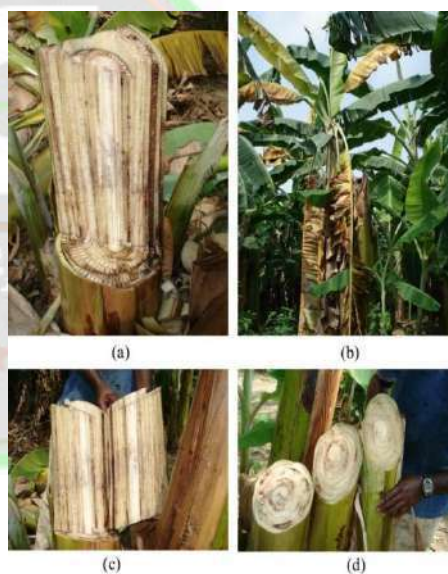
Order: Hypocreales

Family: Nectriaceae

Genus: *Fusarium*

Species: *F. oxysporum*

Forma Species: f. sp. cubense.

Symptoms

- It Infects all stages of crop growth.
- Characteristic yellowing of older leaves accompanied by vascular discolouration in the outer leaf sheath.
- The yellowing develops as a band along the margin and spreads towards the midrib .
- The leaves are wilt, and the leaf hangs between the pseudostem .
- When an affected rhizome is cut transversely, reddish vascular strands appear as yellow, red or brown dots and streaks.
- The infected pseudostem and rhizome emits a characteristic foul odour and the plant dies.

Pathogenic character:

Causal organism is *F. oxysporum* f. sp. Cubense. The pathogen contains colonies of white to purple pigmented mycelium, which is hyaline and septate. Microconidia, macroconidia, conidiophores were observed. Microconidia are non septate, slightly curved. Macroconidia are slightly sickle shaped, thin walled, 3-5 septate.

Mode of spread and survival:

- Fusarium wilt spreads through infected suckers/rhizomes, infested soil (on tools, shoes, vehicles, water), and contaminated irrigation/runoff water.
- The fungus surviving for decades as resting structure chlamydospores in soil and plant debris, making it hard to eradicate once established

Management Practices:**Cultural method:**

- Practice proper crop rotation with paddy or sugarcane
- Choose wilt resistant cultivars such as poovan, nendran
- Remove and destroy infected plant material
- Provide good drainage

Mechanical method:

- Machinery and equipment should be treated with sanitary solution
- Provide mechanical barriers in and around the infected plants

Biological method :

- Application of *opsrudomonas fluorescence* @2.5 kg /ha
- Application of biocontrol agents like *Trichoderma viride* @25g for 4 times

Chemical method:

- Apply 2 percent of carbendazim as injection of carbendazim 50ml capsule application
- Pairing and pralinage should be done
- Application of neem cake @250kg / ha was most effective in controlling fusarium wilt in Rasthali cultivar

Conclusion

Fusarium wilt of banana, caused by *Fusarium oxysporum* f. sp. *cubense*, is one of the most destructive diseases affecting banana production worldwide. Its soil-borne nature, long

survival in soil, and ease of spread through infected planting material make it extremely difficult to control once established. The disease leads to severe yield losses, threatens farmer livelihoods, and poses a serious risk to global banana diversity. Effective management of Fusarium wilt relies primarily on preventive measures, including the use of disease-free planting material, cultivation of resistant or tolerant varieties, strict quarantine and sanitation practices, and integrated disease management approaches. Continued research, surveillance, and farmer awareness are essential to limit its spread and ensure sustainable banana production in the future.

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INTEGRATED RODENT PEST MANAGEMENT IN RICE

Article ID: AG-VO6-I01-83**Inba arasi .M**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Rice is a major staple crop in India, but its production is greatly affected by rodent pests, which cause damage from sowing to harvest, especially during the tillering stage. Rodents attack seeds, seedlings, tillers and panicles, leading to serious yield losses in all rice ecosystems. This article explains the nature of rodent damage in rice and outlines different management practices. Cultural methods such as habitat manipulation and bund management, mechanical methods like trapping and burrow destruction, biological control using predators such as barn owls, and chemical control using rodenticides are discussed. Indigenous Technical Knowledge (ITK) practices, including the use of cow dung and kerosene as repellents, are also highlighted. An integrated approach to rodent management is essential for reducing crop losses, ensuring environmental safety and achieving sustainable rice production.

Introduction

Rice is the staple food crop for over 3 billion people in the globe and is a major cereal in India meeting dietary requirement of nearly 70% of country's population. Rice is cultivated in an areas of 43.79 million hectares with a production of 112.9 million tons of milled rice with an average productivity of 3.38 t/ha in the country. Major rice growing states of India are West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu, Orissa, Bihar and Chhattisgarh account .Andhra Pradesh is the rice bowl of the country with a production of 93.23 lakh tons of milled rice from 23.56 lakh hectares. Among various biological constraints in rice cultivation, rodents are one of the major problem, causes considerable damage to rice crop in India irrespective of the type of rice production system viz., irrigated, wetland or upland. The rodents

can attack rice plants throughout their growth periods i.e. from seedling to harvesting. However, the attack raise during maximum tillering.

Nature of Rodent Damage in Rice

Rodents tend to attack the rice crop from sowing to harvest and cause damage to germinating seeds in the seed bed, growing seedlings in the nursery, tiller damage in the transplanted crop, panicle hoarding in the burrows in ripened crop. Generally lesser bandicoots make a slant cut to the rice tiller.

Before transplanting or immediately after transplanting, the rodent incidence was found less (live burrows) though their populations are at higher rates, because of their immigration from the non cropped areas into the transplanted fields. Meanwhile they are in search of suitable habitat and cause damage to the transplanted seedlings/tillers, which is very scattered in nature. As the crop attains active tillering stage, rodents establish their permanent burrow habitats on field bunds near the crop areas and cause damage to the rice tillers.



Rodent Management Methods in Rice

The aim of rodent control is primarily for damage reduction, but not individual rat killing, there is a necessity of monitoring the situation in different ecosystems through either their damage or through their levels of infestation. The control decision may be taken depending on the monitoring surveys. The majority farmers in these rice growing deltas are renter that too small and marginal, normally do not adopt any rodent control measures, until the initiation of rodent population. The normal practices followed by farmers include bounty payment, trapping with indigenous bamboo traps, poison bait application, which often includes phorate application. Reports on mortality of non-target animals like birds also exist in these districts due to acute poisons and their improper use.

Cultural methods

Habitat manipulation: This technique is primarily based on ecological concepts wherein the rodents' habitat is manipulated in such a way that creates stress among native rodent pests. The methods are low cost treatments and involve little modification in crop husbandry practices, like ploughing, puddling, removal of wild vegetation and refuge of previous crops and reduction in bund size etc. It helps in migration of pest rodents from crop fields. Studies carried out at A.P. rice research institute revealed that the narrow and less number of bunds recorded lower rodent infestations over the larger bunds and they suggested to maintain the bund diameter less than 30-40 cm to control the rodent infestation in rice fields. Further, weed and debris free field bunds recorded 50 % less rodent incidence. Trimming of field bunds before transplanting, immediately after puddling disturbs the rodent burrows on field bunds, thus causes the animals to vacate their habitations.

Mechanical and physical methods

Trapping, burrow smoking, mass hunting, burrow digging/destruction, fumigation and poisoning technologies control rodent's infestation however in some times the above technologies may not give satisfactory results because of rat's (rodent's) adaptability, improper application of methodologies and environmental factors.

Trapping: Among the various rodent management practices, trapping rodents in fields and premises is a common old practice and it was found quite effective in certain conditions. Two basic types of traps are being in use the snap or kill trap and the live trap in southern India. Among the snap traps, the Tanjore kitty a low cost bamboo trap generally used by professional trappers in rice fields in Tamil Nadu and butta a bamboo snap trap containing a basket for lure placement. Butta trap was highly effective in trapping the rodents from rice fields. These two traps are made of local materials viz., palmyra leaves and bamboo sticks, hence they are easily available, eco-friendly, cheaper and easy to operate for trapping rice rodents. Butta traps for rodent control, especially after transplanting to tillering stage. Rat trappers charge about Rs. 20-50 per one successful trap. Bamboo made snap traps are laid along the periphery of fields to trap rodents immigrating from surrounding forests. This practice is often done at crop maturity stage when the rodent's destruction is at its peak, however this eco-friendly method may prove effective if performed in a planned schedule.

**Burrow Smoking:**

Burrow smoking in rat control is a traditional and effective method used in agriculture to manage rodent pests. It involves introducing smoke into rat burrows to suffocate or drive out rats. Materials like dried leaves, straw, cow dung cakes, or sulfur are commonly used. Smoke spreads inside the burrow system, reducing oxygen availability. This method is mainly practiced in fields, bunds, and non-residential areas. Burrow smoking is more effective when all burrow openings are closed except one. It helps in controlling rats without using chemical poisons. The method is low-cost and suitable for small and marginal farmers. It should be done early morning or evening when rats are inside burrows. Care must be taken to avoid fire hazards and inhalation of smoke. Burrow smoking is usually combined with other rat control measures for better results.

Burrow Digging:

Burrow digging in rat control is a mechanical method used to reduce rodent population in agricultural fields. It involves digging out rat burrows to expose and capture rats. The method destroys nests, food stores, and breeding places of rats. Burrow digging is effective during early crop stages and fallow periods. Rats are usually killed manually or trapped once they come out of burrows. This method helps in identifying active and inactive burrows. It reduces rat population without using chemicals or poisons. Burrow digging requires more labour and time. It is eco-friendly and safe for humans, livestock, and wildlife. The method is commonly practiced in small farms and villages. Burrow digging gives better results when combined with flooding or trapping.

Biological methods**Predators:**

Several vertebrates, mainly birds and mammals are listed as natural predators of rodents in literature. However, cats in domestic situation and snakes, owls, mongoose and varanids are predominant vertebrate predators of rodents. In the Cauvery Delta of Tamilnadu, India, studies on barn owl as potential bio-control agent revealed a predation rate of 1-6 (Av 1.58).

rodents/night. Predators such as predators need to be introduced and rehabilitated for ecofriendly management of rodents. Establishment of 2-3 owl perches per acre or artificial owl boxes at undisturbed elevations in crop fields is highly recommended to establish and multiply native owl population to keep the rodent pests under check



Chemical methods:

Use of rodenticides is the most common, expedient and humane method to control pest rodents and therefore form the basis of present day rodent management strategy in most part of the world. They have greater scope in large-scale control operations, since mixed population of several species are encountered in fields.

Botanical rodenticides:

Botanical rodenticides are plant-based materials used to control rats and other rodents in agricultural fields. They are prepared from plants that possess natural toxic or repellent properties, such as Calotropis, Datura, neem. Different parts of the plant, including seeds, leaves, roots are used depending on the type of preparation. These botanical materials act by poisoning rodents, repelling them, or reducing their feeding activity. Since they are derived from natural sources, botanical rodenticides are biodegradable and environmentally friendly. They are generally safer to humans, livestock, and other non-target organisms when compared to chemical rodenticides. This method is low-cost and well suited to traditional and small-scale farming systems. Botanical rodenticides are biodegradable and environmentally friendly. They are generally safer to humans, livestock, and other non-target organisms when compared to chemical rodenticides. This method is low-cost and well suited to traditional and small-scale farming systems. Farmers can easily prepare and apply them using locally available materials.

Chemical rodenticides:

The rodenticides registered under the Insecticides Act, 1978 broadly belong to two categories based on their ingestion - oral and respiratory. Between oral rodenticides again two

types exist (i) fast acting or acute, which bring mortality within 24 hours and (ii) slow acting or chronic, which bring mortality after 3-5 days based on the toxicant. Among oral toxicants, six rodenticides exist registered under the Act, while only one fumigant can be classified under respiratory poison category.

Acute rodenticides:

Among acute rodent poisons, only zinc phosphide, barium carbonate and aluminium phosphide are registered by Government of India for common use. Prakash and Mathur (1987) reported that barium carbonate possesses low toxicity with variable efficacy against rodents, is required at very higher requirements in baits (10-20%) and is therefore not in use presently.

Zinc phosphide (Zn₃P₂):

Zinc phosphide is greyish black, garlic like smelling powder, produced by direct combination on zinc and phosphorus. It is the most commonly used acute rodenticide in the world. In India also it is widely used by the farmers which commonly called by farmers as black powder. Zinc phosphide baits are quite stable in air and non-acidic media & insoluble in water and alcohol, stable when dry, but decomposes gradually in moist air.

Chronic rodenticides:

In chronic rodenticides, only anticoagulants were registered and available for field use in India though several non-anti-coagulant rodenticides (Calciferol, cholecalciferol, bromethalin and Flupropadine) proved their efficacy in several field research experiments conducted in India and elsewhere. Anti-coagulant rodenticides interfere with blood coagulation process leading to internal bleeding and hemorrhage in the target animals. As per the provisions of Insecticide Act (1968) only four anticoagulants i.e. warfarin, coumatetralyl and bromadiolone were registered in India (Mohan Rao and Malla Reddy). Warfarin has been withdrawn from the market as most of the pest rodent species has developed resistance after its large scale use. Presently, bromadiolone is the only anticoagulant rodenticide available in India and it has been in use for containing the field rodents.

Fumigants: Aluminium phosphide (AlP): is an inorganic compound used as a wide band gap semiconductor and a fumigant. Aluminium phosphide reacts with water or acids to release phosphine following hydrolysis



ALP is the most common fumigant rodenticide is available in both tablet and pellet forms, however only pellet formulation is recommended for rodent burrow fumigation (Rao, 2003). But, recently the pellet formulations were banned in India by CIBRC, hence only tablets are available for fumigating the rodent burrows. For fumigation, all the existing burrow openings are plugged with wet mud and aluminium phosphide tablet is inserted in the active burrows, which should also be plugged with mud to check the escape of lethal gas. All the nearby burrow openings need to be plugged invariably. The dead rodents are to be collected next day and disposed off. The fumigant is more effective in humid zone and irrigated fields with heavy soil. It is never recommended for residential premises/indoor use. Because of its extreme toxicity to non-targets and absence of an antidote, Government of India has put this chemical under restricted ban.

ITK In rat managent:

Rat repellent method in paddy crop:

To control rats in paddy fields, a mixture of 10 kg of fresh cow dung and 1.5 litres of kerosene is used. The cow dung and kerosene should be mixed thoroughly to form a thick, uniform paste. This paste is then made into small round balls. These balls are placed along the field bunds, near rat burrows, at about 10 feet interval. The strong smell of this mixture acts as a repellent and helps to drive rats away from the field.

Stem borer management:

For controlling stem borer, fresh cow dung is taken as required and a small quantity of kerosene is added, just enough to prepare a paste. The mixture is blended well to obtain a thick paste-like consistency. This paste should be applied at the base of the plant or over the holes made by stem borer larvae on the stem. The paste seals the holes, thereby preventing further entry of insects, and at the same time the foul smell repels the pests and reduces their activity.

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INDIGENOUS TECHNICAL KNOWLEDGE – PEST MANAGEMENT

Article ID: AG-VO6-I01-84**V.Kalki**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Indigenous Technical Knowledge (ITK) is the traditional knowledge used by farmers to control pests in crops using natural and locally available materials. These methods mainly use plant products such as neem, chilli, garlic, ginger and jatropha, and help reduce the use of chemical pesticides. ITK practices are used to control insect pests, storage pests and rodents. Some common practices include deep summer ploughing to reduce soil pests, spraying neem leaf extract to control sucking pests, leaf clipping in rice to reduce stem borer attack, and using neem leaves in grain storage. Farmers also use simple methods like placing long hair in coconut crowns to control rhinoceros beetle. Plant-based preparations such as chilli solution, jatropha leaf extract and 3G karaisal are effective against pests like aphids and leaf folders. Overall, ITK practices are simple, low cost and eco-friendly, and they help in maintaining crop health and protecting the environment.

Introduction

Indigenous Technical Knowledge (ITK) refers to the management of knowledge existing within the involvement of traditional, location specific, eco friendly methods developed by farmers, using local available resources like plant extract (chilli, ginger, garlic, neem etc.,) offering a sustainable, non-chemical alternative to synthetic pesticides, often integrated with modern Integrated Pest Management (ITK) for healthier life of crops and environment. It is used as a pest and non pest control. The pests are controlled using Neem extracts/cake, and many traps are used to control the non pest like rat and other field pest etc.,. It also manages pests such as stem borers, leaf folder, bugs, and rodents, and reducing reliance on chemical use. These practices

involves the local plants for trapping and disruption of pest cycles, promoting sustainable pest management.

ITKs in insect pest management in field crops

Deep ploughing in summer is helpful in preventing the white grubs, etc., It is mostly prevalent in Madhya Pradesh.

Spraying of neem leaf extract to control the many sucking pests like Aphids, Whiteflies, Thrips, Leafhoppers, Mealy bugs, Mites, Scale insects, Spodoptera etc.,

Leaf clipping of rice seedling to control stem borer attack as because by clipping we can remove egg masses of stem borer.

By placing of neem leaf in the storage place is effectively used to control the storage grain pest.

Placing long hair of women in the crown portion of coconut tree to control the rhinoceros beetle (*Oryctes rhinoceros*). The beetle engulfs with the long hair due to which they cannot move.

Core Concepts of ITK in Pest Management

It is a Holistic and Eco friendly approach and use of locally available resources like plants, cowdung etc., It is often low cost, resource-efficient, and promotes waste recycling, supporting sustainable livelihoods.

Preparation of ITKs for Pest Management

Jatropha leaf extract

Spraying of Jatropha leaf extract to control of leaf folders in paddy.

It is prepared by making of (20Kg of Jatropha leaf + 200 litres of water).

Preparation of chilli solution

To control Aphids in paddy by spraying of (2 Kg of chilli powder + 200 litres of water)



Pungam and neem leaf extract

To repel the grain moth in paddy Pungam and neem leaf are mixed with grains. Pungam contains fatty acids acts as a potent insecticides.



Chilli leaf extract

Spraying of bird eye chilli leaf extract is used at five per cent concentration, it was done usually after the appearance of the incidence.

Chilli leaf extract, rich in capsaicin, is a natural compound used as an organic pesticide to repel insects like aphids, thrips, mites etc.,



3G Karaisal

To control the sucking pests by 3G karaisal involves by the mixture of three plant extracts. 18 grammes of garlic is taken, the outer skin is removed and made into paste. A paste of 9 grammes of green chilli and 9 grammes of ginger is made. All the three pastes are dissolved in 1 litre of water. This mixture is stirred well and filtered before spraying. 500 ml of this extract is made with 100 ml of soap solution and 9.4 litres of water and sprayed on the top.



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MANAGEMENT OF N FERTILIZER IN RICE FIELD: A REVIEW

Article ID: AG-VO6-I01-85***S.Madhu Vini, P. Ilanthamil and R. Karpagavalli**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

*Corresponding Author: S.Madhu Vini

Abstract

Rice is one of the most important cereal crops in the world and a staple food for more than half of the global population, especially in Asia. Rice production in the world was more than 800 million tonnes (Mt) in 2023. Rice belongs to the genus *Oryza*, with *Oryza sativa* being the most widely cultivated species. It is mainly grown in warm and humid climates and requires plenty of water, which is why it is commonly cultivated in flooded fields called Paddy Fields. One of the most prevalent issues with rice in Asia is nitrogen deficiency which is common rice growing soils where modern varieties of rice are cultivated without sufficient mineral nitrogen fertilizer. So it is necessary to implement management practices in order to reduce nitrogen losses and increase the nitrogen use efficiency (NUE) in rice production

Introduction

Nitrogen is essential to crops especially for rice. To increase rice yield and maintain the health of the soil nitrogen application is most important. To prevent N losses from soil proper application techniques and strategies to be followed in rice field. Plant uptake N in various forms like Ammonia, Nitrate, Nitrite. N was applied to the soil through organic and inorganic manner. Organic like FYM and inorganic like Urea. Proper management of nitrogen in rice fields involves the right source, right rate, right time and right method of application. Some symptoms are acquired like old rice leaves and stems become light green under nitrogen stress and the base of the leaf sheath becomes white under severe nitrogen deficiency. Excess nitrogen application can lead to soil deterioration and acidification, chalkiness and poor appearance quality of rice.

Excess nitrogen also causes “luxuriant growth”. Nitrogen also losses from soil as ammonium volatilization, Leaching, Denitrification etc,.. Effective nitrogen management not only increases rice yield and quality but also reduces production costs and minimizes environmental pollution. Managing N fertilizer is essential for sustainable rice cultivation.

ADVANTAGES OF N FERTILIZER IN RICE FIELD

- Promote Vegetative Growth - N encourages vigorous growth of leaves and stems, resulting in healthy plants.
- Improves grain Quality – N helps in protein synthesis, improving the nutritional quality of rice grains.
- Improves Grain yield – Proper application of Nitrogenous fertilizers significantly increases panicle number, grain size, and grain weight.
- Efficient Nutrient Uptake – N enhances the uptake and utilization of other nutrients like P and K.
- Increases Tillering – Adequate nitrogen supply increases the number of productive tillers, which directly contributes to higher grain yield.

LOSSES OF N IN RICE FIELD

LEACHING:

Leaching losses of N from rice fields are harmful to surface and groundwater quality. N leaching in rice fields is the downward movement of nitrogen, primarily as Nitrate and Ammonium through the soil with percolating water, leading to N loss, contamination of groundwater, and reduce fertilizer efficiency, particularly in sandy soils or with heavy rainfall and flood irrigation.

AMMONIUM VOLATILIZATION:

Ammonium volatilization in rice fields refers to the loss of applied nitrogen as ammonia gas, mainly after surface application of urea in flooded or puddled paddy soils. If N containing fertilizer like Urea is broadcast on standing water in paddy field. Urea is rapidly hydrolysed by urease enzyme. This forms Ammonium and increases pH of floodwater and at high pH, ammonium converts to ammonia. This forms of ammonia escapes into atmosphere – leads to N loss.

NITRIFICATION – DENITRIFICATION:

Nitrification is the biological oxidation of Ammonium to Nitrate by aerobic microorganisms like *Nitrosomonas* and *Nitrobacter*. It supplies nitrate to rice roots and provides substrate for denitrification. Denitrification is the reduction of nitrate to gaseous nitrogen forms, causing N loss. Denitrification was done by the microbes like *Pseudomonas spp* , *Bacillus spp*.

MANAGEMENT OF N IN THE FIELD OF RICE

The Core principle to manage N is Right Source, Right Rate, Right Time, Right Place, it is the fundamental framework for efficient N management. Choosing Right Fertilizer like Urea, Ammonium sulphate, Coated Urea which containing N content and increase the yield of rice. Right Rate means applying fertilizer at the recommended dose based on soil and crop need, in rice apply N based on the soil test recommendation, use LCC (Leaf Colour Chart). Right Place refers to applying fertilizer at the correct location where roots can easily absorb nutrients, in rice deep placement of Urea, place Urea near root zone.

Right Time means to applying fertilizer at the right growth stage of the crop, in rice apply N in split doses like Basal, Active tillering, Panicle initiation. Also managing N through real time N management like LCC, SPAD Chlorophyll Meter and optical sensors like Green Seeker. The principle of real-time N management was Nitrogen is applied only when the crop shows deficiency and decisions are made using plant-based tools. Through LCC, for transplanted rice, LCC less than or equal to 4 and for direct-seeded rice, threshold level (35-38). There is also limitations in real-time based management requires regular field monitoring, less effective under severe pest or disease stress, needs trained farmer.

Conclusion

Effective management of nitrogenous fertilizer in rice is crucial for achieving higher yield, better nitrogen use efficiency, and environmental sustainability. Because rice fields experience flooded, aerobic, and anaerobic conditions, nitrogen losses through volatilisation, leaching, nitrification, and denitrification are common if fertilizers are not properly managed. Adopting scientific practices such as the 4R, split application, deep placement of urea, and real-time nitrogen management using LCC or SPAD meter helps to synchronize nitrogen supply with crop demand. The use of coated fertilizers, inhibitors, and integrated nutrient management further reduces losses. Overall, proper nitrogen management in rice fields enhances fertilizer efficiency,

reduces production costs, increases grain yield, and minimizes environmental pollution, making rice cultivation more productive and sustainable.

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CLIMATE CHANGE AND INLAND WATERS: ASSESSING ECOSYSTEM VULNERABILITY AND MANAGEMENT PREPAREDNESS

Article ID: AG-VO6-I01-86**Aparna A^{1*}, V. Rani², D. Manimekalai³, A. Nazeela Barvin¹, S. Bhaskar¹**

¹Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu

²Dean i/c, Dr. M. G. R. Fisheries College and Research Institute, Thalainayeru, Tamil Nadu.

³Assistant Professor, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu, India

*Corresponding Author: Aparna A

Abstract

Inland water ecosystems are highly sensitive to climate change, which alters hydrology, thermal regimes, water chemistry, and biological interactions, ultimately affecting ecosystem services essential for food security, livelihoods, biodiversity, and regional economies. This article synthesizes global and Indian evidence on climate change impacts on inland waters, focusing on ecosystem vulnerability and the adequacy of existing management frameworks. It examines physical, chemical, biological, and socio-ecological dimensions of vulnerability, with particular emphasis on inland fisheries and aquatic resource management in developing countries where climate stressors interact with human pressures. The article critically assesses current governance mechanisms, identifies gaps in adaptive capacity, and proposes science-based, ecosystem-oriented strategies to enhance preparedness and support sustainable inland water management under a changing climate.

Keywords:

Climate change; Inland waters; Ecosystem vulnerability; Adaptive management; Inland fisheries

Introduction

Inland water ecosystems, despite occupying less than one percent of the Earth's surface,

support nearly ten percent of global biodiversity and deliver critical ecosystem services including inland fisheries, freshwater supply, flood mitigation, groundwater recharge, and support for agriculture and livelihoods. These systems are inherently dynamic and highly sensitive to environmental change, responding rapidly and often nonlinearly to climate-driven stressors. Climate change has emerged as a dominant force reshaping inland waters through rising temperatures, altered precipitation regimes, increased frequency and intensity of extreme events, and changes in cryospheric processes, leading to significant impacts on water availability, quality, and ecological integrity.

Even a single extreme event, such as a prolonged drought or severe flood, can trigger irreversible ecological shifts, including species loss, regime changes, and collapse of fisheries. Traditional inland water management, largely based on historical hydrological patterns and assumptions of ecosystem stability, is increasingly inadequate, underscoring the need to reassess ecosystem vulnerability and strengthen institutional preparedness to ensure the long-term sustainability of inland water systems in a changing climate.

Climate Change Drivers Influencing Inland Waters

Rising Temperature and Thermal Stress

Increasing air temperatures directly influence water temperature in rivers, lakes, and reservoirs. Elevated water temperatures reduce dissolved oxygen solubility, increase metabolic demands of aquatic organisms, and accelerate biochemical processes. Thermal stress alters species distribution, favors warm-water and invasive species, and reduces habitat suitability for cold-water and stenothermal organisms. In lakes and reservoirs, enhanced thermal stratification limits vertical mixing, intensifying hypoxia in bottom waters and increasing the likelihood of fish kills.

Altered Precipitation and Hydrological Regimes

Climate change disrupts established precipitation patterns, leading to increased rainfall variability across regions. Intensified rainfall events increase surface runoff, sediment transport, and nutrient loading into inland waters, while prolonged dry periods reduce base flows and water availability. Alterations in seasonal flow patterns disrupt ecological processes such as fish migration, spawning, and floodplain productivity, particularly in monsoon-driven river systems.

Increased Frequency of Extreme Events

Floods, droughts, and heat waves are becoming more frequent and severe under climate

change. Floods can cause habitat scouring, displacement of aquatic organisms, and contamination from agricultural and urban runoff. Droughts fragment aquatic habitats, increase water residence time, elevate salinity and temperature, and concentrate pollutants. Heat waves exacerbate thermal stress and oxygen depletion, often resulting in mass mortality events.

Interaction with Non-Climatic Stressors

Climate impacts on inland waters rarely occur in isolation. Land-use change, dam construction, water abstraction, pollution, and invasive species interact with climate stressors, amplifying ecological vulnerability. These cumulative impacts reduce system resilience and limit the capacity of ecosystems to recover from disturbances.

Ecosystem Vulnerability of Inland Waters

Physical Vulnerability

Physical vulnerability arises from changes in hydrology, connectivity, and habitat structure. Altered flow regimes affect sediment transport, channel morphology, and floodplain connectivity. Reduced environmental flows diminish habitat availability for aquatic organisms, while excessive flow regulation disrupts natural variability essential for ecosystem functioning. In lakes and reservoirs, increased evaporation and reduced inflow lower water levels, affecting shoreline habitats and aquatic vegetation.

Chemical Vulnerability

Climate change influences water chemistry through temperature-driven processes and altered hydrological inputs. Reduced dissolved oxygen levels, increased nutrient concentrations, and shifts in pH are commonly observed. Warmer conditions accelerate eutrophication, promoting harmful algal blooms that release toxins harmful to aquatic life, livestock, and human populations. Changes in redox conditions influence the mobility of metals and other contaminants, increasing ecological and health risks.

Biological Vulnerability

Biological vulnerability reflects the sensitivity of aquatic organisms to climate-induced changes. Species with narrow thermal tolerance ranges, limited dispersal ability, or specialized habitat requirements are particularly at risk. Climate change alters phenology, growth rates, reproduction, and species interactions, leading to food web restructuring. Shifts in plankton communities cascade through trophic levels, affecting fish productivity and ecosystem stability.

Socio-Ecological Vulnerability

Human communities dependent on inland waters experience heightened vulnerability as ecological changes translate into socio-economic impacts. Small-scale fishers, riparian farmers, and indigenous communities often lack alternative livelihoods and adaptive resources. Climate-induced declines in fisheries and water availability exacerbate poverty, food insecurity, and social conflict, highlighting the interconnected nature of ecological and social vulnerability.

Impacts of Climate Change on Inland Fisheries

Inland fisheries are highly sensitive to climate variability due to their dependence on hydrological and thermal conditions. Changes in flow timing and magnitude disrupt spawning migrations and breeding habitats, leading to recruitment failure. Elevated temperatures increase disease prevalence and parasite loads, reducing fish survival and growth. Shifts in species composition toward smaller, fast-growing, low-value species alter fishery yields and economic returns.

Reservoir fisheries are particularly vulnerable to climate-induced stratification and nutrient dynamics, which influence primary productivity and fish distribution. In floodplain fisheries, altered flood pulses reduce access to feeding and nursery grounds, undermining productivity and resilience.

Management Preparedness for Climate Change

Policy and Institutional Context

Water and fisheries management policies in many regions are based on historical climate norms and sector-specific approaches. Climate change considerations are often inadequately integrated into water allocation, fisheries regulation, and land-use planning, resulting in fragmented responses.

Monitoring and Early Warning Systems

Effective preparedness depends on robust monitoring of hydrological, ecological, and climatic variables. However, long-term datasets and real-time monitoring infrastructure remain limited in many developing regions. Insufficient data constrain early warning systems for floods, droughts, and water quality crises.

Governance and Adaptive Capacity

Adaptive governance requires flexibility, stakeholder participation, and learning-oriented institutions. Rigid regulatory frameworks, limited financial resources, and weak enforcement

mechanisms reduce the capacity to respond to climate uncertainty. Strengthening local institutions and community engagement is critical for effective adaptation.

Are We Prepared? A Critical Evaluation

Despite increasing recognition of climate risks, preparedness for managing inland waters under climate change remains inadequate. Management responses are often reactive, focusing on disaster response rather than proactive risk reduction. Integration of climate projections into planning processes is limited, and ecosystem-based approaches are underutilized. Bridging the gap between scientific knowledge and policy implementation remains a significant challenge.

Strategies to Enhance Preparedness and Resilience

Ecosystem-Based Management Approaches

Managing inland waters as integrated socio-ecological systems enhances resilience to climate change. Maintaining environmental flows, protecting riparian buffers, and conserving habitat connectivity support ecological integrity and adaptive capacity.

Nature-Based Solutions

Restoration of wetlands, floodplains, and riparian forests provides natural buffers against climate extremes while delivering co-benefits for biodiversity, water quality, and livelihoods. Nature-based solutions are cost-effective and adaptable across diverse landscapes.

Climate-Resilient Fisheries Management

Adaptive fisheries management includes flexible harvest regulations, protection of spawning and nursery habitats, diversification of livelihoods, and conservation of climate refugia. Community-based management strengthens local adaptive capacity and stewardship.

Technological and Knowledge Innovations

Remote sensing, modeling tools, and decision-support systems improve forecasting and management under climate uncertainty. Integrating traditional ecological knowledge with scientific insights enhances context-specific adaptation strategies.

Role of Research, Education, and Capacity Building

Interdisciplinary research is essential to understand complex climate–water interactions and to inform management strategies. Capacity building among water managers, fishers, and local institutions enhances adaptive responses and promotes sustainable resource use. Education and awareness initiatives strengthen public engagement and support for climate-resilient policies.

Future Outlook

Climate change will continue to reshape inland water ecosystems throughout the twenty-first century. Proactive adaptation, informed by science and supported by inclusive governance, offers the most viable pathway to safeguard ecosystem services and human well-being. Strengthening preparedness today will determine the resilience of inland waters in the decades to come.

Conclusion

Inland waters are at the frontline of climate change impacts, exhibiting high vulnerability across physical, chemical, biological, and socio-ecological dimensions. Current management preparedness is insufficient to address the scale and complexity of these challenges. However, targeted strategies—including ecosystem-based management, nature-based solutions, adaptive fisheries governance, and robust monitoring—can substantially enhance resilience. Preparing inland water systems for climate change is both an environmental necessity and a socio-economic imperative, requiring coordinated action across scientific, institutional, and community domains.

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INDIAN AGRICULTURE SECTOR: REALITIES, CHALLENGES, AND THE WAY FORWARD

Article ID: AG-VO6-I01-87**Manisha M**

ICAR - Agricultural Technology Application Research Institute, Hyderabad, Zone-X,
Hyderabad, Pincode-500059, Telangana, India

Abstract

Indian agriculture plays a vital role in ensuring national food security and rural livelihoods, supporting over 1.4 billion people. Over the years, significant progress has been achieved through technological innovations, policy initiatives, and institutional support. However, farming households continue to face economic, ecological, and market-related challenges that influence farm sustainability and income stability. This article presents a field-oriented perspective on the present condition of Indian farmers, based on observations from farming communities and agri-ecosystems. It discusses farmer's actual needs, emerging production and market challenges, soil health concerns, and the mechanisms involved in crop price determination. It aims to contribute constructively to ongoing discussions on strengthening Indian agriculture through inclusive, sustainable, and farmer-centric approaches.

Keywords: Indian agriculture, farmer's livelihoods, soil health, sustainable farming, FPOs,

Introduction: Strengthening the Backbone of the Nation

Indian farmers remain the backbone of the nation, with agriculture sustaining the livelihoods of a large share of the population while ensuring food security. Over the years, policy reforms, investments, and scientific innovations have strengthened productivity and resilience in the sector. However, Indian agriculture is undergoing a period of transition, facing new challenges from climate variability, changing market dynamics, and increasing costs of production. With shrinking landholdings and increasing complexity in farming systems, farmers are required to adapt continuously. Understanding these realities requires balancing policy perspectives with insights from field-level experiences.

What Farmers Actually Need: Beyond Subsidies and Schemes

Farmer's expectations extend beyond subsidies and financial assistance. At the grassroots level, farmers consistently emphasize the need for stability, clarity, and timely support systems.

- Assured and fair prices for agricultural produce
- Accessible and transparent marketing channels
- Availability of quality inputs at reasonable costs
- Support for soil and water conservation
- Effective extension services tailored to local conditions
- Risk mitigation mechanisms against climate variability

Government initiatives address many of these aspects; however, strengthening last-mile delivery and alignment with local needs can further enhance their impact.

Why Farming Feels Economically Uncertain

A large proportion of Indian farmer's comes under small and marginal landholdings category. Income from agriculture alone may not always meet household requirements, leading many families to depend on allied activities or supplementary income sources. Several factors contribute to income uncertainty:

- Rising costs of seeds, fertilizers, pesticides, labour, and energy
- Stagnant or fluctuating prices for major crops
- Yield variability due to erratic weather and pest pressures
- Post-harvest losses caused by limited storage and processing facilities

When the cost of cultivation increases faster than returns, farming becomes financially challenging, even when productivity is reasonable.

Changing Cropping Patterns and Input-Intensive Agriculture

The predominance of monocropping and input-intensive farming systems has created new challenges. Limited crop diversification gradually depletes soil nutrients and increases vulnerability to pests and diseases.

Excessive use of chemical fertilizers and pesticides affects soil biological health and may lead to groundwater contamination. Rising input costs, combined with unstable crop prices, often reduce profit margins. While crop diversification, conservation agriculture, and natural resource-based practices offer long-term benefits, adoption remains uneven due to knowledge gaps, risk perception, and market constraints.

Market Access & Farmer Income: The Persistent Struggle

Despite being primary producers, many farmers face difficulties in realizing fair returns for their produce. Common challenges include:

- Weak market linkages and limited price discovery
- Dependence on intermediaries
- Infrastructure gaps in storage, grading, and transport
- Payment delays and price volatility

These factors contribute to income instability and influence younger generations' interest in farming as a livelihood.

Technology Adoption and the Digital Gap

Digital tools, precision agriculture, and data-driven advisories are reshaping agriculture globally.

In India, adoption is increasing but remains uneven. Key constraints include:

- Digital illiteracy and language barriers
- Limited access to affordable devices and reliable connectivity
- Low awareness of advanced technologies and their practical benefits
- Preference for proven practices over unfamiliar innovations

Bridging this digital divide through training, demonstration, and affordable solutions is essential for inclusive agricultural growth.

What Is Needed to Strengthen Agricultural Growth

For Indian agriculture to grow in a sustainable and profitable manner, increase in production is not enough. The focus must shift towards improving farmers' income, reducing risks, and making agriculture competitive in both domestic and global markets.

- **Strengthening Market Linkages:** Strong linkages between farmers, FPOs, APMCs, processors, exporters, and retailers are essential. Digital platforms, e-NAM, contract farming, and direct marketing models can help farmers get better prices.
- **Promoting Export-Oriented Agriculture:** Exports will play a major role in future agricultural growth. Farmers must be encouraged to produce quality, residue-free, and globally acceptable produce. Support for post-harvest handling, grading, certification, cold storage, and logistics is crucial to integrate farmers into global value chains.
- **Price Support Policies:** While Minimum Support Price (MSP) protects farmers, in some crops MSP is higher than international prices, affecting export competitiveness. A balanced

pricing policy is needed that safeguards farmers' interests while promoting diversification, efficiency, and market-driven production.

- **Technology Adoption and Innovation:** Improved seeds, precision farming, mechanization, digital advisory services, and climate-smart practices can significantly enhance productivity. Institutions like KVKs, ICAR, and State Agricultural Universities must focus on faster transfer of technologies from labs to farmers' fields.
- **Efficient Use of Natural Resources:** Water, soil, and nutrients must be used judiciously. Promotion of micro-irrigation, rain guns, balanced fertilization, and soil health management will reduce costs and ensure long-term sustainability of agriculture.
- **Risk Management and Climate Resilience:** Agriculture is increasingly affected by climate change. Crop insurance, weather-based advisories, diversified farming systems, and resilient crop varieties are needed to reduce farmers' vulnerability to climate risks.
- **Institutional and Policy Reforms:** Strong institutions are the backbone of agricultural growth. Reforms in extension systems, insurance, and input supply, along with convergence among departments, can improve efficiency and impact at the ground level.

Conclusion

Indian agriculture remains the backbone of the nation, supporting food security and millions of rural livelihoods. Despite progress through technology and government support, farmers continue to face challenges such as increasing input costs, market uncertainty, climate change, and declining soil health. Future growth must focus not only on increasing production but also on improving farm incomes and reducing risks at the field level. Ensuring fair prices, reliable markets, timely access to quality inputs, and locally suitable technologies is essential. Strengthening extension services, Farmer Producer Organizations, and farmer-friendly policies can bridge the gap between research and practice. By promoting resource conservation, climate-resilient farming, and market-oriented approaches, Indian agriculture can become more stable, profitable, and sustainable for farming communities.

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22

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CLASSIFICATION OF CULTIVATED CAPSICUM FRUTESCENS CHILI PEPPERS

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¹Kanthaswamy, V., ^{1*}V. Krishnan, ¹M. S. Marichamy, ²N. Bavya and ³B. Bavithra,

¹Faculty, ²PG Scholar & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V. Krishnan

1. Introduction

Chilli and capsicum, both belonging to the species *Capsicum annuum* L., originated in Central and South America, particularly in regions covering southern Brazil, Bolivia, and Mexico. Archaeological evidence indicates that these crops were domesticated over 6,000 years ago in this region, where several wild species of *Capsicum* still grow. Following the Columbian exchange in the 15th century, chillies and capsicums spread rapidly to Asia, Africa, and Europe, becoming integral to many global cuisines and farming systems.

2. CLASSIFICATION OF CAPSICUM FRUTESCENS VARIETIES

Capsicum frutescens:

The plant's height ranges between 0.3 to 1.5 meters, branching from near the base. The leaf pairs are more or less similar in size and shape, with membranous, concolored, or slightly discolored leaves that are glabrescent or glabrous on both surfaces. The blades of the leaves are ovate or narrowly elliptic, with entire margins and an acuminate to long-acuminate apex. Inflorescences are axillary, typically hosting 2-5 flowers per axil, with solitary flowers being a rare occurrence. The corolla is usually dull white or greenish-white both outside and within, stellate with an interpetalar membrane. Filaments come in cream or purple, and anthers are ellipsoid, bluish-grey, purplish, or, rarely, dark green or yellow, connivent at anthesis. The berry is typically green and yellowish-green when immature, transitioning to yellow, orange red as it matures. Seeds are C-shaped to sub globose, pale yellow, numbering from 10 to 52 per fruit. *Capsicum frutescens* species is further classified into the following botanical cultivated varieties viz.,

a. Tabasco peppers (*Capsicum frutescens* var. *tabasco*):

These are native to Mexico and named after the Mexican state Tabasco. They are bushy shrubs that is trimmed for commercial cultivation. The fruits are erect, 4 cm long and tapering, thin skinned, initially pale yellowish green and turn yellow and orange before ripening to bright red. They remain erect even when matured. The SHU value of Tabasco pepper ranges from 30,000 to 50,000. These are of the following variations viz.,

i. Common Tabasco Peppers: These are perennial plant that grows up to 3 feet tall and produces small elongated fruits that matures from green to bright red. The SHU value ranges from 30,000 to 50,000.

ii. Green Tabasco Peppers: These green fruits instead of red fruits that are having an SHU value of 2,500 to 5,000.

iii. Purple Tabasco Peppers: These produce purple to red fruits, having slightly sweeter and fruitier flavour with SHU of 30,000 to 50,000. They are used to prepare barbeque sauces and spicy chocolate tuffeess.

iv. Chocolate Tabasco peppers: They produce dark brown fruits having SHU of 30,000 to 50,000. They are slightly smoky and earthy flavour and are used in many Mexican dishes.

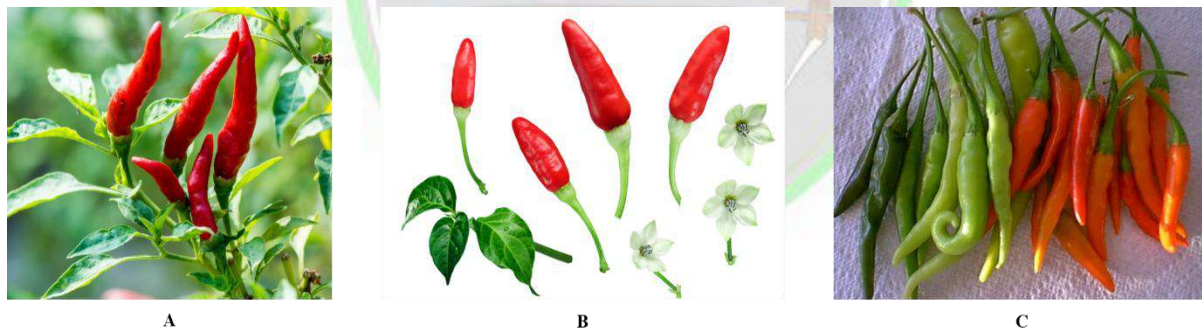


Fig. 1. Tabasco Peppers (*Capsicum frutescens* var. *tabasco*). A. Plant, B. Leaf, flowers and fruits and C. Variation in fruit maturity

b. Malagueta peppers (*Capsicum frutescens* var. *malagueta*): Small tapered fiery chilies, that are native of Caribbean of South America and widely used in Brazilian, Portuguese, and African cuisines. It has a sharp quick heat that hits our tongue fast, delivers a fiery punch, but then fades relatively quickly, leaving behind a pleasant warmth that *makes us want more* rather than overwhelming. These have medium heat of 75,000 Shu and have sweet tangy flavour.

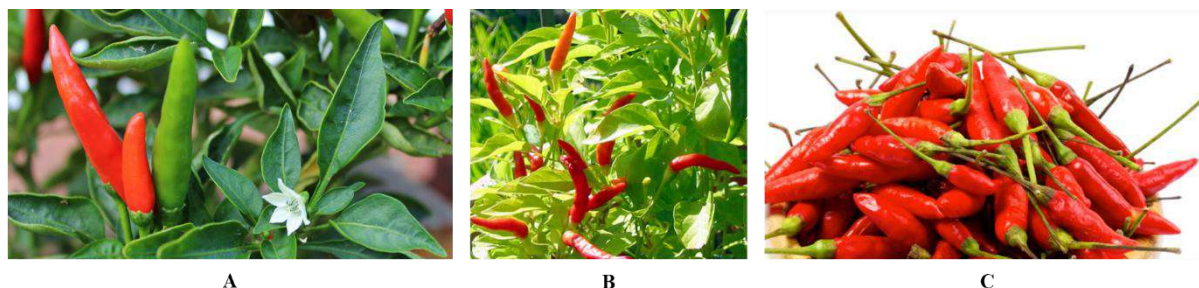


Fig. 2. Malagueta Peppers (*Capsicum frutescens* var. *malagueta*). A. Plant with flower, green and mature fruits, B. Plant with mature fruits and C. Harvested fruits

c. Piri Piri or African Bird's Eye or African Devil Peppers (*Capsicum frutescens* var. *piri piri*): These are native of South America, but domesticated and cultivated in Africa. The fruits are about an inch in length and have an SHU score value of 50,000 to 1,00,000. They have a sweet smoky taste and mostly used as culinary in Africa, India, China and other Asian Countries.



Fig. 3. Piri Piri or African Bird's Eye or African Devil Peppers (*Capsicum frutescens* var. *piri piri*). A. Plant, B. Close-up of fruit cluster, C. Plant with green and mature fruits and D. Harvested fruits

d. Kambuzi Malvian Peppers (*Capsicum frutescens* var. *kambuzi*): The Kambuzi pepper is a *Capsicum frutescens* cultivar from Malawi that produces small, round chili peppers with a Scoville Heat rating of 50,000-175,000 units. Peppers can be yellow, red, or orange, and are used to make sauces, spreads, and condiments.

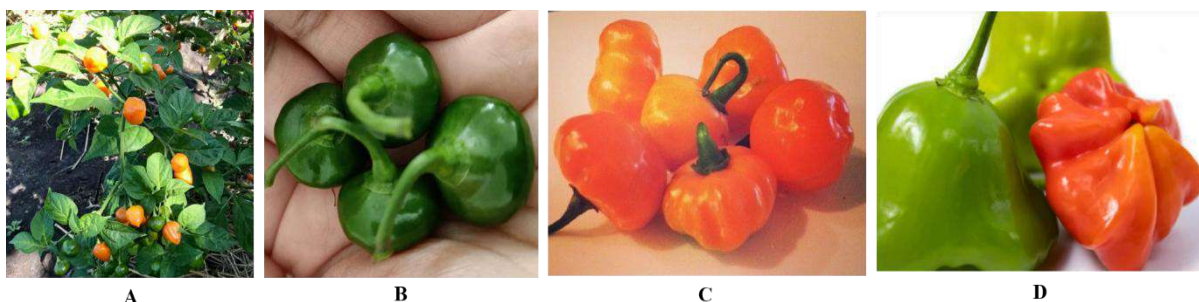


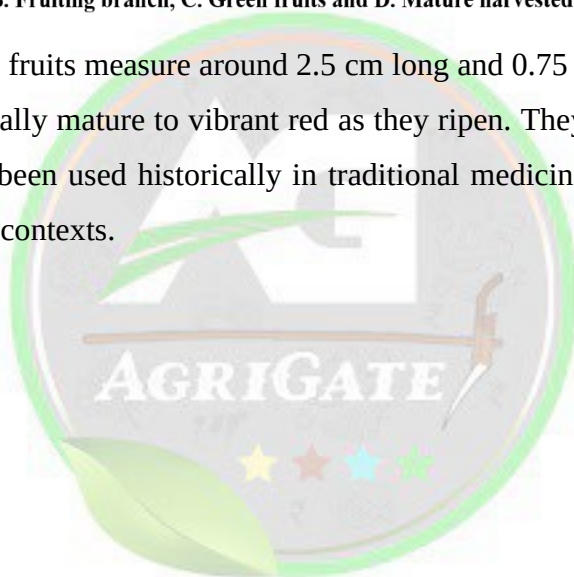
Fig. 4. Kambuzi or Malvian Chili Peppers (*Capsicum frutescens* var. *kambuzi*). A. Plant, B. Green fruits, C. Mature fruits and D. Close-up of green and mature fruits

e. Labuyo or Filipino Bird's Eye Peppers: These are small, cone shaped *Capsicum frutescense* botanical variety, cultivated in Philippines. They have SHU of 80,000 to 1,00,000. The plants grow to be about a meter tall (roughly 3.3 feet), which is pretty typical of chili peppers.



Fig. 5. Labuyo or Filipino Bird's Eye Chili Peppers (*Capsicum frutescens* var. *labuyo*). A. Plant, B. Fruiting branch, C. Green fruits and D. Mature harvested fruits

When fully grown, the fruits measure around 2.5 cm long and 0.75 cm wide. They start as lively green and gradually mature to vibrant red as they ripen. They are used to add spice to many dishes, have been used historically in traditional medicine, and are still used in some modern medical contexts.



CLASSIFICATION OF CAPSICUM CHINENSE CULTIVATED CHILI PEPPERS

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¹Bavya, N., ^{2*}V. Krishnan, ²V. Kanthaswamy, ²M. S. Marichamy, and ³B. Bavithra,

¹PG Scholar, ²Faculty & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V. Krishnan

1. Introduction

Chilli and capsicum, both belonging to the species *Capsicum annuum* L., originated in Central and South America, particularly in regions covering southern Brazil, Bolivia, and Mexico. Archaeological evidence indicates that these crops were domesticated over 6,000 years ago in this region, where several wild species of *Capsicum* still grow. Following the Columbian exchange in the 15th century, chillies and capsicums spread rapidly to Asia, Africa, and Europe, becoming integral to many global cuisines and farming systems. Capsicum, commonly referred to as sweet pepper or bell pepper, is the non-pungent form of *Capsicum annuum* selected for its thick pericarp and mild flavour. It shares the same center of origin as chilli but differs in its end use and growing conditions. Capsicum is grown both in open fields and under protected cultivation such as greenhouses or polyhouses.

2. CLASSIFICATION OF CAPSICUM CHINENSE CHILI

Capsicum chinense is an erect plant, standing 0.5-2.5 meters tall, with few to many branches originating near the base. The leaf pairs are unequal in size but share a similar shape, with membranous, either concoloured or slightly discoloured leaves - dark green above and pale green below. The leaf blades are ovate to elliptic, featuring entire margins and a short acuminate, acuminate, or acute apex. Inflorescences are axillary, typically hosting 2-4 flowers per axil, occasionally with solitary flowers. The corolla is 5 or 6-merous, dull white or greenish-white, occasionally adorned with purple spots both outside and within. The corolla is stellate with an interpetalar membrane, and the filaments come in white, cream, or purple, inserted on the

corolla. Anthers are usually blue or bluish-grey, with rare instances of yellow or greenish-white, broadly ellipsoid or ellipsoid, and connivant or not connivant at anthesis. The berry, measuring less than 10 mm in diameter, is sub globose and orange to red in wild populations. Highly variable in size, shape, and colour, it can be sub globose, triangular, long triangular, campanulate, or even blocky. The apex may be pointed, blunt, or long-acuminate and upcurved, while the base is obtuse or truncate. When immature, the colour ranges from green, yellow, brown, to purple, transitioning to pale yellow, yellow, dark brown, orange, red, or vermilion-scarlet at maturity. The fruits may be deciduous or persistent and are known for their intense pungency, though occasional non-pungent varieties exist. Seeds are C-shaped or sub globose, pale yellow, or nearly white, numbering from 14 to 35 per fruit. This species has the following botanical varieties viz.,

a. Habanero peppers (*Capsicum chinense* var. *habanero*): These are pungent cultivar of *Capsicum chinense* chili pepper. Unripe habaneros are green, and change colour as they mature mostly as orange and red, but may also be white, brown, yellow, green, or purple. Typically, a ripe habanero is 2–6 centimetres (3/4–2+1/4 inches) long. Habanero chilis are very hot, rated 100,000–350,000 on the Scoville scale. They are 76 times hotter than average Japaleno peppers of *Capsicum annum*. Habanero peppers are popular in Australia and Italy. Habanero peppers are further classified into the following groups viz.,

i. Chocolate or Black Habanero Peppers: These are grown in Caribbean and Mexico that are dark brown, almost black fruit with a heat level of 300,000–577,000 SHU. Its rich, earthy flavour with smoky undertones is a staple in Jamaican jerk dishes and mole sauces.

ii. Orange Habanero Peppers: With a heat level of 100,000–350,000 SHU, it offers a sweet, fruity flavour with citrus and floral notes, making it a staple in hot sauces, salsas, and marinades of Yucatan cuisines. They are ideal for pairing with tropical fruits like mango or pineapple, and its vibrant colour adds visual appeal to dishes.

iii. Yellow Habanero Peppers: These are with a heat level of 100,000–350,000 SHU. Its sweet, citrusy flavour with floral undertones is popular in Caribbean hot sauces and chutneys. The 1- to 2-inch pods ripen from green to yellow.

iv. Red Habanero Pepper: These are deep red, wrinkled pods have a slightly smokier, sweeter flavour, having 300,000–450,000 SHU, perfect for salsas, jerk seasonings, and spicy

jams. This variety is common in Caribbean and Mexican cuisines, where its bold heat enhances dishes like tacos and stews.

v. Red Savina Habanero Peppers: These having 250,000–577,000 SHU, are red, wrinkled pods with fiery flavour. This variety is used sparingly in hot sauces and chili powders due to its extreme heat.

vi. White Habanero Peppers: These are native of Yucatan, that are creamy white, jellybean-like fruits having SHU of 100,000–350,000. Its smoky, tangy flavour adds an authentic Mexican touch to salsas, ceviche, and hot sauces.

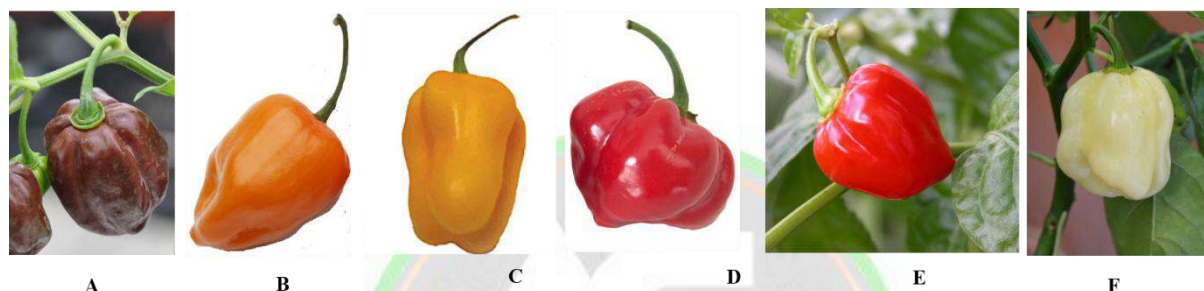


Fig. 1. Different cultivated types of Habanero Peppers (*Capsicum chinense* var. *habanero*). A. Chocolate or Black Habanero pepper, B. Orange Habanero Pepper, C. Yellow Habanero pepper, D. Red Habanero Pepper, E. Red Savina Habanero pepper and F. White Habanero Pepper

b. Scotch Bonnet Peppers (*Capsicum chinense* var. *scotch bonnet*): These are slightly larger than Habanero peppers and have a distinct squat or bonnet-like shape. They have fruity, tropical flavour and are used in Caribbean cuisine. These have SHU value ranging from 100,000 to 3,50,000. There are four major groups viz.,

i. Regular Scotch Bonnet: The fruits change from green to red and showcase multiple green and orange shades in-between as it matures. It has a sweet, tropical taste to it, sort of like a tomato with a slight hint of apples and cherries.

ii. Scotch Bonnet Chocolate (Brown): These are rich, brown colour when mature and has a hint of smokiness and earthiness, and it can be a bit hotter compared to the regular scotch bonnet.

iii. Scotch Bonnet Yellow (Mustard): They have fruits that are bright yellow or mustard colour, with more sweetness and a *slightly* milder heat level, adding a fruity yet less intense kick.

iv. Tobago Scotch Bonnets: Native Tobago Island. The fruit itself is slightly elongated compared to the common squat shape. It comes in multiple colours and shares the same overall level of heat, but has less sweetness.

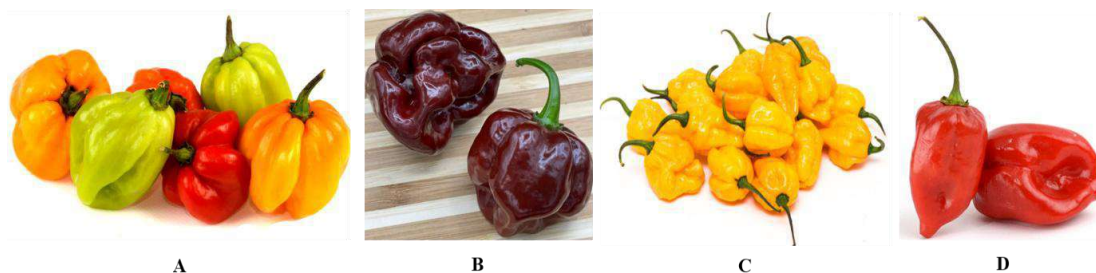


Fig. 2. Different types of Scotch Bonnet Peppers (*Capsicum chinense* var. *scotch bonnet*).

A. Regular Scotch Bonnet, B. Scotch Bonnet Chocolate, C. Scotch Bonnet Yellow and D. Tobago Scotch Bonnet

c. Trinidad Scorpion Peppers: These originated in Trinidad and Tabago regions of Caribbean. These are known for extreme heat with SHU exceeding 2,000,000 units. The fruits are small, wrinkled and red in appearance resembling the scorpion's tail. The fruits offer a sweet and fruity taste, but their extreme heat often dominates. The Trinidad Scorpion peppers are of the following types viz.

- i. **Trinidad Moruga Scorpion Pepper:** Exceeds 2,000,000 SHU
- ii. **Trinidad Scorpion Butch T Pepper:** SHU values ranging from 80,000 to 1,46,000
- iii. **Trinidad Scorpion Douglah Pepper:** With average SHU around 1.85,000
- iv. **Trinidad Sunrise Scorpion Pepper:** Has 3,00,000 SHU
- v. **Trinidad Scorpion Yellow Pepper:** Has SHU in the range of 1,200,000 - 1,900,000.
- vi. **Trinidad Scorpion Seven Pot Pepper:** Has SHU 1,000,000 to 1,200,000.

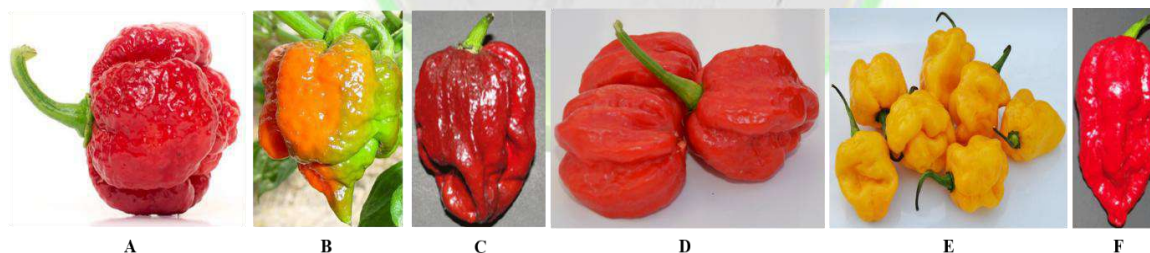


Fig. 3. Different types of Trinidad Scorpion Peppers. A. Trinidad Moruga Scorpion Pepper, B. Trinidad Scorpion Butch T Pepper, C. Trinidad Douglah Scorpion Pepper, D. Trinidad Sunrise Scorpion Pepper, E. Trinidad Scorpion Yellow Pepper and F. Trinidad Scorpion Seven Pot Pepper

d. Fatalii Peppers: Native of South-Central Africa. They are renowned for their intense heat, with SHU ranging from 125,000 to 400,000, placing them among the hottest peppers in the world. Fruits are usually yellow in colour, although there are variations that are red or white. They are elongated and tapered, usually about 2 to 3 inches long. The flavour of the Fatalii pepper is unique and often described as fruity with a hint of citrus, making it a popular choice for citrus-based hot sauces and salsas.

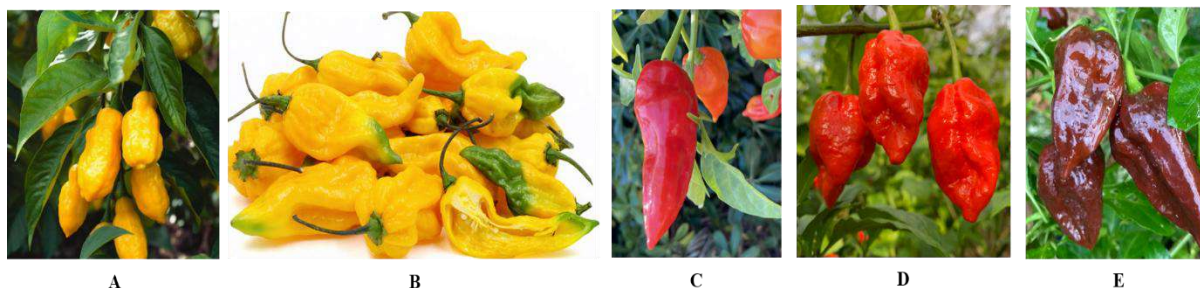


Fig. 4. Fatalii Peppers (*Capsicum chinense* var. *fatalii*). A. Fatalii pepper plant. B. Fatalii Yellow Peppers. C. Fatalii Red Peppers, D. Fatalii Orange Peppers and E. Fatalii Chocolate Peppers

e. Bhut Jolokia or Ghost Peppers or Naga Chili: Bhut Jolokia, also known internationally as the Ghost Pepper and Naga Chilli, is one of the world's hottest peppers, with a SHU exceeding 1 million. This fiery chili, native to Northeast India, is cultivated predominantly in Assam, Nagaland, and Manipur. Bhut Jolokia has a distinct appearance, with its wrinkled skin, vibrant red or orange colour, and thin, delicate flesh. Known locally as Raja Mircha or "King of Chillies," Bhut Jolokia is a symbol of regional identity and pride in the Northeast. Beyond its reputation for extreme heat, Bhut Jolokia has a deep-rooted presence in traditional Northeast Indian cuisine, medicine, and even local folklore.



Fig. 5. Bhut Jilokia or Ghost Pepper or Nga Chili Peppers (*Capsicum chinense* var. *bhut jilokia*). A. Plant, B. Fruits at different stages of maturity and C. Close-up view of matured fruits

f. Carolina Reaper: The Carolina Reaper chili pepper is a cultivar of the *Capsicum chinense* plant. Developed by American breeder Ed Currie, the pepper is red and gnarled, with a bumpy texture and small pointed tail. It was the hottest chili pepper in the world according to Guinness World Records from 2013 to 2023 before it was surpassed by Pepper X, which was also developed by Currie.

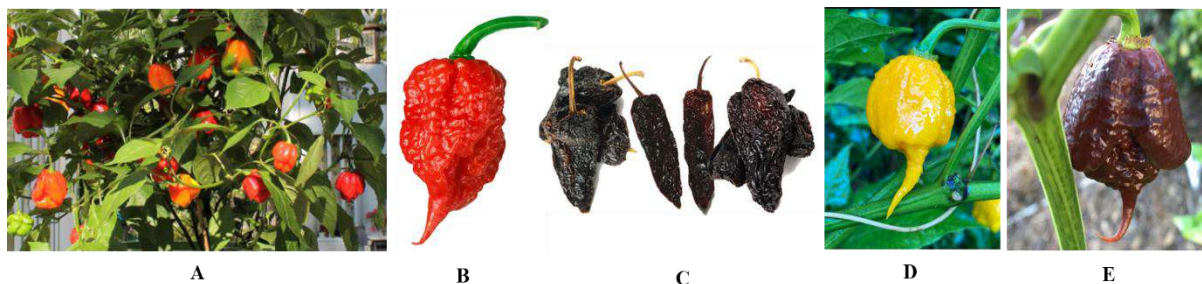


Fig. 6. Carolina Reaper Peppers (*Capsicum frutescens* var. *carolina reaper*). A. Plant, B. Red pepper fruit, C. Mature dried fruits, D. Yellow Pepper fruit and E. Chocolate Pepper fruit

g. Pepper X: Pepper X is officially the hottest pepper in the world, weighing in with 2.693 million Scoville heat units. The creator reveals his process and experience tasting the pepper. This has 2,693,000 SHU units.

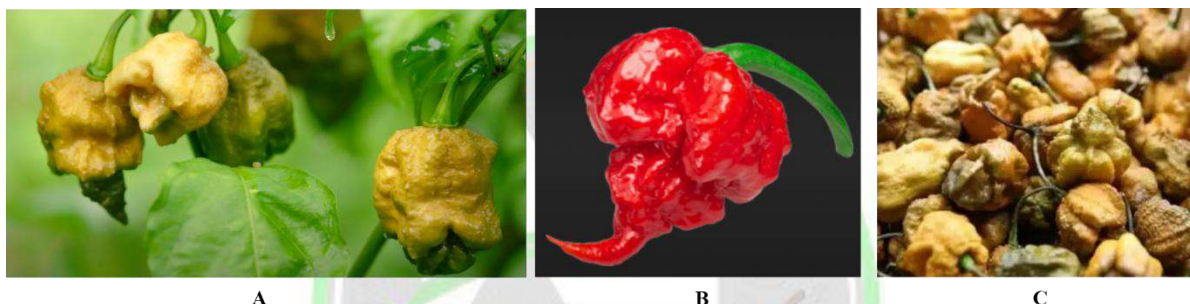


Fig. 7. Pepper X Peppers (*Capsicum frutescens* var. *pepper x*). A. Plant, B. Red pepper fruit, C. Mature dried fruits, D. Yellow Pepper fruit and E. Chocolate Pepper fruit

PHYSIOLOGY OF STRESS TOLERANCE IN PLANTS

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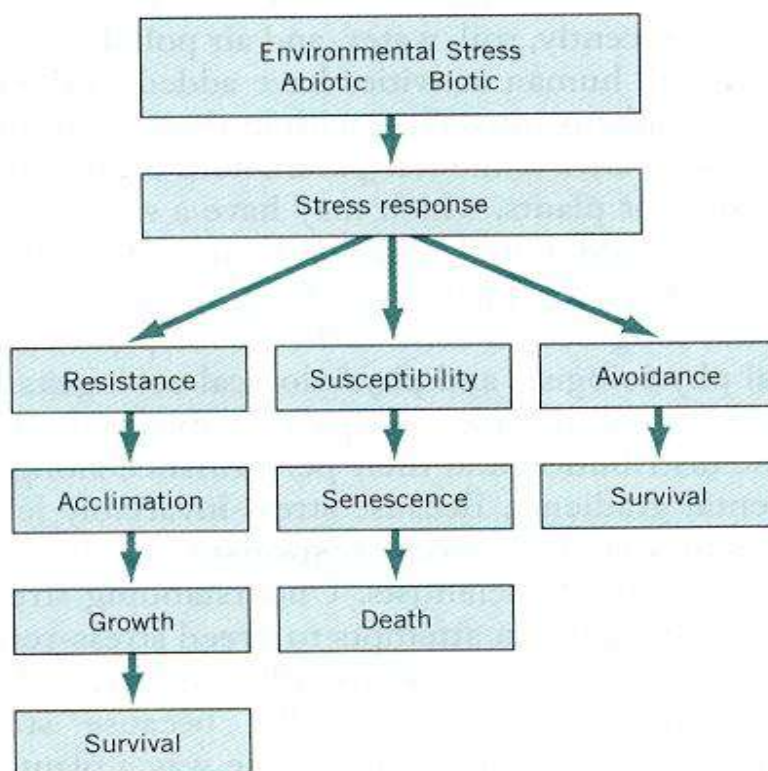
¹Bavithra, B., ^{2*}V. Krishnan, ²V. Kanthaswamy, ²M. S. Marichamy, and ³N. Bavya

¹Ph. D. Scholar, ²Faculty & ³PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author: V. Krishnan

Introduction

Higher plants are sessile and therefore cannot escape from stress factors. They are continuously exposed to different stress factors without any protection. On the other hand animals are mobile and can escape the direct harsh conditions. The immobile nature of plants



needs more protection. This enabled them to develop unique molecular mechanisms to cope with different stress factors. However, variations do exist in tolerance mechanisms among plants. Certain morphological features of some plants however, make them avoid stress factors. But it may not be the case in all plants. The only option for plants is to alter their physiologies, metabolic mechanisms, gene expressions and developmental activities to cope with the stress effects. Therefore, plants possess unique and sophisticated mechanisms to tolerate stresses. Those plants that have better tolerant, resistant, protective and acclimation mechanisms alone can survive while others cannot. Gene products play a key role in the molecular mechanisms of stress tolerance in plants.



I. Biotic stress:

Biotic stress is stress that occurs as a result of damage done to plants by other living organisms, such as bacteria, viruses, fungi, parasites, beneficial and harmful insects, weeds, and cultivated or native plants. The type of biotic stress will depend on geography, the host plant and its susceptibility to a particular stress, plant pathogens being the most common. Biotic stress remains a broadly defined term and faces many challenges in fully understanding its limits. This is partially due to the higher difficulty of controlling plant stresses during experiments, compared to abiotic. The damage caused by these various living and non-living agents can appear very similar. Even with close observation, accurate diagnosis can be difficult. For example, browning of leaves on an oak tree caused by drought stress may appear similar to leaf browning caused by oak wilt, a serious vascular disease, or the browning caused by anthracnose, a fairly minor leaf disease.

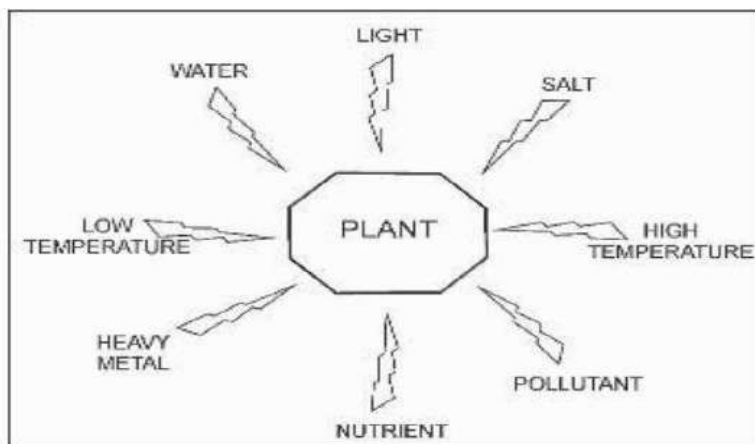
Agriculture

It is a major focus of agricultural research, due to the vast economic losses caused by biotic stress to cash crops. The relationship between biotic stress and plant yield affects economic decisions as well as practical development. The impact of biotic injury on crop yield

impacts population dynamics, plant-stressor coevolution, and ecosystem nutrient cycling. Biotic stress also impacts horticultural plant health and natural habitats ecology. It also has dramatic changes in the host recipient. Plants are exposed to many stress factors, such as drought, high salinity or pathogens, which reduce the yield of the cultivated plants or affect the quality of the harvested products. *Arabidopsis thaliana* is often used as a model plant to study the responses of plants to different sources of stress.

II. Abiotic stress:

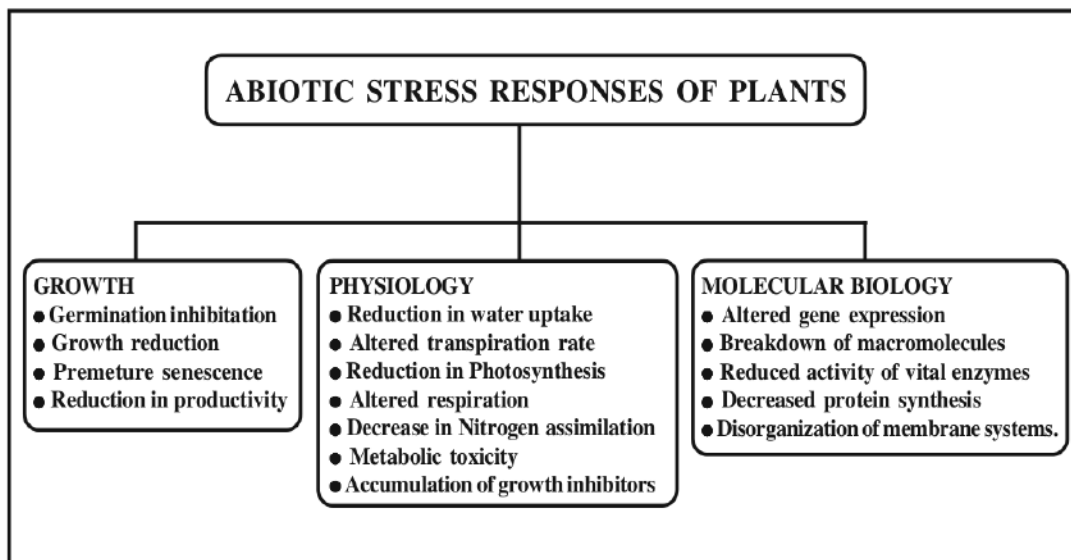
Abiotic stress is defined as the negative impact of non-living factors on the living organisms in a specific environment. The non-living variable must influence the environment beyond its normal range of variation to adversely affect the population performance or individual physiology of the organism in a significant way. Abiotic stress is essentially unavoidable. Abiotic stress affects animals, but plants are especially dependent on environmental factors, so it is particularly constraining. Abiotic stress is the most harmful factor concerning the growth and productivity of crops worldwide. Abiotic stresses are commonly caused by drought, salinity, high or low temperatures, light, deficient or excess nutrients, heavy metals, pollutants etc either individually or in combinations. The stress caused by abiotic factors alter plant metabolism leading to negative effects on growth, development and productivity of plants. If the stress become harsh and/or continues for longer period it may lead to unbearable metabolic burden on cells leading to reduced growth and in extreme cases results in plant death. However, plant stress may vary from zero to severe through mild and moderate levels. In nature, plants may not be totally free from stresses. Plants are expected to experience some degree of stress of any factor or factors. To overcome these stresses, plants exhibit several mechanisms which make them



Some common abiotic stress factors that affect plants

withstand the stress with the formation of new molecules and molecular mechanisms of stress tolerance.

Avoidance mechanisms though considered to be advanced, which by modification of morphology and anatomy prevents plants from various stress factors, they may not be of much importance in immediate crop improvement. Therefore, the immediate emphasis is on the development of tolerance mechanisms in plants, since plants exhibit great variations in their tolerance mechanisms, within species, between species and among the plants of different groups. These variations are highly significant in developing stress tolerance in plants.



1. DROUGHT STRESS:

Mechanism of drought tolerance:

Several mechanisms have been adopted by drought tolerant plants to adapt water stress including reduction in water loss by increasing stomatal resistance, increase of water uptake by developing large and deep root systems and accumulation of osmolytes. The osmolytes accumulated include amino acids such as proline, glutamate, glycine-betaine and sugars (mannitol, sorbitol and trehalose). These compounds play a key role in preventing membrane disintegration and enzyme inactivation in the low water activity environment. The identification of suitable plant characters for screening large numbers of genotypes in a short time at critical stages of crop growth, with the aim of selecting drought tolerant cultivars, remains a major challenge to the plant breeder.

Physiological parameters:

At genetic level, the adaptive mechanisms by which plants survive drought, collectively referred to drought tolerance (Jones et al., 1980), can be grouped into three categories, viz.

drought escape, drought avoidance and drought tolerance (Leonardis et al. 2012).

Drought escape: The ability of a crop plant to complete its life cycle before development of serious soil and plant water deficits is called as drought escape. This mechanism involves rapid phenological development i.e. early flowering and maturity, variation in duration of growth period depending on the extent of water scarcity.

Drought avoidance: Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil moisture. Improving the mechanisms of water uptake, storing in plant cell and reducing water loss confer drought avoidance. Drought avoidance mechanisms are associated with physiological whole-plant mechanisms such as canopy tolerance and leaf area reduction, stomatal closure and cuticular wax formation, and adjustments of sink-source relationships through altering root depth and density, root hair development and root hydraulic conductance (Beard and Sifers 1997; Rivero et al. 2007).

Drought tolerance: The ability of a crop to endure moisture deficits at low tissue water potential or dehydration tolerance (Levitt, 1972). Drought tolerance mechanisms are balancing of turgor through osmotic adjustment (solute accumulation in cell), increase in elasticity in cell but decrease in cell size and desiccation tolerance by protoplasmic tolerance (Ugherughe, 1986). Most of drought adaptations have disadvantages as the genotypes of short duration are less productive compared to that of normal duration. The drought tolerance mechanisms conferred by reducing water loss (such as stomatal closure and reduced leaf area) usually result in reduction of assimilation of carbon dioxide (Mitra, 2001). Drought tolerance can be increased through osmotic adjustment by maintaining plant turgor, but the increased solute concentration responsible for osmotic adjustment may have detrimental effect in addition to energy requirement for osmotic regulation (Turner, 1979). Therefore, crop adaptations to drought may be established through a balance between escape, avoidance and tolerance while maintaining adequate productivity.

2. WATER STRESS:

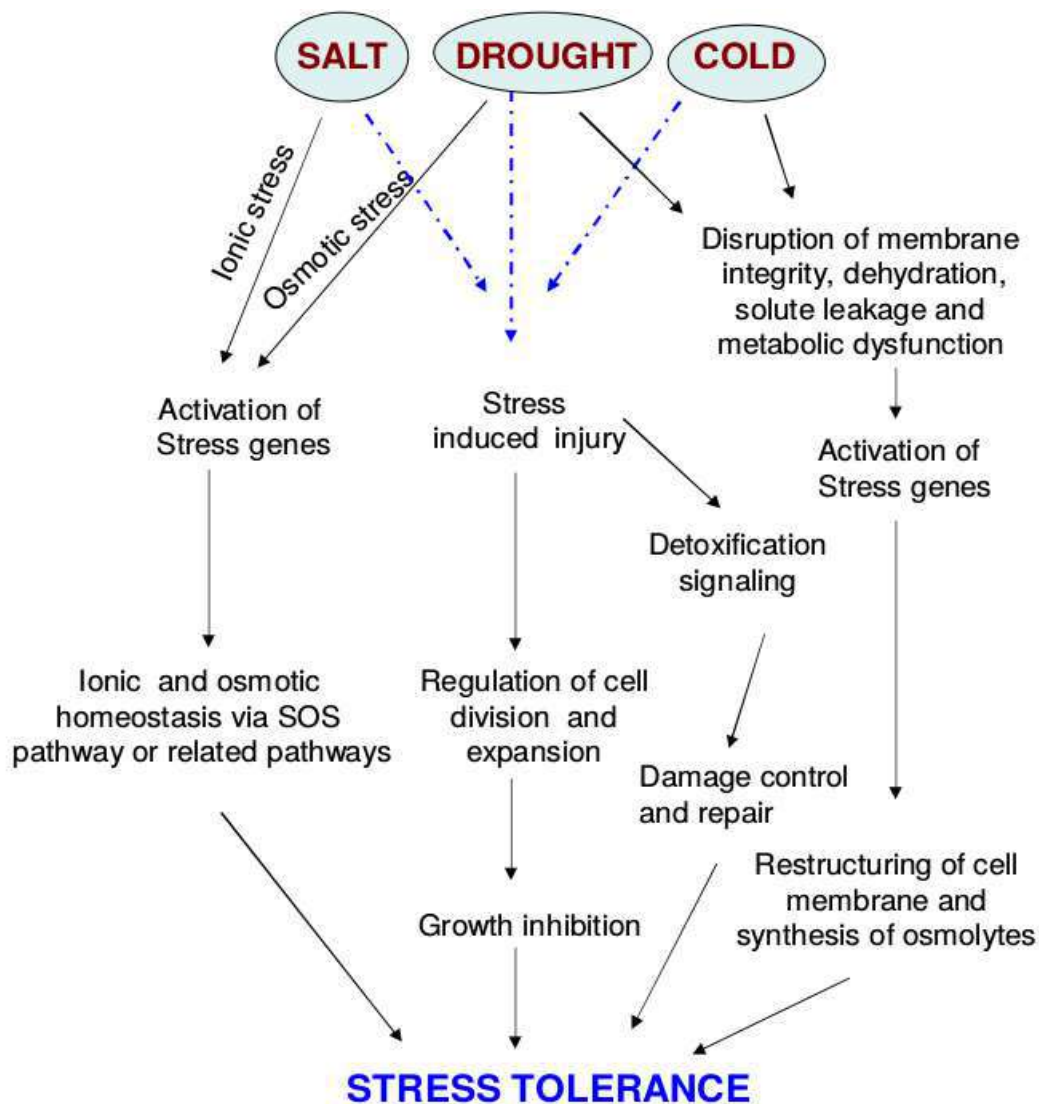
Drought leading to water stress in plants is a major problem in reducing agricultural productivity especially in tropical, semi-arid and arid regions of the world. Water deficits result from low and erratic rain fall, poor soil water storage and when the rate of transpiration exceeds water uptake by plants. The cellular water deficits results in the concentration of solutes, loss of turgor, change in cell volume, disruption of water potential

gradients, change in membrane integrity, denaturation of proteins and several physiological and molecular components (Griffith and Parry, 2002; Lawlor 2002; Lawlor and Cornic, 2002; Raymond and Smirnoff, 2002; Parry et al., 2002; Bartels and Souer, 2003). The stress effects depend on the degree and duration of the stress, developmental stage of the plant, genotypic capacity of species and environmental interactions. Several attempts were made to understand the water stress recognition and the subsequent signal transduction (Bohnert et al., 1995; Leung and Giraudat, 1998). The gene induction leads to the formation of gene products such as proline, glycinebetaine, and other products, which may act to maintain cellular function through protection of cellular processes by protection of cellular structures and osmotic adjustments (Bray, 1993; 1997; 2002). Absciscic acid concentration increases under water stress as well as under some other abiotic stresses (Christmann et al., 2005). In fact absciscic acid is considered as a 'stress hormone' (Zeevaart and Creelman, 1988) although it may serve several other functions in the absence of stress. Understanding the functions of the various gene products formed, which are usually involved in osmotic adjustment, protection and repair of cellular structures, are of great value in evaluating water stress tolerance mechanisms and to develop water stress tolerant plants. A large number of genes with a potential role in water stress tolerance have been identified and characterized (Ingram and Bartels, 1996).

3. SALT STRESS

Salinity affects agricultural production and its quality in arid and semiarid regions, where rainfall is limited and is not sufficient to transport salts from the plant root zone (Quesada et al., 2000; Tester and Davenport, 2003). Poor water management also results in salinity. The basis for salinity is evaporation in which water evaporates in a pure state leaving salts and other substances behind (Carter, 1975). Salinity arises due to increase in the concentration of salts like sodium chloride, sodium carbonate, sodium sulphate or salts of magnesium. The dominant salts are either sodium chloride or sodium sulphate or mixtures of the two. The saline soil management includes crop selection, crop stand establishment, leaching requirement, drainage and other reclamation practices. It is also anticipated that the importance of salinity as a breeding objective will increase in the future (Flowers and Yeo, 1995). The effect of salinity on plants is complex and its adverse effects include ion toxicity, water deficits and nutrient imbalance and deficiencies.

Much information is available on morphological and anatomical adaptations in response to salinity (Poljakof-Mayber, 1975). Considerable information on physiological and molecular



responses of plants to salinity stress is also available (Adams et al., 1992; Moons et al., 1995; Hasegawa et al., 2000; Munn, 2002; Z ö r b et al., 2005). Salt tolerance and resistance mechanisms are highly complex since the effects are diverse and are controlled by a number of genes or groups of genes (Flowers and Yeo, 1995). Salt tolerance is generally associated with regulated ion uptake, compartmentation of ions and gene products including stress proteins (Flowers and Yeo, 1986; Cheeseman, 1988; Winicov, 1998; Zhu, 2001). Ion homeostasis is an important component of salt tolerance (Zhu, 2002). However, based upon its complexity, the mechanisms underlying salt tolerance are to be investigated in detail. Dajic in Chapter 3 deals in

detail the molecular basis of salt tolerance in addition to related physiological, genetical and biotechnological aspects.

4. HIGH TEMPERATURE STRESS

High temperature stress in plants arises in response to many factors such as the exposure of plants to high ambient temperatures, exposure of germinating seeds to the soil which is warmed by absorbed infrared radiation from the sun, more plant transpiration followed by less water absorption, reduced transpiration capacity in certain plant organs, forest fires, natural gas blowouts, etc. Though, much work has been carried out at ultrastructural, molecular and gene expression level under different temperature extremes, the temperature perception and the molecules involved in the perception are not known clearly (Burke and Usda-Ars, 1988; Iba, 2002; Rao et al., 2002; Camejo et al., 2005). All the cells of an organism respond to high temperature stress. All organisms when exposed to rapid increases in external temperatures, generally 5 to 10 °C above normal growth temperatures for a period of few minutes to a few hours exhibit synthesis of an elite set of proteins called heat shock proteins (HSPs) which are not present, or are present in small quantities in unstressed organisms (Sridevi et al., 1999). These HSPs are involved in cellular repair, rescue, cleanup and/or protection during the stress and from its recovery. Understanding the mechanisms and development of thermotolerant plants is of great significance in tropical, semi-arid and arid regions of the world. Sharkey and Schrader (Chapter 4) emphasizes the effect of high temperature stress on various physiological and molecular biological processes and discusses several strategies for improving heat tolerance in plants.

5. FREEZING STRESS:

Plants growing in temperate and frigid areas are exposed to freezing temperatures. It is well known that membrane systems are the primary sites of freezing injury to plants (Rudolf and Crowe, 1985; Hughes and Dunn, 1996; Thomashow, 1999). In addition, cell damage in response to freezing stress is also caused by protein denaturation. Freezing tolerance is characterised by changes in metabolite levels and enzyme activities (Levitt, 1980; Mazur, 1968; Steponkus, 1984; Guy, 1990). Freezing tolerance is associated with the accumulation of sugars, several types of proteins including heat shock proteins, lipids, abscisic acid and other products of altered metabolism (Siminovitch et al., 1968; Nagao et al., 2005). They are expected to depress the freezing point of the tissue, may act as nutrient and energy source and play a key role in

rectifying the cellular damage caused by freezing stress. Freezing tolerance increases with decreasing water content. Abscissic acid accumulation also increases freezing tolerance. However, much information is not available regarding the freezing injury and tolerance mechanisms against freezing stress. Recently much interest has been shown towards the identification, characterization and functioning of genes with roles in freezing tolerance and the mechanisms involved in low temperature gene regulation and signal transduction (Thomashow, 1999). In this connection, a systems biology approach to study cold acclimation of plants possesses great significance (Chapter 5: Trischuk, Schilling, Wisniewski and Gusta).

6. PHOTOOXIDATIVE STRESS

Among the abiotic stress factors, light stress is one of the important environmental constraints that limit the efficiency of **photosynthesis** and plant productivity (Foyer and Noctor, 2000; Das, 2004; Reddy et al., 2004). When absorbed light energy exceeds the capacity for light energy utilization in plant photosynthesis, then the photosynthetic efficiency will be reduced due to the formation of AOS, which can damage photosynthetic apparatus and chloroplast components. In order to mitigate the photooxidative stress, plants have developed certain strategies of tolerance mechanisms (Mittler, 2002; Mittler et al., 2004). Understanding how plants respond to light stress has a high priority in several plant biotechnological programmes. Foyer et al., (1994) and Apel and Hirt, (2004) reviewed the mechanism of photooxidative stress tolerance in higher plants.

7. NUTRIENT STRESS

Plant growth, development and yield are contributed by 17 essential elements (Hopkins and Hüner, 2004). Plants may be subjected to nutrient stress due to several factors such as negligence of the farmer leading to nutrient deficiency or excess supply of nutrients because of the farmer's over enthusiasm to obtain more yield, natural deposits or mining processes etc. Nutrient stress and associated metabolic disorders decrease plant growth and yield (Lynch and Brown, 2001). Plant growth and metabolism is also affected by heavy metal and salinity stress. Developing nutrient stress tolerance in crop plants may help to extend agriculture to unexplored harsh and nutrient poor soils (Cobbet, 2000; Clemens, 2001).

8. HEAVY METAL STRESS

Super optimal concentrations of heavy metals such as Cd, Pb, Hg, Cu, Zn and Ni affect growth, development and yield of plants (Pahlsson, 1989; Sresty and Rao, 1999). However, Cu,

Zn and Ni are essential micronutrients at low concentrations. Heavy metals affect several physiological (Barceló and Poschenrieder, 1990) and metabolic processes (Van Assche and Clijsters, 1990; Hall, 2002; Schützendübel and Polle, 2002). Plants have developed several mechanisms that control and respond to the uptake and accumulation of both essential and nonessential heavy metals (Cobbet and Goldsbrough, 2002). These tolerance mechanisms in plants vary from species to species and their genetic background. The important heavy metal tolerance mechanisms include, metal binding to wall, reduced transport across the cell membrane, active efflux of metals, compartmentalization, chelation and sequestration of heavy metals by particular ligands such as phytochelatins and metallothioneins (Tomsett and Thurman, 1988; Cobbet and Goldsbrough, 2002). Antioxidative systems are also involved in heavy metal tolerance (Rao and Sresty, 2000). Certain plants specially many brassicaceae family members including numerous *Thalspi* species have relatively high tolerance for heavy metals such as Ni and Zn and act as hyperaccumulators which can be used for phytoremediation (Clemens, 2001; Freeman et al., 2005).

9. METABOLIC ENGINEERING

To cope up with different abiotic stresses plants alter their metabolic pathways to adjust to changed environments (Rathinasabapathi, 2000). The metabolic pathways such as proline, glycinebetaine, polyols, antioxidant components become more active to keep the plant survive under stress conditions. However, the initiation and efficiency of these pathways differ from species to species or genotype to genotype to a great extent. Installing these stress tolerating pathways utilise recombinant DNA technology (Stephanopoulos, 1999). Stitt, (1995) has given an interesting account of production of transgenic plants for metabolic design. The use of novel approaches combining the techniques of genetic, genetic engineering and molecular biology are expected to provide exciting avenues for future research (Madlung and Comai, 2004). Understanding the mechanisms by which plants perceive and transduce stress signals to initiate adaptive response is essential for engineering stress-tolerant crop plants (Xiong and Zhu, 2001).

Salicylic acid induces systemic acquired resistance:

Local salicylic acid production induces distal production and SAR via salicylic acid transport in xylem. Methylation into MSA, volatilization and distal detection. High constitutive SA levels result in plants with high ability to withstand pathogens. Mechanism by which

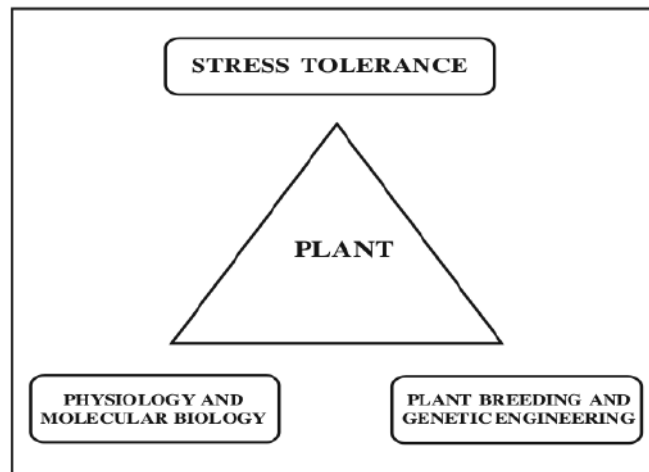
salicylic acid induces SAR is unknown. Jasmonic acid also mediates disease and insect resistance.

The hypersensitive reaction initiates a plant immune response:

The long term plant resistance to a pathogen is similar to a mammalian immune response. This is known as systemic acquired resistance (SAR). Secondary metabolites induced by the hypersensitive reaction initiate changes in metabolism in other plant organs through control of signal transduction chains. The capacity to resist pathogens spreads throughout plant immune capacity=SAR signaling involves salicylic acid (SA), a natural secondary metabolite. SA both induces pathogenesis related gene expression and enhances resistance to infection by plant viruses. Early activation of defense related genes to synthesize pathogenesis related (PR) proteins Protease inhibitors to stop cell wall lysis by specific enzymes expressed by pathogen. Bacterial cell wall lytic enzymes (chitinase, glucanase), Change cell wall composition & express enzymes providing structural support to cell walls via synthesis of lignin, suberin, callose, glycoproteins. It synthesizes secondary metabolites to isolate and limit the pathogen spread. These include isoflavonoids, phytoalexins. Apoptosis at invasion site to physically cut off rest of plant.

Plant stress measurement:

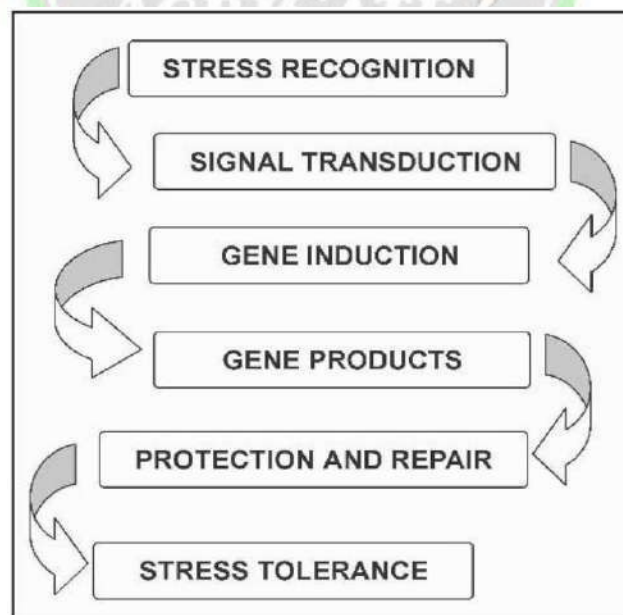
Plant stress measurement is the quantification of environmental effects on plant health. When plants are subjected to less-than the ideal growing conditions, they are considered to be under stress. Stress factors can affect growth, survival and crop yields. Plant stress research looks at the response of plants to limitations and excesses of the main abiotic factors (light, temperature, water and nutrients), and of other stress factors that are important in particular situations (e.g. pests, pathogens, or pollutants). Plant stress measurement usually focuses on taking measurements from living plants. It can involve visual assessments of plant vitality. However, more recently the focus has moved to the use of instruments and protocols that reveal the response of particular processes within the plant (especially, photosynthesis, plant cell signalling and plant secondary metabolism) Determining the optimal conditions for plant growth, e.g. optimising water use in an agricultural system. Determining the climatic range of different species or subspecies. Determining which species or subspecies are resistant to a particular stress factor.



Knowledge of physiology and molecular biology combined with plant and genetic engineering techniques are expected to enhance stress tolerance in plants

Instruments used to measure plant stress:

Measurements can be made from living plants using specialised equipment. Among the most commonly used instruments are those that measure parameters related to photosynthesis (Photosynthesis systems, chlorophyll content, chlorophyll fluorescence, Modulated fluorometer, gas exchange) or water use (porometer, pressure bomb).



IMMORTAL JELLYFISH: THE CREATURE THAT CHEATS DEATH

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A.Nazeela Barvin^{1*}, D. Manimekalai², A. Aparna¹, S. Bhaskar¹

¹PG Scholar, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu

²Assistant Professor, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu, India

*Corresponding Author: A.Nazeela Barvin

Abstract

The concept of immortality has fascinated humans for centuries, inspiring myths, philosophy, and modern biomedical research. Surprisingly, nature has already evolved a biological phenomenon that closely resembles immortality in the form of a tiny marine organism known as the immortal jellyfish (*Turritopsis dohrnii*). Unlike most living organisms that follow a linear life cycle culminating in death, this jellyfish possesses the extraordinary ability to revert from its adult stage back to its juvenile form, effectively restarting its life cycle. This process, known as transdifferentiation, allows the organism to escape senescence under favorable conditions. This article presents a comprehensive and professional overview of the immortal jellyfish, covering its taxonomy, life cycle, cellular mechanisms of rejuvenation, ecological significance, global distribution, and potential implications for ageing research and regenerative medicine. Additionally, the article explores the environmental factors contributing to the increasing spread of jellyfish populations and discusses the broader lessons this organism offers for science and sustainability.

Keywords: Immortal jellyfish; *Turritopsis dohrnii*; biological immortality; life-cycle reversal; transdifferentiation; ageing avoidance

Introduction

Ageing and death are considered universal biological realities. From microscopic bacteria to complex mammals, all living organisms undergo a life cycle that ultimately ends in death. However, the discovery of the immortal jellyfish challenged this long-standing assumption and forced scientists to rethink the biological limits of life. The immortal jellyfish (*Turritopsis dohrnii*) is a small hydrozoan species that has gained global attention due to its unique ability to reverse its developmental cycle. When faced with environmental stress, physical damage, or ageing, it can transform its adult body into a juvenile polyp stage, thereby escaping death caused by senescence. This rare biological phenomenon has earned it the title of the only known biologically immortal animal. The significance of this organism extends beyond curiosity. Its cellular behavior has become a valuable model for understanding regeneration, cellular plasticity, and the mechanisms that control ageing. In an era where humans seek solutions to age-related diseases and tissue degeneration, the immortal jellyfish offers a natural blueprint worthy of scientific attention.

Taxonomy and Classification

The immortal jellyfish belongs to the phylum Cnidaria, a group of aquatic animals characterized by the presence of stinging cells called cnidocytes. Its detailed taxonomic classification is as follows:

- Kingdom: Animalia
- Phylum: Cnidaria
- Class: Hydrozoa
- Order: Anthoathecata
- Family: Oceaniidae
- Genus: *Turritopsis*
- Species: *Turritopsis dohrnii*



Hydrozoans are generally small and often overlooked, yet they display remarkable biological diversity. Within this group, *Turritopsis dohrnii* stands out due to its exceptional regenerative capabilities.

Physical Characteristics and Habitat

The immortal jellyfish is extremely small, measuring approximately 4–5 mm in diameter. It has a transparent, bell-shaped body with a reddish stomach visible at the center. Fine tentacles

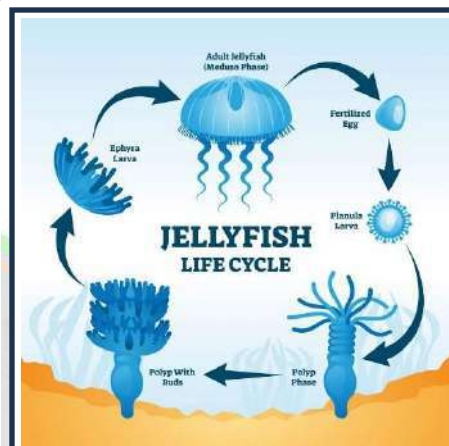
extend from the margin of the bell, enabling the jellyfish to capture plankton and other microscopic prey. Originally native to the Mediterranean Sea, *Turritopsis dohrnii* has now been reported in oceans worldwide. Its global distribution is largely attributed to human maritime activities, particularly the discharge of ballast water from ships, which unintentionally transports larvae across vast distances. The jellyfish inhabits coastal and open ocean waters, preferring temperate to tropical environments. Its ability to tolerate varying salinity, temperature, and oxygen levels enhances its survival and dispersal potential.

The Typical Jellyfish Life Cycle

Most jellyfish follow a predictable and irreversible life cycle consisting of four main stages:

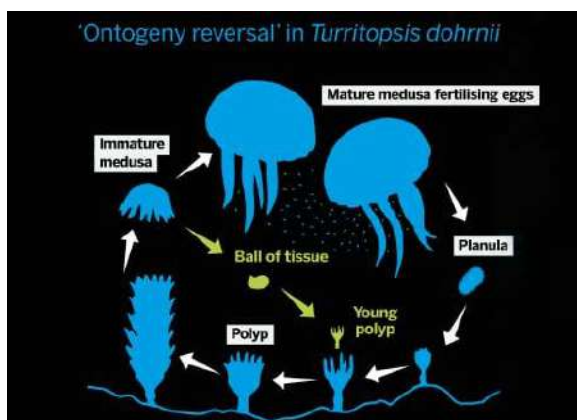
1. **Planula Larva** – A free-swimming larval stage formed after fertilization.
2. **Polyp** – The larva attaches to a substrate and grows into a polyp colony.
3. **Medusa** – The polyp produces free-swimming adult jellyfish.
4. **Reproduction and Death** – After sexual reproduction, the adult jellyfish typically dies.

This linear progression mirrors the life cycle of many animals, where development proceeds in a single direction toward senescence and death.



The Typical Jellyfish

What distinguishes *Turritopsis dohrnii* from all other jellyfish species is its ability to reverse this life cycle. When exposed to stressors such as starvation, injury, temperature fluctuations, or ageing, the adult medusa does not die.



The Unique Life Cycle of the Immortal jelly fish

Instead, it undergoes a remarkable transformation. The jellyfish's cells reorganize, and the organism settles onto a surface, forming a cyst-like structure. From this structure, new polyps emerge, eventually giving rise to genetically identical medusae. This process can occur repeatedly, allowing the jellyfish to bypass death due to ageing.

Cellular Mechanism: Transdifferentiation

The biological foundation of immortality in *Turritopsis dohrnii* lies in a process known as transdifferentiation. This phenomenon allows mature, specialized cells to convert directly into different cell types without reverting to a stem cell state. In humans and most animals, cells are highly specialized and irreversible once differentiated. In contrast, the immortal jellyfish retains cellular plasticity throughout its life. Muscle cells, nerve cells, and reproductive cells can transform into polyp cells, effectively rebuilding the organism. This cellular flexibility is extremely rare and represents a significant deviation from conventional developmental biology.

Genetic and Molecular Insights

Recent genomic studies have revealed that *Turritopsis dohrnii* possesses an enhanced set of genes associated with DNA repair, cell cycle regulation, and stress resistance. These genetic traits likely support its regenerative abilities and resistance to ageing. Scientists have identified similarities between the jellyfish's gene expression patterns and those observed in human stem cells. This has sparked interest in exploring how these genetic pathways might be applied in biomedical research, particularly in regenerative medicine.

How Does the Immortal Jellyfish Die?

Although popularly known as the "immortal" jellyfish, *Turritopsis dohrnii* is not completely immune to death. Its immortality refers only to its ability to avoid ageing-related death by repeatedly reversing its life cycle. The jellyfish can still die due to external factors such as predation, disease, severe physical damage, or extreme environmental conditions. If it is eaten by predators, infected by pathogens, exposed to toxic pollution, or destroyed before it can initiate life-cycle reversal, regeneration becomes impossible. In addition, the rejuvenation process itself requires suitable environmental conditions and sufficient energy reserves. If these requirements are not met, the jellyfish may fail to undergo transdifferentiation and eventually die. Therefore, the immortal jellyfish is best described as biologically immortal rather than absolutely immortal, it escapes natural ageing but remains vulnerable to the hazards of its environment.

Ecological Role of the Immortal Jellyfish

Despite its small size, the immortal jellyfish plays an important role in marine ecosystems. It contributes to planktonic food webs by feeding on microscopic organisms and serving as prey for larger species such as fish and turtles. However, increasing jellyfish populations can disrupt ecosystems by competing with fish larvae for food and altering nutrient cycling. Understanding their ecological role is essential for maintaining marine balance.

Jellyfish Blooms and Environmental Change

Jellyfish blooms, sudden increases in jellyfish populations, have become more frequent in recent decades. Factors contributing to this trend include:

- Ocean warming due to climate change
- Overfishing, which reduces jellyfish predators
- Coastal pollution and eutrophication
- Habitat modification

These conditions often favor jellyfish survival over that of fish, potentially leading to long-term ecosystem shifts.

Conclusion

The immortal jellyfish is one of nature's most extraordinary creations. Its ability to reverse ageing challenges traditional biological concepts and opens new pathways for scientific exploration. Though small and nearly invisible, *Turritopsis dohrnii* carries a powerful message: life is more adaptable and resilient than we once believed. By studying this remarkable organism, humanity gains not only scientific knowledge but also a deeper appreciation for the complexity and wisdom of the natural world.

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ROLES OF MICROBES IN SOIL FERTILITY

Article ID: AG-VO6-I01-92**Dr. Naresh Gupta**

Senior Technical Officer (Soil Science), R.V.S.K.V.V. Gwalior (M. P.), India

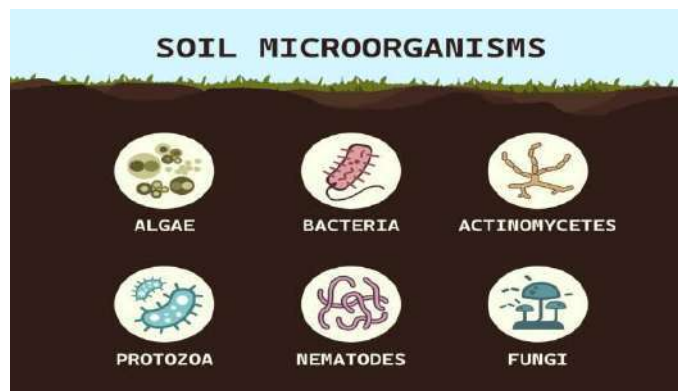
Present address: Krishi Vigyan Kendra, Manawar (Dhar-2)

Introduction

Soil fertility is critical in determining agricultural productivity, ecosystem health, and sustainable land management. Among the many factors contributing to healthy soil, soil microbes stand out as an essential component. These tiny organisms are vital for improving soil fertility and supporting plant growth, making them an important part of any healthy ecosystem. This article explores the role of microbes in soil fertility and their significant impact on plant health, soil structure, and biological fertility.

Soil Microbes:

Soil microbes, including bacteria and fungi, are microscopic organisms that live in the soil. They include diverse species, such as nitrogen-fixing bacteria, arbuscular mycorrhizal fungi (AMF), and other beneficial organisms. The diversity of soil microbes is crucial because each group performs specific roles that contribute to overall soil health and fertility, which will be explained later. A higher diversity of soil microbes often leads to better soil conditions, improved nutrient cycling, and greater resilience against environmental stressors.



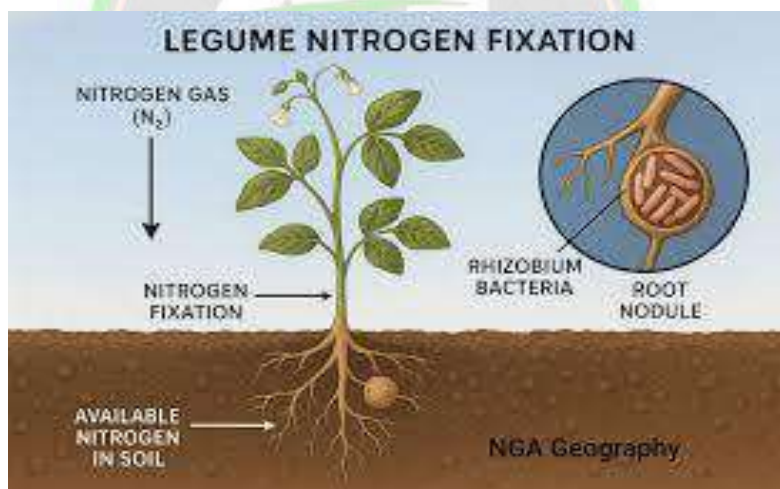
Functions of Soil Microbes

- One of the primary functions of soil microbes is to decompose organic matter. This process breaks down dead plant and animal materials, releasing essential nutrients such as nitrogen, phosphorus, and potassium into the soil.
- These nutrients are then available for plant roots to absorb, promoting healthy plant growth. Without microbes, organic matter would accumulate, and nutrient cycling would slow down, negatively impacting soil fertility.

Roles of Soil Microbes in Soil Fertility:

1. Convert Nitrogen

Nitrogen-fixing bacteria, such as *Rhizobium* and *Azotobacter*, play an important role in converting atmospheric nitrogen into a form that plants can use. This process, known as biological nitrogen fixation, is essential for maintaining nitrogen levels in cropping soil. Nitrogen is needed to support the production of amino acids, proteins, and chlorophyll, which are vital for plant growth and development.



By working symbiotically with plant roots, nitrogen-fixing bacteria help increase plant productivity and reduce the need for synthetic fertilizers, which can harm the environment.

2. Helps Plants to Absorb Nutrients

Arbuscular mycorrhizal fungi (AMF) form symbiotic relationships with plant roots, extending their [hyphal networks](#) into the soil. This network enhances the plant's ability to access nutrients, particularly phosphorus, which is often limited in soil. Additionally, AMF improves soil structure by binding soil particles together, creating a stable environment for plant roots. Their presence is closely linked to healthy soil and robust plant growth.

3. Enhance Soil Organic Carbon

Soil organic carbon is a key indicator of soil fertility and health. Microbes contribute significantly to [soil organic carbon](#) accumulation by breaking down organic matter and incorporating it into the soil matrix. This not only improves soil structure but also enhances its ability to retain water and nutrients. Higher soil organic carbon levels are associated with better soil conditions and increased resilience to climate change.

4. Improve Soil Structure and Conditions

Soil microbes play an integral role in shaping soil structure. By producing substances like polysaccharides and glomalin, microbes bind soil particles together, forming aggregates. These aggregates improve soil aeration, water infiltration, and root penetration. A well-structured soil supports plant growth and increases the [efficiency of water and nutrient uptake](#). Additionally, microbes help regulate soil pH and [reduce compaction](#), creating optimal soil conditions for plants.

5. Support Biological Fertility in the Soil

Biological fertility refers to the capacity of soil to support microbial life and biological processes. Healthy soil teeming with microbes ensures the continuous cycling of nutrients and the maintenance of soil health. Bacteria and fungi play an important part in maintaining biological fertility by breaking down organic matter, fixing nitrogen, and suppressing soil-borne diseases. By fostering a thriving microbial community, farmers and land managers can sustainably increase plant yields and improve soil fertility.

6. Sequester Carbon

Microbes also play a role in mitigating climate change by sequestering carbon. According to a recent study, the role of microbes in sequestering carbon is four times

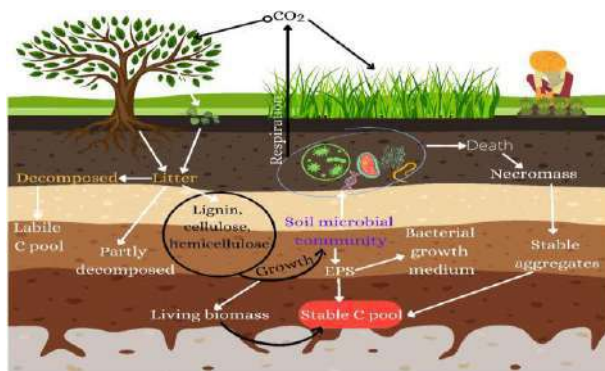


Fig: Soil Carbon Sequestration

more important than any other process, even when compared to the decomposition of organic matter, which is known to store carbon in the soil. When microbes use carbon for growth, carbon is sequestered in the microbes' cells and the soil later on when they die.

Managing Soil Microbes for Sustainable Agriculture

Given the critical role of microbes in soil fertility, it is essential to adopt practices that support their activity and diversity. Here are some strategies for managing soil microbes effectively:

1. **Add organic matter.** Incorporating compost, manure, and crop residues into the soil provides food for microbes and enhances their activity.
2. **Reduce chemical inputs.** Overuse of synthetic fertilizers and pesticides can harm beneficial microbes. Opt for organic or integrated nutrient management practices to maintain microbial diversity.
3. **Encourage Crop Rotation and Cover Crops.** Diverse cropping systems and cover crops support a wide range of microbial species, improving soil health over time. In contrast, monoculture practices—where single crops is grown repeatedly in the same soil— reduce the variety of organic matter inputs into the soil, which in turn limits the types of microbes that can thrive.
4. **Minimize tillage.** Reduced tillage preserves soil structure and protects microbial habitats, fostering a healthy soil ecosystem.
5. **Utilize biochar.** [Biochar](#), a carbon-rich material produced by heating organic matter, provides a habitat for microbes, enhancing their growth and activity. Its porous structure offers shelter and nutrients to a wide variety of soil microbes, including bacteria and fungi, thereby fostering a thriving microbial ecosystem.

Conclusion

Soil microbes are indispensable for improving soil fertility and maintaining healthy soil ecosystems. By decomposing organic matter, fixing nitrogen, and enhancing soil structure, microbes create an environment conducive to plant growth and sustainable agriculture. The diversity of soil microbes, including bacteria and fungi like nitrogen-fixing bacteria and arbuscular mycorrhizal fungi, ensures the efficient cycling of nutrients and the sequestration of carbon dioxide. To harness the benefits of soil microbes, it is essential to adopt sustainable soil management practices that support their activity and diversity.

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BUND CROPPING IN PADDY FIELDS: TURNING FIELD BOUNDARIES INTO PROFIT ZONES

Article ID: AG-VO6-I01-93

P.Prakash^a and *S.Ranjani^a

S.Thangapazham Agricultural College (Affiliated to TNAU), Vasudevanallur, Tenkasi-627760,
Tamil Nadu, India

.*Corresponding Author: S.Ranjania

Introduction

Bund cropping in a paddy field is the practice of growing crops on the bunds or embankments that surround rice fields. These bunds are mainly constructed to hold water for paddy cultivation, but they can also be used for growing useful crops. Normally, bunds are left unused, but by adopting bund cropping, farmers can make better use of this space.

This practice helps farmers get additional income without affecting the main paddy crop. It also improves soil fertility, reduces soil erosion, and supports sustainable agriculture. Crops such as pulses, vegetables, flowers, and fodder crops are commonly grown on paddy bunds. Bund cropping is a simple, low-cost, and eco-friendly method, especially suitable for small and marginal farmers in rice-growing areas.

Importance of Bund Cropping:

Additional Income: Vegetables, pulses, flowers, and fodder crops grown on bunds provide extra revenue.

Efficient Land Use: Makes productive use of otherwise wasted space.

Soil Health Improvement: Leguminous crops like cowpea and green gram fix atmospheric nitrogen, enriching the soil.

Reduced Soil Erosion: Crop roots strengthen bunds and prevent damage during irrigation or rainfall.

Pest Management: Flower crops like marigold attract beneficial insects and reduce pest incidence in paddy.

Suitable crops for Paddy Bunds:

Suitable crops for bund cropping in paddy fields include pulses, vegetables, flowers, greens, and fodder crops. Pulse crops like cowpea, green gram, black gram, and red gram are highly suitable because they improve soil fertility by fixing nitrogen. Vegetables such as chilli, okra, brinjal, tomato, and gourds can also be grown on bunds to provide additional income. Flower crops like marigold and sunflower attract beneficial insects and help in pest control. Greens and spices such as coriander, fenugreek, and spinach are easy to grow and useful for home consumption. Fodder crops like fodder cowpea and grasses can be grown on strong and wide bunds to support livestock.

**Advantages of Bund Cropping:**

Bund cropping has many advantages in paddy cultivation. It helps farmers earn additional income by using the bunds that are normally left unused. This practice improves land use efficiency without affecting the main paddy crop. Growing pulse crops on bunds increases soil fertility by adding nitrogen to the soil. The roots of bund crops strengthen the bunds and reduce soil erosion. Bund cropping also provides vegetables, fodder, and flowers for home use. Flower crops attract beneficial insects, which help in reducing pest problems. Overall, bund cropping is a simple, low-cost, and eco-friendly practice that supports sustainable agriculture.

Examples:

In Paddy the diseases like Rice Tungro virus, Rice blast, Bacterial Blight is Controlled. And the pests like Green leafhopper is controlled.

Conclusion

Bund cropping is a simple, low-cost, and eco-friendly practice. It helps farmers increase income, protect the environment, and make better use of available land in Paddy cultivation.



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FISH WASTE IS NOT WASTE: VALUE ADDITION AND SUSTAINABILITY IN MARINE PROCESSING

Article ID: AG-VO6-I01-94**B. Deepika* and P. Ganesan**

PhD scholar in Fish Processing Technology

Department of Fish Processing Technology, Fisheries College and Research Institute,

Thoothukudi – 628 008, Tamil Nadu, India

**Corresponding Author: B. Deepika*

Abstract

The rapid growth of the marine processing industry has resulted in the generation of large quantities of fish waste, traditionally considered an environmental burden. Recent advances in processing technologies have demonstrated that fish waste is a valuable resource rich in proteins, lipids, minerals, enzymes, and bioactive compounds. This article highlights the sources, nutritional value, and utilization of fish processing waste for the production of value-added products such as fish meal, fish oil, collagen, gelatin, bioactive peptides, fertilizers, and silage. Effective utilization of fish waste supports sustainability, reduces environmental pollution, and promotes a circular economy in the marine processing sector.

Keywords: Fish waste, Value addition, By-product utilization, Sustainability, Circular economy

Introduction

Fish and seafood play a vital role in global food security, nutrition, and livelihoods, especially in coastal countries like India. However, along with the rapid growth of the marine processing industry comes a major challenge—generation of large quantities of waste. During processing, only 30–60% of the fish is used for direct human consumption, while the remaining portion such as heads, bones, skins, scales, viscera, and fins is often discarded. Traditionally, this fish waste has been considered a burden, leading to environmental pollution, foul odour, and disposal problems.

In recent years, the perception of fish waste has changed significantly. Scientists and

industry experts now recognize that fish waste is a valuable resource rich in proteins, lipids, minerals, enzymes, and bioactive compounds. With appropriate processing technologies, fish by-products can be converted into high-value products such as fish meal, fish oil, collagen, gelatin, bioactive peptides, fertilizers, and animal feed. This popular article explores how fish waste can be effectively utilized, contributing to sustainability, economic growth, and environmental protection in the marine processing sector.

Sources and Types of Fish Processing Waste

Fish processing waste varies depending on the species and processing method. In filleting and peeling operations, large quantities of heads, frames, skins, and trimmings are generated. Shrimp processing units produce shells and heads, while tuna and large pelagic fish processing generate viscera and dark meat as waste. Fish drying and smoking units also generate scales and rejected raw material.

These wastes are highly perishable and can quickly deteriorate due to microbial activity if not handled properly. Improper disposal leads to water and soil pollution, attracts pests, and releases unpleasant odours. Therefore, effective utilization of fish waste is not only economically beneficial but also essential for maintaining hygiene and environmental quality in coastal regions.

Nutritional and Biochemical Value of Fish Waste

Fish waste is nutritionally rich and often contains higher concentrations of valuable compounds than edible muscle. Fish heads and frames are excellent sources of calcium, phosphorus, and collagen. Skin and scales are rich in collagen and gelatin, which are widely used in food, pharmaceutical, and cosmetic industries. Viscera contain digestive enzymes such as proteases and lipases that have industrial applications.

Fish liver and fatty tissues are rich in omega-3 fatty acids like EPA and DHA, which are known for their cardiovascular and anti-inflammatory benefits. Shrimp shells contain chitin and chitosan, biopolymers with applications in food preservation, water treatment, agriculture, and medicine. This immense biochemical potential makes fish waste an important raw material for value-added processing.

Value-Added Products from Fish Waste

Fish Meal and Fish Oil

One of the most common uses of fish waste is the production of fish meal and fish oil.

Fish meal is a high-protein ingredient widely used in aquaculture feed, poultry feed, and livestock feed. Fish oil extracted from waste is rich in omega-3 fatty acids and is used in nutraceuticals, pharmaceuticals, and animal feed industries.

Collagen and Gelatin

Fish skin, scales, and bones are increasingly used for the extraction of collagen and gelatin. Compared to mammalian sources, fish collagen has better bioavailability and fewer religious or cultural restrictions. These products are used in food formulations, wound healing materials, cosmetics, and health supplements.

Bioactive Peptides and Enzymes

Through enzymatic hydrolysis, fish waste proteins can be converted into bioactive peptides with antioxidant, antimicrobial, and antihypertensive properties. Enzymes extracted from fish viscera are used in detergent, leather, and food processing industries.

Fertilizers and Silage

Fish waste can be converted into organic fertilizers and fish silage. Fish silage is a liquefied product produced by acid or fermentation methods and is used as animal feed or soil conditioner. These products support sustainable agriculture and reduce dependence on chemical fertilizers.

Environmental and Economic Benefits

Utilization of fish waste significantly reduces environmental pollution by minimizing dumping and uncontrolled decomposition. It supports the concept of a **circular economy**, where waste from one process becomes raw material for another. This approach reduces resource wastage and enhances sustainability.

Economically, value addition to fish waste creates new income streams for processing units and generates employment opportunities in coastal areas. Small-scale entrepreneurs can engage in fish waste-based industries such as silage production, composting, and dried fish meal preparation. For developing countries, efficient waste utilization can improve export earnings and overall profitability of the marine processing sector.

Challenges in Fish Waste Utilization

Despite its potential, fish waste utilization faces several challenges. Lack of infrastructure, inadequate cold storage facilities, and poor awareness among processors limit large-scale adoption. Transportation and storage of waste require careful handling to prevent

spoilage. In addition, initial investment costs and technical expertise are required for setting up value-added processing units.

Addressing these challenges requires government support, training programs, industry–academia collaboration, and adoption of low-cost technologies suitable for small and medium enterprises.

Conclusion

Fish waste is no longer just a disposal problem; it is a valuable resource with immense economic and environmental potential. Through scientific processing and innovative technologies, fish by-products can be transformed into a wide range of useful products that support sustainability, food security, and rural livelihoods. Promoting fish waste utilization not only reduces environmental pollution but also strengthens the marine processing industry by improving efficiency and profitability.

In the future, greater emphasis on research, awareness, and policy support will be essential to fully harness the value of fish waste. By adopting a waste-to-wealth approach, the marine processing sector can move towards a more sustainable and resilient future.

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FROM SEA TO PLATE: JOURNEY OF FISH THROUGH MARINE PROCESSING

Article ID: AG-VO6-I01-95**B. Deepika* and P. Ganesan**

PhD scholar in Fish Processing Technology

Department of Fish Processing Technology, Fisheries College and Research Institute,

Thoothukudi – 628 008, Tamil Nadu, India

***Corresponding Author: B. Deepika**

Abstract

Fish is a highly perishable but nutritionally important food commodity that supports food security, livelihoods, and international trade. The journey of fish from harvest to consumption involves a series of carefully controlled steps collectively known as marine processing. This article describes the key stages in the journey of fish from the sea to the consumer's plate, including harvesting, onboard handling, landing, transportation, primary and secondary processing, packaging, storage, and distribution. Emphasis is placed on the importance of hygiene, cold chain maintenance, and scientific processing in preserving quality, safety, and nutritional value. Understanding these processes helps consumers appreciate the role of marine processing in delivering safe, high-quality fish products.

Keywords: Marine processing, Fish handling, Cold chain, Fish preservation, Seafood safety

Introduction

Fish is one of the most important sources of animal protein for millions of people across the world. In coastal countries like India, fish not only contributes to nutrition but also supports livelihoods, employment, and export earnings. When consumers buy fish from markets or supermarkets, they often see only the final product—fresh, frozen, dried, or canned fish—without realizing the long and carefully controlled journey it has undergone. This journey from harvesting in the sea to reaching the consumer's plate involves several scientific, hygienic, and technological steps collectively known as marine processing.

Marine processing plays a crucial role in maintaining the quality, safety, nutritional value, and shelf life of fish. Since fish is highly perishable, improper handling at any stage can lead to rapid spoilage and health risks. This popular article explains, in simple terms, how fish travels from the sea to the plate, highlighting the importance of each processing step and its impact on consumers.

Harvesting of Fish: The First Step

The journey of fish begins in the sea, rivers, or aquaculture farms. Marine fish are harvested using different fishing methods such as trawling, gill netting, long lining, and purse seining. The method of capture influences the quality of fish, as excessive stress, physical damage, or delayed handling can reduce freshness.

Immediately after capture, fish begins to deteriorate due to enzymatic activity and microbial growth. Therefore, proper onboard handling is essential. Washing with clean seawater, removal of excess slime, and rapid icing are commonly practiced to slow down spoilage. Maintaining a low temperature from the very first stage is critical for preserving quality throughout the processing chain.

Landing and Transportation

After harvesting, fish is landed at fishing harbours or landing centres. Here, fish is sorted based on species, size, and quality. Poor handling at landing centres can undo all the care taken onboard vessels. Exposure to sun, contamination from dirty surfaces, and lack of ice can accelerate spoilage.

Fish is then transported to processing plants or markets using insulated boxes, refrigerated trucks, or iced containers. This stage forms a vital link in the cold chain, which refers to maintaining low temperature from harvest to consumption. Any break in the cold chain can reduce shelf life and affect food safety.

Reception and Quality Assessment at Processing Plants

At the processing plant, fish undergoes inspection and quality assessment. Trained personnel evaluate freshness using sensory parameters such as appearance, odour, texture, and colour. In export-oriented units, chemical and microbiological tests may also be conducted to ensure compliance with food safety standards.

Only fish meeting quality requirements is accepted for further processing. Rejected or low-grade fish may be diverted for by-product utilization such as fish meal or silage production.

This step ensures that consumers receive safe and high-quality products.

Primary Processing Operations

Primary processing involves basic preparation of fish for further processing or consumption. This includes washing, descaling, heading, gutting, peeling, and filleting depending on the species and final product requirement. These operations are carried out under hygienic conditions using potable water and sanitized equipment.

Proper handling during primary processing prevents contamination and minimizes quality loss. Workers are trained in personal hygiene, and processing areas are maintained at low temperatures to control microbial growth.

Secondary Processing and Value Addition

Secondary processing transforms raw fish into consumer-ready or ready-to-cook products. Common methods include freezing, drying, salting, smoking, canning, and marination. Each method has a specific purpose in extending shelf life and enhancing convenience.

Freezing is one of the most widely used preservation methods, as it effectively slows down microbial and enzymatic activity. Drying and salting are traditional methods still widely practiced, especially in coastal regions. Canning involves thermal processing that makes fish shelf-stable for long periods without refrigeration. Value-added products such as fish fingers, cutlets, and ready-to-eat meals are gaining popularity among urban consumers.

Packaging and Storage

Packaging plays a key role in protecting fish products from contamination, oxidation, and moisture loss. Materials such as polyethylene pouches, vacuum packs, and modified atmosphere packaging are commonly used. Proper labeling provides information on product name, processing date, storage conditions, and expiry.

Processed fish products are stored under appropriate conditions—chilled, frozen, or ambient—depending on the type of product. Efficient storage helps maintain quality until distribution and sale.

Distribution, Marketing, and Retail

From processing plants, fish products are distributed to wholesalers, retailers, supermarkets, and export markets. Maintaining hygiene and temperature during distribution is essential to ensure product safety. In retail outlets, proper display, icing, and cleanliness influence consumer perception and purchase decisions.

Consumer awareness about quality indicators such as freshness, packaging integrity, and labeling is increasing, leading to higher demand for well-processed and branded fish products

Role of Marine Processing in Food Safety and Nutrition

Marine processing helps reduce post-harvest losses, which are significant in the fisheries sector. By extending shelf life and improving safety, processing ensures year-round availability of fish and seafood. Nutrient losses during processing are minimized through improved technologies, allowing consumers to benefit from high-quality proteins, omega-3 fatty acids, vitamins, and minerals.

Conclusion

The journey of fish from sea to plate is a complex process involving careful handling, scientific processing, and strict hygiene at every stage. Marine processing ensures that fish remains safe, nutritious, and appealing by the time it reaches the consumer. Understanding this journey helps consumers appreciate the effort behind seafood products and encourages informed choices.

As demand for fish continues to grow, strengthening marine processing infrastructure, cold chain facilities, and awareness will be essential for sustainable development of the fisheries sector. From the moment fish is harvested to the time it is served on the plate, marine processing plays a vital role in connecting the sea with the consumer.

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NATURAL FARMING AS A SUSTAINABLE PATHWAY FOR FARMING COMMUNITIES IN CUDDALORE

Article ID: AG-VO6-I01-96

Dr.C.Thatchinamoorthy* , Ms.R.Yoga Priya* , Ms.R.Rajagayathri , Ms.V.Ramyam** ,
Mr.M.Raveenkumar** and Mr.R.Ragul****

*Assistant Professor, Department of Agricultural Extension and

** B.Sc.,(Hons.)Agriculture IV year students, JSA College of Agriculture and
Technology (JSACAT), Avatti, Tamil Nadu 606108, India

*Corresponding Author: Dr.C.Thatchinamoorthy

Abstract

Natural farming has emerged as a sustainable agricultural practice that addresses major challenges such as soil degradation, high input costs, and declining farm incomes. In districts like Cuddalore, where agriculture is largely dependent on rainfall and small landholdings, natural farming offers an effective alternative to chemical-based farming systems. This approach emphasizes the use of locally available bio-inputs, organic practices, and ecological processes to improve soil fertility and crop productivity. Farmers adopting natural farming report reduced cultivation costs, improved soil health, and enhanced environmental sustainability. Despite initial challenges such as yield fluctuations and limited market access, natural farming has significant potential to strengthen farmer livelihoods and promote sustainable rural development in Cuddalore District.

Keywords: Natural farming, Sustainable agriculture, Soil health, Farmer livelihoods

Introduction

Agriculture in India is facing serious challenges such as soil degradation, rising input costs, water scarcity, and declining farm income. In districts like Cuddalore, where farming communities depend heavily on seasonal rainfall and small landholdings, these challenges directly affect livelihoods. In this context, natural farming has emerged as a promising and sustainable alternative that supports both the environment and farming communities.

Natural farming is an agricultural practice that avoids the use of synthetic fertilizers, pesticides, and chemicals. Instead, it relies on natural inputs, biological processes, and local resources to improve soil fertility and crop productivity. Over the past few years, farmers in Cuddalore District have increasingly shown interest in natural farming as a way to reduce costs and restore soil health.

Natural Farming Practices Followed in Cuddalore District

Farmers practicing natural farming in Cuddalore use several eco-friendly techniques that are affordable and locally adaptable. One of the most common practices is the preparation and application of bio-inputs such as Jeevamrutham and botanical extracts. These inputs are prepared using cow dung, cow urine, jaggery, pulse flour, and soil from the farm, which help increase beneficial microbial activity in the soil.

Mulching is widely practiced to conserve soil moisture and suppress weed growth. Farmers use crop residues and dry leaves, which also contribute organic matter to the soil. Green manuring, especially with leguminous crops, improves soil fertility by fixing atmospheric nitrogen naturally. For pest management, farmers rely on neem-based formulations, chilli-garlic extracts, and fermented plant solutions, which are effective in controlling pests without harming beneficial insects.

Benefits of Natural Farming for Farmers

One of the major advantages of natural farming is the significant reduction in cultivation costs. Farmers no longer depend on expensive chemical fertilizers and pesticides, which often push them into debt. By using farm-made inputs, farmers reduce external dependency and gain financial stability.

Natural farming also improves soil health. Continuous use of organic inputs increases soil organic matter, enhances microbial diversity, and improves water retention capacity. This is especially beneficial in drought-prone areas of Cuddalore District. From a health perspective, natural farming produces chemical-free food, which benefits both farmers and consumers. Many farmers report improved personal health after shifting away from chemical spraying.

Role of Natural Farming in Sustainable Development

Natural farming supports environmental sustainability by reducing soil pollution, protecting groundwater, and conserving biodiversity. It aligns with the principles of sustainable agriculture by maintaining ecological balance and reducing carbon emissions. Socially, natural

farming promotes community participation and knowledge sharing. Farmer groups, self-help groups, and local organizations play an important role in spreading awareness and training farmers. Women farmers, in particular, actively participate in preparing bio-inputs and managing farm activities. Economically, natural farming strengthens livelihood security by lowering production costs and encouraging diversified cropping systems such as millets, pulses, and oilseeds.

Challenges Faced by Farmers

Despite its benefits, farmers face certain challenges while adopting natural farming. During the initial transition period, crop yields may fluctuate, which can discourage farmers. Lack of proper training, limited market access for natural produce, and absence of premium pricing are also major concerns. However, these challenges can be addressed through continuous extension support, farmer training programs, and better marketing systems.

Conclusion

Natural farming has the potential to transform agriculture in Cuddalore District by making it more sustainable, resilient, and farmer-friendly. By restoring soil health, reducing cultivation costs, and strengthening farming communities, natural farming offers a viable solution for long-term agricultural development. With proper institutional support and awareness, natural farming can play a key role in ensuring food security and rural prosperity.

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SMART AND PRECISION AQUACULTURE: SUSTAINABLE DEVELOPMENT WITH THE INTEGRATED TECHNOLOGIES

Article ID: AG-VO6-I01-97**Subhasrita Nayak**

Research scholar (YP-II),

ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar-751002, Odisha, India

1. Introduction

Aquaculture is one of the fastest growing food-producing industries worldwide and has become the lifeblood of food and nutrition for billions. The last few decades have seen aquaculture rapidly become more intensive, following growing international demand for seafood, declining capture fisheries and increased economic prospects in freshwater, brackishwater, marine and recirculating systems. However, along with growth there has been a battery of complex and interconnected issues hampering profitability, productivity and sustainability across the sector. These challenges include water-quality instability, unpredictable disease outbreaks, suboptimal feed utilization, environmental degradation, lack of traceability, and high operational risks. Conventional management models characterized mainly by manual sampling, intermittent monitoring and farmers' intuition have become inadequate in the face of more volatile trends and activities with the advent of high water demand associated with intensive aquaculture systems. For example, rapid changes of dissolved oxygen or ammonia concentrations can happen within minutes, leading to stress, reduced feeding, and mass mortality if not corrected in time (Boyd & Tucker, 2012).

In the same way, diseases induced by bacteria, viruses and parasites can spread quickly in high-density (in systems that are poorly monitored) locations. Meanwhile, international markets and regulators are now demanding more open, authentic products with sustainability certification which also complicates the complexity of contemporary aquaculture operations. Such environmental, biological, economic and regulatory influences have forced the sector into that technology-oriented transformation. Smart and Precision Aquaculture is the realization of this

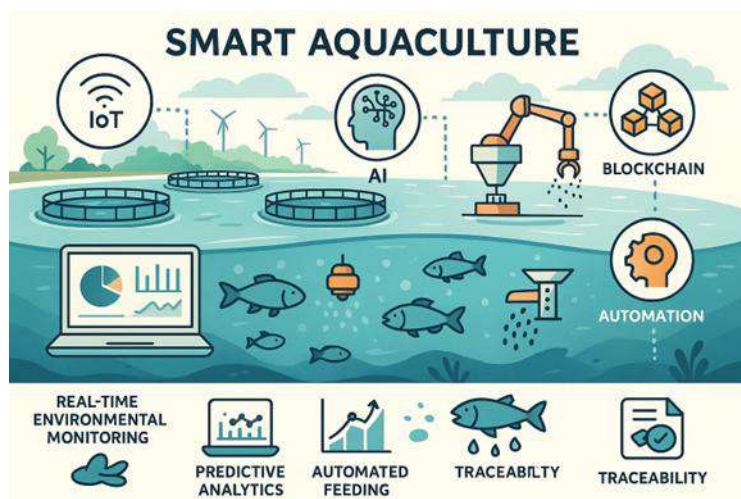
innovation. It embeds modern digital technologies, including the Internet of Things (IoT), Artificial Intelligence (AI), automation and blockchain, within aquaculture production systems. Such technologies allow real-time environmental monitoring, predictive analytics, automated feeding and aeration, and the collection, analysis, and sale (CD) of relevant data. They transform aquaculture from a practice that is reactive to an intelligent proactive production system that is data-driven.

With the shift in aquaculture towards Industry 4.0 and 5.0 models the smart systems can no longer be imagined in the future. Recent discoveries from sensors, cloud platforms, machine learning, and automated infrastructure has already led to remarkable advances in feed conversion, water-quality stability, biosecurity, and resource utilization. In this chapter we consolidate these insights, by critically extending and describing the integrated framework of in more than one scientific and technological domain.

2. Smart and precision aquaculture:

Concept and technology framework

The progression of aquaculture from traditional, knowledge-based systems to the modern, data-hungry production model is one of the most significant technological shifts in the history of aquatic food production. As global aquaculture booms we must have more accurate, reliable, and agile management. Conventional methods of aquaculture are mostly based on intuition, observation by hand, and the occasional environmental measurement that can be influenced by subjective interpretation and delayed reaction. These constraints tend to be particularly restricting where culture density is high and water quality, fish health, and feeding patterns vary frequently.



In this context, the innovative concept of smart aquaculture has taken off, characterized by integrating digital technologies — especially IoT, artificial intelligence, automation, and blockchain systems — to build a connected and intelligent production system. This broad paradigm contains precision aquaculture, which emphasizes optimizing farming practices at the fine scale, site-specific, and stock-specific level by utilizing continuous monitoring, data analytics, and targeted interventions

Digitalization in smart aquaculture is not just a toolset of practices, but rather an epistemological transformation on how it is possible to create or implement a smart decision-making regime for farm management. Incorporation of such sensors on IoT to AI analytics, automated control systems, and blockchain verification to connect all these fields is part of an interrelated architecture that can revolutionize aquaculture into a predictive, efficient, and traceable industry. Their framework illustrates the synergy between these technologies contributing to an ecosystem, where real-time detection, smart decision-making, predictive actions, and immutable records are synergistic and mutually reinforcing.

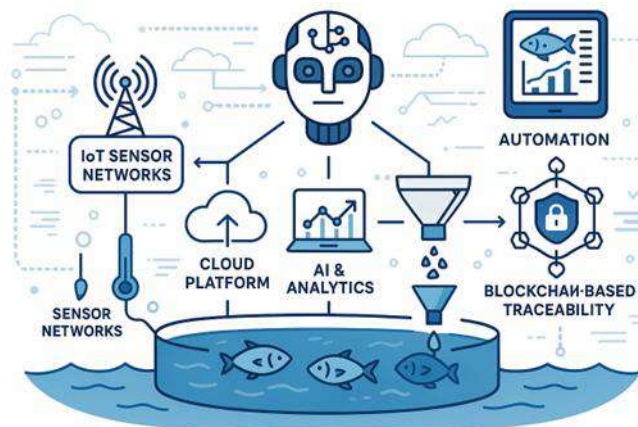
At the conceptual level, smart aquaculture describes the use of integrated digital systems (e.g. sensor networks, cloud platforms, AI predictive engines, and automated actuation technology) to continuously monitor, analyze, and manage the operations of aquaculture. The “smart” dimension is driven by the capacity of the system to learn from data, detect anomalies, forecast environmental changes, optimize feeding decisions, and trigger corrective actions with minimal human involvement. This marks a movement from a static approach to a rule-based solution towards a dynamic process in which the system evolves and performance improves depending on the amount of information captured. Whereas precision aquaculture aims for better results at relatively minute levels, spatially as well as temporally. It aims to provide the appropriate amount of feed, aeration, water exchange, or treatment at the optimal time and in the appropriate point to meet the needs of the specific biological and environmental context of the stock.

Its application is based on precision agriculture, which takes advantage of site-specific management and real-time sensing to effectively minimize waste and support greater animal welfare and sustainability within a given area. Although smart aquaculture has a widespread reliance on digital technologies, precision aquaculture uses these technologies to attain extremely finely-tuned control and resource efficiency. The two concepts together create a synergistic

approach that can accommodate both small-scale and large-scale operations. At the core are IoT sensor networks—libraries of environmental and biological sensors that measure variables like dissolved oxygen, temperature, pH, ammonia, turbidity, salinity, fish movement, biomass distribution, and feeding behavior. A raw data set of these sensors provides the raw data for all subsequent higher-level processes. They are on continuous service which means farms can record environmental dynamics which would be impossible to observe by hand, obtaining a fine-grained, real-time understanding of pond or tank conditions.

Above the sensor layer is the data transmission and cloud computing infrastructure, where wireless communication systems (LoRa, NB-IoT, GSM, Wi-Fi etc.) send data to a centralized base. These platforms – typically cloud-based offer access to farm information remotely through mobile apps or dashboards. Farmers can note environmental trends, get alerts, and take care of operations when they are far away from the farm. The cloud layer also houses computation capabilities for AI algorithms, long-term storage for historical data, and the capacity to combine several points of input to a unified analytic. This cognitive fabric of the smart aquaculture framework is embodied in the AI and analytics layer. AI models analyze the environmental data to spot anomalies, find patterns or trends, and make predictions. Machine learning algorithms classify conditions such as “normal,” “stress,” or “disease risk” based on multivariate patterns.

Deep learning-based models read images and footage of behavior to predict biomass or feeding reaction or disease symptoms. Advanced time series forecasting models predict dissolved oxygen fluctuations, ammonia accumulation, and feed demand hours before such events occur.



With the aid of integrated data sources, AI translates raw sensor readings into actionable information and suggestions, helping farms move from reactive to proactive management. The next layer includes automation and control systems; such systems either execute AI recommendations or respond to sensor thresholds. Feeders are automated and deliver feed based on active sensing of appetite, aerators and pumps automatically adjust dissolved oxygen as such. In these sophisticated systems as well, AI may control devices on a closed loop, with sensing and prediction to actuation-pumps that actuate all simultaneously across their control systems. Automation is crucial for achieving the speed and accuracy needed to effectively control high-density aquaculture systems these days.

The stack of the framework finishes off with a blockchain-enabled traceability, that stores all of your information - environmental conditions, feeding history, treatments, and harvest logs - in secure and immutable digital records. This provides traceability for transparency and trust across supply mechanisms, regulatory compliance, and consumers and buyers to understand all in-depth about product quality and sustainability. By combining blockchain technology with IoT sensors and automated systems, data is collected without human intervention, minimizing the possibility of alteration and creating better trust in traceability assumptions. These elements as such cumulatively constitute a multi-tier, comprehensive, immersive technology ecology with unprecedented potential for change in aquaculture. Shifts away from episodic monitoring and manual intervention are possible, as farms can now function as cyber-physical systems - adaptive, intelligent, sustaining top-shelf conditions with a reduced human role. The setup is also paving the way for breakthrough technologies like digital twins, self-learning feeding systems, autonomous offshore farms. Aligning real-time sensing to predictive analytics, automated control, and trustworthy data recording illustrate how smart aquaculture addresses these and other problems of sustainability, traceability, and productivity, providing a new pattern for global aquaculture systems with the potential to improve productivity, sustainability, and traceability.

3. Sensor-based water quality and environmental monitoring in smart aquaculture

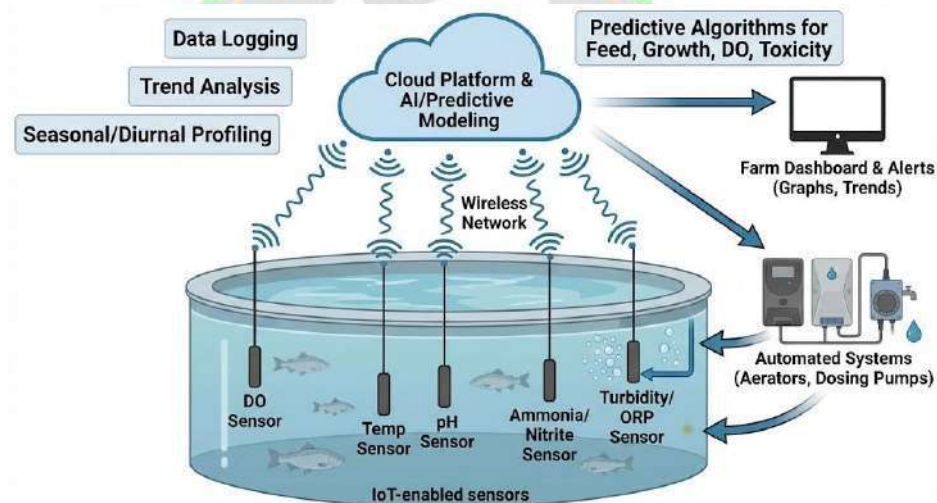
Water quality monitoring has always been at the core of successful aquaculture, as the chemical, physical, and biological properties of the aquatic environment directly affect fish physiology, behavior, immunity, and overall productivity. Conventional water-quality assessment techniques are mainly based on routine sampling methods including manual sampling (generally once daily, or sometimes twice daily), handheld tools, or colorimetric test

kits. Although these methods have been satisfactory for extensive and semi-intensive systems, they are inadequate for modern high-density production facilities where the complexity of water chemistry can be very variable within minutes. Metabolic activity is vigorous, microbial processes are dynamic, and the environment is highly responsive in these intensive ponds, biofloc systems, raceways, RAS units, and offshore cages. Thus, manual work fails to provide the finer detail and real-time dynamics required to have the best possible conditions and avoid stress events. Smart aquaculture is capable of overcoming these constraints by employing sensor-based continuous monitoring systems to monitor the environment at high time resolution, usually in real time.



These sensors, attached using IoT technologies, continuously monitor important parameters like dissolved oxygen (DO), temperature, pH, electrical conductivity, ammonia, nitrite, nitrate, turbidity, salinity, oxidation–reduction potential (ORP), and so on. Smart monitoring systems provide farmers with a holistic, minute-to-minute view of pond or tank conditions by transmitting this information over wireless networks to cloud platforms or farm dashboards. IoT-enabled sensors enable automated data logging, trend analysis, seasonal or diurnal water-quality profiling, all of which are critical for predictive modeling. Monitoring dissolved oxygen is incredibly vital. Oxygen concentrations within aquaculture systems fluctuate with fish respiration, microbial decomposition, photosynthesis, and temperature changes. Early-morning oxygen drops, or oxygen saturation drops, are associated with stress and mass death, which happens when oxygen is depleted by nocturnal respiration. The continuous monitoring of DO integrated within automated aerating systems enables farms to effectively maintain the stability of the oxygen levels without the use of manual monitoring systems. In the context of fish health and feeding mechanisms, a homogeneous DO environment has positive effects on

nitrification in biofilters, reduces the negative impact on resistance to disease brought by stress, as well as reduces energy loss by running aerators only when necessary. Monitoring temperature is also essential since temperature regulates metabolic rate, digestion, oxygen consumption, and immune activity. Any small amount that deviates from species-specific optimum range will lead to changes in appetite, growth performance, and stress whereas a large deviation will cost the living species in mortality. Intelligent sensors monitor the temperature variation of the day and send alerts when extreme temperatures occur. Temperature information allows AI algorithms to predict expected feed needs, growth rates, and DO consumption trends. The pH is another important parameter that is always monitored continuously in smart aquaculture systems. pH affects ammonia toxicity, microbial balance, and water buffering ability. pH has been known to decrease in biofloc and RAS systems due to nitrification and carbon dioxide retention; therefore, farmers can respond in time with buffer agents in their biosystems via real-time monitoring.



Sensors combined with automatic dosing schedules stabilize alkalinity and prevent the abatement of microbial communities, which is critical for water treatment efficiency. Ammonia and nitrite are two of the most toxic nitrogenous compounds, and they are critical for water quality. In traditional systems, these metabolites are only monitored periodically, and farms are prone to sudden spikes in toxicity, particularly with feeding or weather changes. IoT ammonia and nitrite sensors, though still nascent, offer frequent measurements and can provide early patterns in the accumulation of metabolites. AI-powered models employ these trends to predict upcoming spikes via prediction tools to adjust feeding standards, aeration, or water exchange for farms.

This predictive ability contributes to much mortality reduction and prevents water quality collapses during intensive operations. Turbidity and ORP tracking are important in smart aquaculture. Turbidity sensors measure variation in suspended solids, suggesting feed waste, plankton blooms, or biofloc density. ORP gives information about the oxidative or reductive reactions taking place in the water enabling farmers to have an idea about microbial activities and organic load dynamics. These attributes are also crucial in biofloc and RAS systems where microbial equilibrium is sensitive, and impacts fish health and water stability. The best way to enhance sensor-based monitoring is by data collection and then automatically integrating this data into automated systems. When the environmental parameters exceed threshold values, automated aerators, pumps, blowers, and buffering systems immediately react. This hybrid of monitoring and actuation establishes a self-regulating cycle that provides environmental stability by preventing human intervention to a lesser extent. Smart aquaculture minimizes risks caused by human error, ensures production accuracy, and facilitates resource management through dynamic monitoring and automated notifications. Sensor network long-term environmental datasets serve in addition to use-cases for direct management.

These datasets enable the development of prediction based on seasonal water quality patterns for farms, and the detection of chronic issues, best stocking and feeding practices, and climate impact on aquaculture performance. Collected data can also contribute to studies of environmental trends, disease associations, and ecological dynamics at systemic level. Smart monitoring gradually transforms aquaculture management from a state of reactive troubleshooting to proactive and preventive control in aquaculture over time. Sensor accuracy, calibration, and maintenance continue to be essential factors. Over time, however, environmental pressure, biofouling, sedimentation, and temperature variability may influence the accuracy of the sensor. Therefore, smart systems provide calibration schedules, diagnostic alerts, and backup methods to maintain the monitoring uniformity. As the technologies evolve, additional generations of anti-fouling coatings, self-cleaning systems, and long service life sensors are expected to provide even greater reliability from generation to generation. Sensor-based monitoring therefore constitutes the basic layer of the smart aquaculture architecture. Without accurate, continuous, and high-resolution data, AI models cannot run effectively, automated systems cannot respond intelligently, and blockchain traceability fails to resemble real environmental conditions. Consequently, sensor networks are not mere secondary tools, but

essential pieces enabling aquaculture systems to become a data-governed system backed on accurate and sensitive technology for environmental benefit.

4. Automation and intelligent control systems in current aquaculture.

Automation has become one of the most radical pillars for smart farming, changing the way that farms operate on an ongoing basis, and respond to environmental instability. Traditionally, aquaculture was highly labor-intensive and manual activities including, for example, feeding, aeration switching, water exchange and water quality monitoring were carried out. Although these, are fundamental, labouring procedures and their handling by a number of workers is time-consuming and prone to human error. With agricultural production and environmental conditions worsening with climate change, the limitations of manual management come to light. Automation—combined with IoT sensing, AI analytics and blockchain traceability provides a mechanism to support more self-regulated aquaculture systems with potential to optimise resource utilization, stress events and both biological and economic performance.

Automation can be highly efficient at decreasing dependency on labor, particularly in places where skilled aquaculture workers are in deficit or where farms span large stretches of land for continuous monitoring. Automated systems enable continuous monitoring and early intervention at night, so that no time-to-time disturbances occur, such as a dip into low dissolved oxygen or surge in ammonia when they appear. This increases continuity and minimizes the variability of subjective human judgement by automating feeding procedures, aerator activation and pumping control, among other factors. This move toward automated precision brings better conversion rates for feed into the system, steadier water quality profiles, and predictable operation results. The accuracy and stability provided by automation have a huge impact in intensive aquaculture systems where tiny variations in water quality or feed patterns can have a major impact over time.

On top of that, little things like fatigue or bad weather can make it hard for human operators to detect small shifts in nutrition levels or track feeding quantities accurately, or push off aeration activation. Automation systems respond to real-time data quickly and accurately to deliver accurate timing of feed distributions, accurate aeration cycles and persistent maintenance of ideal water flow. This precision not only reduces waste but also helps in the creation of more controlled and biosecure production environment.

Automation also speeds up how rapidly farms can adjust to environmental changes. In a lot of aquaculture systems, there can be a steep decline in dissolved oxygen levels after midnight due to respiration by fish and microbial communities. Mechanisms for manual response often fail to respond quickly enough to prevent the stress or deaths due to stress or death. Automated aeration systems connecting with DO sensors, in contrast, trigger immediately whenever the oxygen levels fall below a predetermined level. The same mechanism can control pumps under temperature spikes, high ammonia concentrations or sudden pH shifts. By removing the lag time inherent in human response, automation safeguards stock health and stable production cycles. The second great benefit that automation brings to the table is the cost-efficiency that it can bring to our operations. Aeration pumping and process operations, when coupled in commercial aquaculture facilities; traditional process techniques often are less efficient than is indicated because of the unavailability of an appropriate monitoring system. Automated systems minimize this waste by only running equipment when data shows it is in need.

AI-guided predictive aeration algorithms decreased aeration energy consumption by 35% with 91% stability of dissolved oxygen at crucial morning times. Such efficiencies may be gained in feeding, as smart feeders minimise overfeeding and nutrient removal back into the ecosystem. Automation in aquaculture occurs in a number of settings, and aeration is the foundation for water level regulation where automation technologies are introduced to various aspects including aeration systems. Smart aeration systems leverage dissolved oxygen probes, IoT gateways, and predictive AI models to ensure the best oxygen levels. When DO levels fall below species-specific thresholds, e.g. a rate of 5 mg/L in warm-water fish, automatic systems activate paddlewheel aerators, blowers, or diffusers without humans' intervention. These systems help prevent early-morning hypoxia, are physiological stress reducers, and are efficient catalysts for nitrification in biofilters. They enable rapid feed conversion and optimal growth performance by providing stable oxygen conditions. Feed automation is another important feature for intelligent aquaculture. Feed contributes to greater than half of total costs of operation, thus improvement of feeding efficiency is essential for economic sustainability and ecological protection.

The automated feeding systems can range from primitive time-based feeders to sophisticated AI-based smart feeders with underwater cameras, acoustic monitoring, pellet-fall detection, and so on. These systems adapt feeding rates on the fly according to instant sensing of

appetite, fishery activity, and environmental parameters. AI-based feeding systems such as have observed remarkable progress in feed conversion ratio improvements (i.e. from 1.8–2.0 down to 1.2–1.4) and feed waste reductions of 20–40%, up to 23% increase in growth. It can be said that automation of the above is an enormous asset in costs saving, water pollution prevention and manufacturing efficiency. The same applies to water exchange and circulation systems. Monitoring ammonia, nitrite, and oxidation–reduction potential (ORP) in real time can be set up in automated pumps and valves to keep a constant flow of water according to the current quality of your water, rather than fixed, predetermined schedules. This dynamic water management ensures non-accumulation of metabolites, better distributed dissolved oxygen, less stratification on ponds, and avoids anaerobic zone formation. Automation is essential in RAS and recirculating aquaculture systems.

The automated control of biofilter oxygenation, drum filter rotation, UV or ozone disinfection, pump flow, temperature, CO₂ stripping, backwashing cycles are the main technologies for the RAS plants. Programmable logic controllers (PLCs) can integrate these functions seamlessly to ensure stable water chemistry, minimizing labor requirements, and facilitating the high stocking densities that render RAS viable. Automation helps to support the intricate microbial dynamics used in water treatment and nutrient recycling in biofloc systems. Automated blowers create consistent aerating needed for floc suspension, while carbon-dosing units fine-tune C:N ratios according to ORP trends. Automated pH controllers add more buffering agents to steady alkalinity, and sludge extraction systems eliminate any buildup of solids. In the absence of automated controls, biofloc stability is hard to achieve and labor intensive, resulting in system stoppages. Automation also has an important role in offshore and open-sea aquaculture, which operates in more difficult environmental conditions and with more difficult human intervention.

Offshore cages use autonomous feed vehicles, camera-based feeding systems, sonar biomass scanners, underwater drones, and automated net cleaning robots. Wave- and wind-compensated mooring systems provide a stability into cages in unstable waters, lowering the likelihood of structural failure, whilst increasing worker safety. Integrated in these systems helps to maintain ongoing operations even when faced with rough sea conditions, decreasing divers and further improving biosecurity. Automation has taken huge benefits on biosecurity and disinfection systems. Automated UV units set the light level depending on turbidity, ozone generators

administer disinfectants in increments, and smart vaccination robots are deployed for high-value species like salmon. AI-driven disease monitoring apps will augment biosecurity by recognizing behavioral signs or environmental trends to provide early warning. But the most sophisticated layer of automation comes in the form of artificial intelligence (AI); control systems analyze sensor data, spot anomalies and autonomously solve problems. AI processes dissolved oxygen trends to anticipate when aeration will be necessary, evaluates feeding behavior to optimize ration size, detects ammonia escalation to initiate water exchange, and interprets pH fluctuations to initiate buffering.

These systems are functioning as autonomous farm managers, mitigating risk and maximizing biological performance. While there are advantages to automation, there are shortcomings as well. High capital investment, sensor service problems, low digital literacy, poor rural connectivity, and power supply vulnerability deter its broad adoption. Farms in rural areas generally do not have the resources necessary for the smooth running of automated equipment. To prevent the possibility of sensors getting foul or losing their accuracy, it's essential to calibrate accordingly. To be too reliant on automation can create vulnerabilities if backups are missing or if human oversight is inadequate. To overcome these barriers needs for phase-in implementation, appropriate training and robust, farmer-oriented interfaces. In the future, the state of automation in aquaculture is based on highly autonomous production systems. New technologies feature everything from autonomous surface vehicles for pond monitoring, through to underwater robots to investigate cages, intelligent feeding drones to the production of large-scale farms based on digital twins to mirror real-time conditions to enable real-time decision making. Self-cleaning sensors, corrosion resistant materials and satellite connected IoT architectures would advance the ability of automation, especially of offshore. In the end, automation will help push aquaculture towards “Autonomous Aquaculture 5.0,” in which intelligent sensing, prediction and control systems function with minimal input, ultimately to further efficient production and sustainably protect aquatic systems.

AI has moved from an interesting research field to a transformative technology in modern aquaculture, changing the way that farms monitor, interpret and operate complex biotic and environmental systems, and so change how they manage them. In more traditional intensive operations - be it in recirculating aquaculture systems (RAS), biofloc units, high-density ponds, raceways, or offshore cages - millions of data points are produced every day. Water quality

probes, underwater cameras, feeding sensors, weather stations, behavioral monitoring systems - these devices produce an information pipeline: a nonstop stream of high-frequency and multi-dimensional data. Although human observation may be valuable, it cannot equal the analytical power offered by AI systems, able to assess patterns in real time, detect slight deviations, and give predictive insights within seconds. AI decision-making in aquaculture takes aquaculture from being a reactive practice over time where problems are only reported after becoming glaringly visible, to a discipline which is predictive and prescriptive in nature where problems are foreseen, before they spread further. AI is an important aspect because of the non-linear nature of the aquaculture environment. Water quality, fish metabolism, microbial activity, feeding, and disease development combine and sometimes in unexpected and volatile relationships. Biological and chemical processes, as well as other environmental factors (e.g. dissolved oxygen, pH, ammonia, nitrite, temperature) cause rapid changes in environmental parameters. Precipitation, cloud cover, wind speed, and solar radiation are some of the external pressures that generate extra variability that can easily elude manual monitoring, but that can also be extremely subtle or fast to record. That's because artificial intelligence models are adept at understanding these multidimensional ecologies; they can see relationships across datasets, identify multi-faceted interactions, and catch deviations from the norm early on, before stress or disease take over. AI, combined with data feed from a variety of sensors at once, can allow farms to predict when oxygen levels will lower or rise, predict ammonia levels, monitor microbial health in biofloc systems and predict demand of food based on environmental and behavioral changes.

Current aquaculture generates data at a scale that, due to the nature of such data, requires automatic analysis. Dissolved oxygen can be measured every 15 seconds, pH every minute, temperature every few seconds and turbidity continuously, and underwater video can record fish movements and feeding responses in high resolution. Hydroacoustic technologies collect sound patterns as feeding occurs and reveal knowledge about appetite, and feed efficiency. AI can process these huge data streams and generate warning signals at just the time, classify behavior, predict biomass, and optimize feed schedules. These skills directly improve farm resilience by proactively preventing catastrophic events like nocturnal oxygen crashes, early-morning ammonia spikes or silent disease outbreaks — events that can ravage productivity if not detected in time. Artificial Intelligence in aquaculture AI models fit into several types. Machine Learning

(ML) methods using structured sensor and environmental data (Random Forests, Support Vector Machines, K-Nearest Neighbors, Gradient Boosted Trees, and others) can be referred to among other regressions or classifications. This model is especially good for interpreting numerical data and can be utilised in tasks such as classification of water quality, prediction of dissolved oxygen fluctuations, disease risk and forecasting of feed demand. ML algorithms used to predict dissolved oxygen changes several hours in advance with high accuracy, empowering automated aeration systems to respond before an oxygen withdrawal event. On the contrary, deep learning (DL) is especially ideal for image/video/complex time-series analysis. Convolutional Neural Networks (CNNs) find spatial characteristics to underwater pictures for performance as fish counting in real time, estimation of biomass, and early detection of certain visual disease symptoms (gill damage, fin erosion, skin lesions, or abnormal coloration). Recurrent Neural Networks (RNN), especially Long Short-Term Memory (LSTM) network architectures, are well suited for the task of temporal forecasting, for example, in the prediction of oxygen supply, temperature and microbial variability. Through the growing application of 3D CNNs and transformer models, farms have been able to examine behavioral patterns in video sequences, to identify deviations in swimming speed, schooling cohesion, depth usage, or posture - signs commonly preceding a clinical disease. With these features, they lay the groundwork for precision aquaculture as a deep learning approach, particularly for systems in which visual behavior is a major driver of feeding dynamics and health status. Reinforcement learning (RL) presents yet another promising frontier.

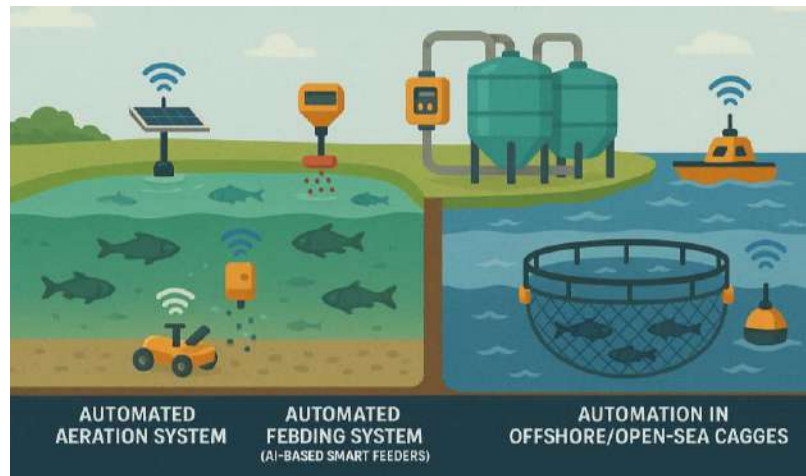
Unlike ML and DL for the most part, RL systems learn by trial and reward and gradually establish the best way to do the feed, aeration, pumping or energy management. An RL-driven feeder gradually learns to adjust feed amounts according to appetite, fish activity, oxygen availability and pellet fall detection through repetitive interactions with the environment over time. It has been developed to create a system that optimizes feed conversion ratios (FCR), and to manage waste and water quality in the process. RL-based feeding systems have been reported to improve FCR by 15–25% in the studies conducted around the world, which makes them very attractive for larger scale applications. AI is of special importance in predicting water-quality. Dynamics of dissolved oxygen are influenced by the dynamic interplay of respiration, photosynthesis, microbial evolution, feeding intensity, and temperature shifts. AI models that

consider these characteristics can predict drops in oxygen levels just hours in advance, allowing aerators to be activated at the right time.

It has been found that LSTM models reached nearly 87 percent accuracy in DO prediction and helped reduce mortality due to oxygen consumption by 30–40%. Similarly, AI-driven predictive modeling of ammonia and nitrite dynamics can alert for early metabolite build-up—an important consideration in systems such as RAS and biofloc, where quick microbial changes can destabilize the system. In addition, artificial intelligence (AI) predicting pH and oxidation–reduction potential (ORP) helps buffer dosing, as well as biofloc stability to reduce acidification or nitrification stress. This makes use of AI especially applicable in the domain of fish health and disease prediction. Fish express stress and disease in behavioral cues, many of them too subtle, or just too slow, for humans to perceive early on. AI can measure minute changes — patterns of tail-beat frequency and schooling patterns, speed of swimming, movement of the gills and spatial distribution within the water column. Changes in these metrics can also happen one or two days ahead of their patients' ability to recognize visible disease symptoms. When combined with behavior, water quality, feeding responses, and microbial signals, AI systems predict susceptibility to disease 48–72 hours before symptoms develop. With this early identification significantly reduced mortality risk and reduction of the requirement for antibiotics, benefits of better welfare and more sustainable production are realised.

Another radical use of AI is biomass estimation. Biomass measurements had initially involved net sampling, which was harsh to fish, disturbed feeding, and supplied only rough estimates. AI-supported camera systems have developed to predict biomass by measuring fish length, width and three-dimensional body form through CNNs and stereoscopic imagery. Hydroacoustic systems support this, especially in marine cages that are characterized by a lack of water clarity. Correct biomass estimation can be used to refine feeding options, better harvest planning, and stocking densities. Feeding optimization is still one of the most prominent AI-based applications in aquaculture. Predicting appetite models consider feeding intensity, pellet-fall trajectories, fish motion toward feeders and acoustic feeding signatures. When it notices that their appetite is weak, AI systems automatically slow or stop feeding entirely to save food for later use. In experimental environments, reinforcement learning models can fine-tune feeding strategies based on the growth we observe, and they have shown to reduce feed waste with a consistent 20–40% and speed up growth with up to 25% higher. These advancements are of

serious economic and environmental consequence, since feed is the largest single source of operating costs and an important driver of nutrient pollution.



AI-driven emergency-response systems are proving to be a viable defence model for farms. When dissolved oxygen falls steeply, when ammonia starts expanding past forecast thresholds or when fish behaviors show acute stress, the AI system can quickly turn on backup aerators, accelerate circulation, halt feeding or send alerts to farm managers. Such rapid, automated responses protect farms from catastrophic losses and enable early intervention in extreme weather events or equipment failures. Notwithstanding these benefits, it is far from easy to use AI. The need for high-quality training data is still there for true prediction -- any noisy, inconsistent, or sparsely sampled dataset will not make good predictions from its raw data. Skilled workers are needed to manage systems, read outputs, and resolve hardware or connectivity problems. Combining AI with available farm infrastructure typically requires extensive technical adaptation and video models are resource intensive.

However, AI is becoming rapidly available for all farm sizes and hardware expenses are dropping-off. AI will be further enhanced in the future, even the transformation of autonomous precision aquaculture. Virtual digital twins of aquaculture systems (as in digital twins of aquaculture) will facilitate simulation-based decision making, in which farmers can simulate some cases before doing something to make them real to some scenario. Underwater robots driven by AI will work autonomously, checking the cage safety, health assessments, and net cleaning. Such emotion-identifier models trained on low-key behavioral inputs can potentially provide real time welfare analysis. By combining acoustic, visual and water-quality information

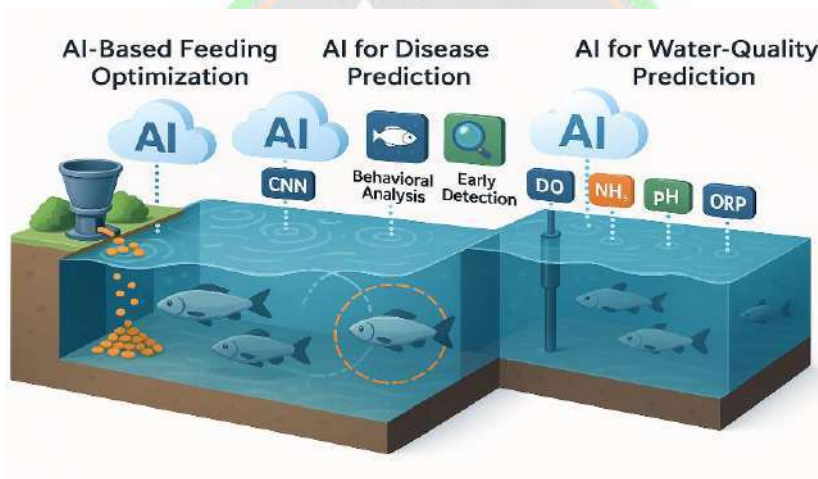
to create hybrid sensor fusion models, they can offer integrated intelligence. Altogether these innovations are driving aquaculture to a future of adaptive, resilient, self-optimizing production systems.

5. Blockchain in aquaculture, traceability, transparency and digital trust

With increasing consumer demands, pressure and demands of the regulatory authorities, and the global demand that there is a need for authentic, safe and sustainable aquatic food products now traceability has become one of the big issues for the global aquaculture market. The world's seafood supply chain is more complex than ever before, involving hatcheries, nurseries, farms, feed mills, processors, transporters, exporters, importers, wholesalers, retailers and, finally, consumers. Maintaining effective documentation at all the stages can be a real challenge. Old-Traditional paper-based or centralized digital record-keeping systems are subject to manipulation, loss, delays, errors, and inaccuracies. These vulnerabilities erode consumer confidence and subject producers to reputational and compliance risks.

Blockchain technology, creates an entirely new paradigm with regard to the storage, sharing and validation of aquaculture information. Essentially, blockchain is a decentralized, tamper-resistant ledger that records all transactions or events in sequential blocks linked cryptographically to the previous one. Such immutable nature, together with distributed verification, render blockchain particularly appropriate in settings where trust, transparency, and auditability is a crucial concern. In aquaculture, blockchain does not work in isolation. It is the final part of how the IoT–AI–Automation combined infrastructure will work, which is the archival and verification of data generated along the entire production cycle in a secure and reliable manner. Each sensor reading, feeding event, water-quality record, health treatment, stocking batch, harvest operation and transportation detail are all saved as transactions of the blockchain which allows us to produce a single unchangeable, time-stamped “digital identity” for each production batch. And this guarantees data can't be updated again, thus preventing forgery by mislabeling species, hiding antibiotic use, or counterfeiting water quality record. One of the very strong characteristic of blockchain is the possibility of smart contracts, that is, self-executing digital rules that will automatically enforce pre-set rules provided certain criteria are met. Take, for instance a smart contract, that can stop a batch of harvesting product from entering the supply chain if water quality or the quantity left in the vessel exceeds threshold levels or after a certain rate of drug residue.

Thus, blockchain is more than just a passive record keeping tool but also an active regulatory compliance instrument which makes regulations and quality with extreme effectfulness. The facilitation of farm-to-fork tracing of aquaculture, by blockchain has great potential. Think of a farm exporting shrimp goods to a European buyer. Leveraging a blockchain enabled application, the buyer can scan a QR code published on the final product packaging and get instantly verifiable records of stocking dates, pond water-quality histories, feed brands and quantities used, laboratory test results, vaccination or treatment events, harvest times, cold-chain data, and transport logs. The instantaneous visibility promotes food safety confidence, reduces disputes in transaction and enhances the pricing of certified sustainable and traceable products. For the farmers the Blockchain is an equally transformational concept. Small and medium-sized aquaculture enterprises have difficulty showing compliance, authenticating products, and reaching the higher end of the value chain.



We can turn to blockchain that is complemented by IoT sensors and by automation to monitor and produce the products we provide. Using blockchain combined with IoT sensors and automated monitoring, farmers now have a strong digital and physical footprint, enabling certifications such as ASC, BAP and organic labels. These are types of certifications that used to require a lot of paperwork, farm audits etc., however blockchain is greatly reducing paperwork and the amount of verification that happens. Beyond market benefits, blockchain supports biosecurity and disease control. When disease epidemics strike, swift, accurate movements histories that can be traced become essential. Blockchain allows authorities to pinpoint risk pathways — like hatcheries providing infected seed or traders dishing out diseased fish — with high precision and speed. This results in vastly enhanced response efficiency and can greatly

reduce the spread of pathogens that go uncontrolled, and across the regions. The fact that with an integrated solution, blockchain is most powerful, due to the use of IoT sensors and automated systems. For example, water quality sensors can record measurements for the blockchain automatically with no human intervention and allow the integrity of the data.

AI-enabled feeding or health notifications can also be logged as time-stamped and retained as a part of the official production record. This helps prevent falsified data entries, which have repeatedly plagued conventional “self-reported” farm logs. Blockchain implementation in aquaculture has a number of practicalities even though it promises. One concern is more immediate cost, complexity and a few more. Public blockchains - which are very secured - can be costly to use because of transaction costs and need to generate a lot of computational power. Private chains, while less expensive, should have strong governance methods, and a certain level of knowhow. Another constraint is the digital divide many small farmers don't have the infrastructure, connections or digital literacy to manage blockchain-enabled systems. Also, data collected from the point of collection are not guaranteed by blockchain alone. If faulty sensors, wrong calibrations, and even human error affect the input data, though, the blockchain will retain wrong information—unrecoverable—with no error whatsoever. Therefore, blockchain must be seen as a complementary technology to complement rather than replace the high-quality sensing and monitoring systems.

Next, blockchain is likely to penetrate into national and international seafood governance structures. Over the next 10 years, importing markets, such as the EU, the US, and Japan, would increasingly require blockchain-verified production records for high-risk commodities, like shrimp and salmon. This will not only help corporate producers to embrace blockchain, but also progressively incorporate smallholder systems via cooperatives, digital extension services, and cloud-based traceability services. In conclusion, blockchain is an important step forward in aquaculture traceability. Its convergence with IoT and AI - opens up an unheard level of transparency, accountability and digital assurance. This not only confirms that aquaculture products are not just safe and sustainable but also verifiably so, but in this way builds consumer confidence and access to premium markets while also laying the groundwork for harmonized, technology-based seafood traceability networks around the world.

6. Sustainability, environmental values and social and economic impacts of smart aquaculture

Sustainability is a key pillar of contemporary aquaculture and is shaped as a result of both ecological necessity, economic issues, policy constraints, and societal norms. The increase of the aquaculture enterprise has contributed significantly to global protein production in the past three decades, but the high energy consumption and water stress, water depletion, habitat erosion, antibiotic overuse, infection spread, and carbon emission caused from energy use in the industry have also proven to be associated with environmental challenges. Smart aquaculture, especially applied through the integrated IoT–AI–automation framework, represents a significant way forward toward reconciling productivity with planetary health. A significant sustainable benefit of the smart aquaculture is resource optimization, notably in feed, water, and power.

Feed is the single most important environmental loading source in aquaculture. Overeating not only generates costs to produce, but also gives uneaten feed and its metabolic waste to the water, leading to ammonia accumulation, oxygen depletion, eutrophication and the growth of opportunistic pathogens. Smart feeding mechanisms, comprising of real-time cameras, acoustic sensors, and AI appetite predicting models have been found that can reduce waste of feed by scheduling feeding according to fish behavior, instead of preplanning predrawn rations. This has led to diminished organic pollution, more consistent water chemistry and hence lower water column chemical activity quality and reduced nutrient loss to water, especially in pond and cage systems, where the loss of feed plays the largest part in environmental destruction. Optimised feeding can reduce ammonia spikes by 20–40%, a positive impact that is well understood by itself in terms of reducing the ecological impact of production output. Efficiency of water use is also the fundamental aspect of environmental sustainability.

Typical aquaculture, particularly in some semi- or intensive-intensity ponds, often depends on large rates of water exchange to treat the waste metabolites of their metabolism. This operation is not only responsible for the heavy water requirement, but also exfoliation of nutrient rich effluents into downstream water bodies. Smart aquaculture systems, on the other hand, provide a more advanced means of the latter. It is through the real-time monitoring ammonia, nitrite, ORP, and DO levels that farmers can only be able to perform water exchange as needed and not at a predetermined time. Automated controls can pass water through treatment plants or biofilters prior to discharge, significantly limiting the ecological footprint. In RAS and biofloc

systems, smart controls ensure efficient nitrification, maintain C:N ratios, and prevent system crashes. Such technologies enable aquaculture operations to move from water-intensive systems to water-conserving or water-neutral ones. Energy sustainability is also an important dimension. Aeration, pumping and water circulation are the most energy-intensive parts of aquaculture, as many as 40-60% of aquaculture energy requirement in intensive systems. Classic aeration also depends on the active running of paddlewheels or blowers with no real need for oxygen. Smart aeration in aquaculture, powered by AI, uses a lot less energy consumption when required by activating aerators, when DO approaches the critical thresholds, or AI models forecast a drop down to a later period of time when DO would be expected based on the diurnal respiration pattern. A 30-35% reduction in energy expenditure through predictive aeration algorithms - both an environmental and an economic challenge, particularly in areas where the cost of electricity is increasing or where diesel powered aerators are prevalent. Environmental issues are also significant, since disease outbreaks often result in deaths in great numbers, misuse of antibiotics, and exposure to polluted waste products. Smart aquaculture systems contribute to biosecurity by identifying behavioral anomalies and water quality deviations long before symptoms seen in disease. Early detection prevents widespread death, but also greatly minimizes dependence on antibiotics and chemicals. This coincides with a world perspective of sustainability that promotes antimicrobial stewardship and ecosystem-centric aquaculture. Furthermore, for closed environments such as RAS and biofloc units, the automated biosecurity systems such as UV sterilization controllers, ozone dosing systems, real time pathogen detection model help maintain the microbial balance.

Apart environmental considerations, smart aquaculture has significant macro-socio-economic ramifications. In this way at the farm level, smart technologies reduce erratic weather events, diseases outbreaks, and water quality disruptions, hence stabilizing production. This improves farmer confidence, supports more efficient financial forecasting and lessens their susceptibility to devastating losses. Regularity of production ensures the sustainability of long term supplier relationships, and the potential for integration in the form of value chains. Another socio-economic dimension has to do with the balance of labor. Automation reduces labor intensive labor and shifts the skill profile of aquaculture. Although long-term demand for conventional labor will decrease, smart aquaculture stimulates new employment opportunities in technical support, data analytics, AI-supported farm management, sensor calibration, and digital

extension services. Such a shift, though, also emphasizes the importance of capacity-building and digital literacy in fisheries and aquaculture education. Smart aquaculture also increases market potential, particularly for SMEs.

Blockchain-assisted traceability and digital production records allow farmers to access the high-value markets that require close adherence to sustainable and food safety standards. Traceability guarantees are turned into better pricing, lower rejection probability at the export door and better trust by the consumer. This is especially true in certain commodities and products like shrimp, tilapia and salmon, where international markets are now becoming more and more susceptible to problems linked to antibiotic residues, farm-origin fraud and sustainability claims. At a deeper level, smart aquaculture plays a substantial role in rural development and promotes economic development among farmers by providing means of a livelihood that can be depended on year-round with stable incomes; employment for all types of workers and downstream activities like feed manufacturing, equipment supply and processing, packaging and logistics. While data-based aquaculture lowers production risks, financial institutions are increasingly committed to providing loans, insurance products and credit facilities to farmers, a provision now less constrained by the inherent insecurities that come with traditional aquaculture. It is a socio-economic sustainability, but socio-economic sustainability must also address social and economic inequalities of technology adoption. A lack of sufficient infrastructure, lack of technical skills, and high up-front investment, coupled with poor digital infrastructure and limited technical competency may lead to inequities between well-resourced agricultural farms and smallholder farmers. Unless policy interventions have been inclusive, smart aquaculture will exacerbate existing inequalities in rural communities. Scalable, low-cost models, government funded digital extension schemes, farmer cooperatives and shared infrastructure (for example, standard IoT systems) is of utmost importance in order to ensure fair uptake. Over the long term, the sustainable development of smart aquaculture should be based not only in its environmental benefits, but also in contributing to the uplift of the community's wellbeing, on mitigating risk of production and promoting positive economic growth. When implemented prudently, the IoT-AI-automation-blockchain model provides aquaculture with a route to efficiency, resilience, and ecological responsibility -- placing it at the heart of international Blue Economy.

7. Implementation issues, technological limitation and the difficulties of adoption of smart aquaculture technology

The potential of smart aquaculture applications is transformative, yet translating such solutions into practical, large scale in agriculture is no easy task. Combining IoT, AI, automation and blockchain-offers a robust theoretical model. But as in rural ponds/ pond systems, brackishwater shrimp farms, RAS facilities and offshore cages, real-world settings such as these present socio-economic, infrastructural, environmental, and institutional contexts involving a variety of socio-economic, infrastructural and environmental and institutional challenges. Knowing these constraints is of crucial importance for the design of policy, technology application and sustainability to avoid a disaster or for the stability of the system over the long term. The very first and most evident barrier to smart aquaculture is technology cost. IoT sensor arrays, underwater cameras or automatic feeders, edge computing devices, smart cloud dashboards and blockchain-enabled services are expensive at first pass. Large commercial farms may incorporate new technology as part of their current modernization strategy, but small and medium-sized farmers (the vast majority in Asian and African countries) frequently lack the capital to implement sophisticated monitoring and automation solutions. Even low-cost sensors, when used over several ponds or tanks, incur costs not only for procurement but also for installation, calibration, regular maintenance and ultimately replacement. Tied up with cost is the question of technical durability and environmental resilience.

Aquaculture systems expose electronic devices to varying salinity, high humidity, biofouling, temperature changes, and corrosive environments that can impair their performance. The accuracy of sensors degrade with time as sediment collects, algal deposits, or microbial biofouling develops. This requires regular cleaning and recalibration for reliable data. So many low-budget sensors break down fast, creating inconsistencies in data that limit AI predictions and control automated decisions. Sensor reliability is "core to the entire smart-aquaculture approach," and wrong inputs inevitably yield erroneous predictions, and sometimes destructive operations.

Another major barrier is digital connectivity, especially in rural and coastal aquaculture regions which may not have developed telecommunications infrastructure. LoRaWAN systems provide for long-range coverage at low energy levels, but they require gateway towers and stable power sources - neither of which may be constantly available everywhere. The higher bandwidth of cellular networks (4G/5G) for video and AI-assisted camera systems results in

unreliable network coverage in remote farming clusters. Frequent connectivity interruptions result in data gaps, latency of real-time alerts, and less effective dashboard monitoring. For offshore cages, the issue becomes more critical since high-quality satellite communication systems are still expensive and energy-intensive. Energy supply is also a practical limitation. Farms situated in areas of unreliable electricity cannot power automated aerators, pumps, cameras, and gateways uniformly. Backup diesel generators — more prevalent options — bring extra costs, CO₂ emissions and transportation problems when it comes to transporting fuel. Despite increased adoption of solar powered technology, it still faces the risk of seasonal changes, equipment theft and constraints in energy holding capacity. But technical literacy has another significant obstacle. Smart aquaculture requires farmers to read dashboards, answer sensor alerts, calibrate machinery, tune feeding algorithms, troubleshoot problems, debug the connectivity issues, and use mobile applications.

Most conventional aquaculture communities are skilled practitioners with a strong intuitive understanding of the ecological aspects of species, but digital resources are not widely used. The transition from intuition-based to data-driven management requires training, human capital and support of management. Without sustained commitment, most farmers may opt the ‘fancy road,’ abandoning technologies. And where farmers have skills and infrastructure to exploit intelligent technology integration between heterogeneous devices complicates matters. Farms don’t buy all the equipment from a single vendor at most. This could involve DO sensors from one manufacturer, cameras from another, pumps from one provider and even AI-enabled feeders created for them by another. These devices tend to run on incompatible communication protocols, software ecosystems, and data formats. In most instances, proprietary platforms also confine farmers to closed systems, which makes interoperability impossible and the development of unified dashboards and AI models more difficult.

Interoperability is crucial for the establishment of truly integrated smart farms, as if without it technology adoption becomes fragmented and inefficient. The challenge of data management adds another category of issue. Smart aquaculture techniques capture large amounts of data: time-series environmental data, high-resolution video streams, metadata generated through AI, even blockchain transactions. The storage, analysis, and management of these data sets need cloud subscriptions, compute resources, and digital infrastructure to manage it. Even though cloud storage is becoming more affordable, costs go up when farms have multiple video

cameras or multiple tanks on site. And besides, farmers also face issues about data ownership, privacy and governance - all still poorly regulated in many countries. The other hurdle is the technology dependency risk. Intelligent controllers could automate feeding, aeration and water-exchange processes: but if a sensor malfunctions or provides wrong data, the automatic system may act inappropriately. For instance, a faulty DO sensor may fail to start aeration which results in sudden drops of oxygen load and mass mortality. Farmers, especially those with high-value stocks such as shrimp or salmon, will hesitate. Therefore, redundant mechanisms, fail-safe protocols, and regular manual checks are necessary tools for any comprehensive smart aquaculture system. This has also included economic and social resistance.

In traditional aquaculture communities there is concern of adopting technologies that can substitute human roles or require new tools of work that are not immediately recognizable to the local community or that the people are not familiar with. Some farmers see technology as too risky or too complex - or as culturally out of sync with accepted ways of doing things. Local technicians that can service and maintain IoT devices or AI-enabled equipment might not be available, and they are dependent on external vendors. Lastly, regulatory frameworks are still being developed. Standardized frameworks for digital traceability, reporting environmental data, sensor calibration, and AI-based disease alerts are absent in many lands. Without standardized protocols, there is uncertainty for technology providers as well as farmers. So when there aren't regulatory programs or certificates tied to digital compliance, some producers do not see the real economic potential advantages through moving to smart technologies and thus reduce their transition to those technologies. Nevertheless, the near-term outlook is still optimistic. With reduced costs, interoperability, and the integration of digital compliance practices by governments in the national aquaculture policies, adoption is likely to increase. The future of smart aquaculture will rely not only on innovative technology but on participatory governance, farmer support mechanisms, and flexible models adapted to various social and economic settings. That will ultimately result in a shift in aquaculture systems from reactive management to preventive and predictive control due to the interplay of cloud, AI, and blockchain. Thus, overcoming the implementation bottlenecks is, indeed, shared responsibility of farmers, engineers, policymakers, extension agencies, and technology companies.

8. Future Directions, Research Gaps and Prospects of Smart Aquaculture.

In this digitalizing, automated era, forage for intelligent decision systems, as aquaculture

is entering the era of new forms, it is obvious not only the adoption of singular technology products will define it, but the union of an intelligent system that will operate with continuous optimization will also change the paradigm. Smart aquaculture future outlook is multifaceted on various fronts—technological, ecological, socio-economic, and regulatory. Current applications make a significant contribution from the stability of water quality and feed efficiency to traceability while in the next decade's period innovation will change aquaculture into an increasingly autonomous, predictive and climate-resilient system. However, these are also opportunities that face some major research gaps that will demand interdisciplinary collaboration across marine engineering, artificial intelligence, blockchain systems, aquaculture biology, microbiome science, and sustainability policy. One key trend that defines these future development directions is the emergence of **digital twins** in aquaculture.

Digital twins are simulations, rather than physical models or real-life ponds, tanks, cages, or hatcheries who continue to receive real-time data from IoT sensors. Leveraging cutting-edge simulation technologies, machine learning, and mechanistic modelling, digital twins have the capability of predicting future conditions in the environment, the health of an organism, biomass accumulation, and system performance at almost unprecedented accuracy. Such systems would enable farmers and researchers to test alternative feed strategies, stocking densities, aeration schedules and the water-exchange regime in an unriskier virtual environment before applying it in practice. Although initial prototypes are available, much work is needed in terms of precise, biological descriptions, microbial dynamics and computational efficiency for practical on-farm applications. One further frontier is the integration of omics technologies — genomics, transcriptomics, proteomics, metabolomics - with AI-fueled environmental and behavioral models. Such convergence of AI and omics could revolutionize disease diagnostics and selective breeding. For instance, farms could scan for changes of infection susceptibility before behavior change is made, by combining real-time sensor data and molecular “markers.” Such insights provide new capabilities for both farmers and the general public to better target disease development. Likewise, genomic selection through AI could spot broodstock with enhanced tolerance of changing water quality, high-density culture conditions, and novel pathogens. However, the costs of omics technologies, the requirement for standardized protocols, and the challenge of merging biological and environmental data are some of the significant research challenges.

Smart aquaculture is likely to expand into offshore and open-ocean ecosystems under the pressure of increasingly scarce global freshwater and appropriate coastal lands. Offshore cages placed in deep, nutrient-rich waters can support high volumes and low ecological footprints. Nevertheless, these settings require reliable automation systems that are resistant to bad weather, high salinity, ultraviolet UV light, biofouling and mechanical stress. Systems in future will employ mostly autonomous underwater vehicles (AUVs), robotic net cleaners, drone-mounted surveillance and satellite-connected IoT networks. Research gaps remain in the area of energy-efficient offshore monitoring devices, materials resistant to corrosion and hybrid communication architectures that will enable high-bandwidth AI applications within remote marine environments. The area of emotion and welfare surveillance in fish is one of the most hopeful, as well in underdeveloped areas. Fish welfare science moving fast on the basis of the realisation that the physiological stress and the behavioral responses of fish are complex, they have crucial importance for growth and immunity. New evidence in computer vision hints that even minor changes in fin movement, gill rate, tail-beat frequency and posture could be linked to welfare outcomes such as stress, fear, aggression or pain. There are potential ways in which these indicators could be incorporated into the future AI systems in order to offer real-time welfare evaluations. But, much richer behavioral datasets, species-specific validation, and ethical guidelines cannot get us far without it. Another aspect that looms ahead for future research is climate change. With increasing temperature changes, increased variability in rainfall, salinity disturbance and extreme weather events posing a threat to aquaculture technologies, smart technologies must also adapt to a more climate fit.

Climate-adaptive AI models might help farms predict stress periods associated with the seasons, tweak feeding, change aeration techniques and optimize seed stocking or harvest timing. However linking climate projections to farm-level environmental dynamics is still not clear. Chandran et al. (2025) emphasize longitudinal data sets like these are important and need to be extended to cover the entire time in terms of long-term prediction. Another future line consists in developing decentralized, farmer-friendly AI systems. Many smart-farm algorithms today depend on cloud computing. Cloud-based machines depend on remote regions where connectivity is intermittent. Edge AI — where predictive models operate on local systems (for example, microcontrollers and embedded systems) — is a big step forward toward democratization of smart aquaculture. Nevertheless, advanced research is required to build light-

weight computing models to retain accuracy within a constrained processing capability. Future-style innovation in blockchain could also transition from simple traceability to a multi-level governance architecture.

Smart contracts could be used to automatically enforce environmental conservation, antibiotic curbs or certification demands in real time. For example, in a future world regulated such as one where ammonia volumes would likely exceed legislative standards, a sensor could indicate through a system where ammonia concentrations exceed statutory thresholds, this is where the blockchain could automatically tag that production batch as “non-export compliant” until the corrective actions taken are verified. Virtual audit systems would lessen reliance on in-store visits, increasing the savings on costs and confidence in audits in multiple supply chains. Yet, legal and regulatory coordination is needed to facilitate blockchain-facilitated compliance across countries. There remains a notable research hole in sustainability metrics and life cycle assessments (LCAs) for smart aquaculture. Although digital technologies save labor and make operation more efficient, the most common demand for this new technology is rare-earth materials, electronic components, and power-intensive data infrastructure. The net sustainability impact of large-scale digitalisation is still poorly investigated. Comprehensive LCAs that include sensor production, data transmission, cloud computing and electronic waste management are necessary to quantify the net ecological impact of smart aquaculture systems in the long term. There is a need for socio-economic research as well. Smallholder farmers, for example, are often not adopting smart technologies due to cost, perceived system complexity, and digital skills gaps, despite its clear advantages; nevertheless, in most cases, adoption is stratified.

The inclusive models of innovation (for instance common sensor networks, community data platforms, pay-as-you-go feeders, and government-supported IoT initiatives) were suggested for future studies. Research on social science is important for identifying attitudes, contextual hurdles, and individual attitudes to the practices within different parts of the aquaculture community. Finally, smart aquaculture should build a cohesive systems approach which integrates ecology, engineering, economics and governance into a digital foundation. Technical feasibility of integrating IoT, AI, Automation and Blockchain solutions. In the next phase, the proposed framework runs for different ecological regions, species groups, and production intensities with the aim of being interoperable, scalable and economical. In conclusion, the future of smart aquaculture opens up a great and diverse horizon, yet it also

brings immense complexity. It will take ongoing investment in research, inclusive policies, technology innovation and multi-sector collaboration to realize that ideal. The goal is not just to digitalize aquaculture, but to make resilient, efficient, ethical, and ecologically compatible aquatic food systems for the benefit of global nutrition and economic development for decades to come.

Conclusion

Aquaculture is confronted by a change in its global development. Traditional methods that require observation through manual observation, decision making based on experience, and reactive interventions have increasingly been discredited as people and environment have started demanding ever more of them and as long as the market for aquatic food remains at its height in growth pressure. Modern production systems in general, characterized by dynamic water chemistry, high-density stocking, changing climatic conditions, and globalized value chains, require a new paradigm based on digital intelligence, predictive analytics, and integrated management. Integrating IoT-enabled sensing, AI-driven analytics, automated control, and blockchain-facilitated traceability as an early effort to build on this approach. Their work demonstrates that smart aquaculture is not a series of standalone technologies but an ecosystem interlinked to one another, and in which each component buttresses the other.

Sensors provide the steady stream of data that drives the AI models to perform optimal actions, AI converts data to actions, automation handles the activities at the farm level, and blockchain stores the information stored in transparent and tamper-proof storage. This combined setting creates an independent, flexible production facility that enables both economic performance and environmental sustainability. Throughout the chapter we have delved into the multiple aspects of this transition. IoT systems facilitate real-time observations of water quality, biological response and environmental variability, thus providing early warnings of stressors that previously went unnoticed. Automatic feeding, aeration and water treatment stations stabilize conditions, save resources and maintain the welfare of fish. Artificial intelligence puts aquaculture in a predictive game, predicting the likelihood of diseases, oxygen dynamics, growth paths and feeding behaviors with significant precision. Blockchain promotes transparency and reinforces trust in the supply chain as well as regulatory compliance in the global value chain. Collectively, these systems enhance sustainability in terms of waste reduction, input optimization, conservation of energy and water, and the sector's environmental footprint. But

getting to large-scale adoption is still a complicated endeavor. Tackling these critical issues—cost, sensor longevity, digital literacy, infrastructure, interoperability, governance -- will require a holistic approach. These problems do not necessarily negate the potential for smart aquaculture; instead, they reinforce the importance of broader policy design, farmer education, community driven digital extension and long-term research approaches. As technology matures and costs diminish, adoption will undoubtedly explode in the next decade, especially when the collaboration of governments, development agencies, private technology companies and farmer cooperatives ensures a rapid uptake. And as we move forward with the innovation around digital twins, AI–omics fusion, edge computing, autonomous offshore ecosystems, and greater welfare tracking, these innovations will further define aquaculture’s technology terrain.

Such approaches suggest an aquaculture future that always adapts to new data driven learning cycles, feedback loops and automated decision-making. The vision is for a high productivity aquaculture sector without compromising our ecological resilience, food safety or inclusive economy. And, in the end, smart and precise aquaculture is about far more than just an upgraded technology; it’s about a radically different way to think about the management of aquaculture — from a more reactive approach to fixing wrongs to an approach in which the damage is corrected before they happen to be irreversible, from a single, isolated operation to connected ecosystems, from gut instinct to a science-based precision. With the support of these developments, aquaculture may have the opportunity to meet its twofold task of feeding an expanding world population and maintaining the ecological infrastructure that forms the base for food production. The shift toward smart aquaculture is a must, not only a desirable progression. With conceptual frameworks that are integrative, smart and sustainable. The future of aquaculture appears to be one in which it will operate with resilience, transparency, and sustainability. This chapter has explored that transition in detail providing conceptual foundations, technical insights and directions for the future that can contribute to a framework that will allow researchers, practitioners, educators and policy makers to build future aquaculture systems.

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MULTI-TIER CROPPING SYSTEM-A SMART WAY OF FARMING

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P.Muneeswari

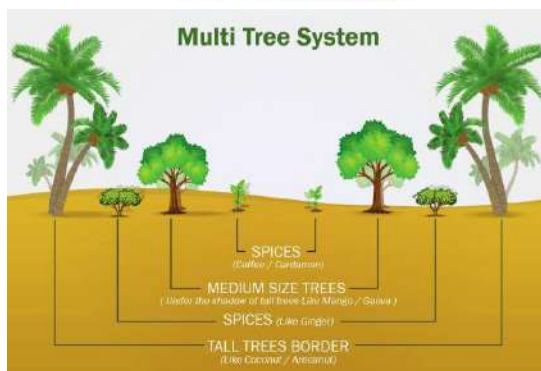
UG Student B.Sc (Hons.)Agriculture, S. Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi – 627 758, Tamil Nadu, India

Introduction

The multitier cropping system is an advanced and efficient farming practice in which two or more crops are grown together on the same land by arranging them at different height levels. This system helps farmers make the best use of available natural resources like sunlight, water, soil nutrients, and space. It is especially useful in areas where land is limited and farming costs are increasing.

What is Multi-Tier Cropping?

Multi-tier cropping is a way of growing different crops at different heights on the same piece of land. Taller crops form the top layer, medium-height crops grow in the middle, and small crops stay near the ground. By stacking plants this way, farmers can grow more food, save space, and protect the soil.



Concept of Multitier Cropping:

In this system, crops are arranged in layers or tiers according to their height and growth pattern. Tall crops form the top tier, medium-height crops form the middle tier, and short or

spreading crops grow at the bottom. Because each crop occupies a different layer, competition among crops is reduced.

Crop Arrangement and Examples:

Tall crops such as coconut, arecanut, mango, or sunflower form the upper layer. Medium-height crops like banana, papaya, pigeon pea, or maize occupy the middle layer. Short-duration and low-growing crops such as ginger, turmeric, pineapple, vegetables, pulses, or fodder crops form the bottom layer.



Multitier Cropping System Models :

Coconut-based model: Coconut as the top tier, banana or cocoa as the middle tier, and pineapple, ginger, turmeric, or vegetables as the bottom tier.

Arecanut-based model: Arecanut as the main crop, black pepper or banana as the middle tier, and turmeric, ginger, pineapple, or vegetables as the lower tier.

Fruit-based model: Mango, guava, or sapota as the top tier, papaya or pigeon pea as the middle tier, and pulses or vegetables as the bottom tier.

Agroforestry-based model: Timber or shade trees like teak or neem as the top tier, fruit crops or shrubs as the middle tier, and fodder crops or vegetables as the bottom tier.

Vegetable-based model: Tall vegetables like maize or sunflower as the top tier, creepers like cucumber or bitter gourd as the middle tier, and leafy vegetables as the bottom tier.

Advantages of Multitier Cropping System:

- It increases total crop yield from the same area of land.
- It makes better use of sunlight, water, nutrients, and space.
- Farmers get regular income as different crops are harvested at different times.
- It reduces the risk of total crop failure.
- Weed growth is reduced due to full land coverage.
- It improves soil fertility by adding more organic matter.

- Soil moisture is conserved and soil erosion is reduced.
- Pest and disease incidence is often lower due to crop diversity.
- It is suitable for small and marginal farmers with limited land.
- It promotes sustainable and eco-friendly farming practices.

Disadvantages of Multitier Cropping System:

- Initial planning and crop selection are difficult.
- Requires more management skill and technical knowledge.
- Competition for water and nutrients may occur if crops are not properly selected.
- Pest and disease control becomes complicated due to mixed cropping.
- Mechanization is difficult in multitier systems.
- Initial cost of cultivation may be high.
- Irrigation management becomes complex.
- Harvesting operations may be labor-intensive.
- Not suitable for all crops and all regions.
- Poor planning can lead to reduced yield of main crop.

Conclusion

The multitier cropping system is an efficient and sustainable farming practice that makes best use of land, sunlight, water, and nutrients by growing different crops at various height levels. It helps farmers increase total productivity, improve soil health, and obtain regular income throughout the year. By reducing the risk of crop failure and promoting eco-friendly agriculture, multitier cropping is especially beneficial for small and marginal farmers. With proper planning, crop selection, and management, this system can play an important role in improving farm profitability and ensuring long-term agricultural sustainability.

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SELECTIVE BREEDING IN AQUACULTURE: ESTABLISHMENT OF BASE POPULATIONS, BREEDING STRATEGIES, AND ACHIEVEMENTS

Article ID: AG-VO6-I01-99***J. Sam Rejin and B. Asvitha**

UG Student, College of Fisheries Science, St. Devasahayam Institute of Fisheries Science & Technology, Amanattantheri, Kanniyakumari, Tamil Nadu - 629 193, India

*Corresponding Author: J. Sam Rejin

Abstract

Aquaculture is one of the fastest-growing food-producing sectors in the world, and its sustainability largely depends on the development of efficient and genetically improved farmed stocks. Selective breeding plays a vital role in enhancing growth rate, survival, disease resistance, and feed efficiency of cultured aquatic species. Establishing a genetically diverse base population is the cornerstone of any successful breeding program, as it prevents inbreeding and ensures long-term genetic gain. A structured selective breeding program involves careful selection of parents, performance evaluation, pedigree recording, controlled mating designs, and dissemination of improved stocks to farmers. Globally successful programs such as Atlantic salmon breeding, GIFT tilapia, Jayanthi rohu, GI scampi, and Amrit catla demonstrate the immense potential of selective breeding in improving aquaculture productivity. By aligning genetic improvement with commercial and environmental goals, selective breeding contributes significantly to sustainable aquaculture development, increased production efficiency, and enhanced adaptability to changing market and farming conditions.

Keywords: Selective breeding, Genetic improvement, Brood stock management, Growth performance, Disease resistance, Sustainable aquaculture, Fish breeding programs, Improved strains, Genetic diversity.

Introduction

Aquaculture has become one of the fastest-growing food-producing sectors worldwide, and its long-term success depends on sustainable and efficient production systems. A

fundamental objective of any breeding program is to lay a strong foundation for sustainable aquaculture by developing productive, domesticated stocks. Compared to unimproved or wild animals, domesticated and genetically improved individuals utilize feed, water, and land resources more efficiently, resulting in higher productivity and reduced environmental impact. Despite these advantages, genetically improved stocks currently contribute to less than 10% of global aquaculture production, highlighting the vast potential for improvement through structured breeding programs.

The establishment of a genetically diverse base population is a critical first step in any selective breeding program. A broad genetic base helps to avoid rapid inbreeding and maximizes the potential for long-term genetic gain. Past failures of several fish breeding programs have often been attributed to low genetic variation in the founding populations. Therefore, careful selection of brood stock whether from wild populations, farmed stocks, or pedigreed lines is essential to ensure adequate genetic diversity and effective population size.

Selective breeding is a systematic genetic improvement strategy that enhances the breeding value of a population by choosing and mating individuals with superior phenotypic traits, such as faster growth, higher body weight, or desirable coloration. When supported by a well-designed base population and low initial selection intensity, selective breeding can maintain genetic variability while achieving sustained genetic progress, thereby contributing significantly to the sustainability and efficiency of aquaculture production.

Steps in the Process

- Choosing of parents
- Selection of desirable traits
- Mating between selected parents
- Choosing best offspring's
- Repeat the process

Steps of Selective Breeding Programme

1. Collection of Strains

- A total of four base populations were produced, reflecting the four-year generation interval of the species.
- Each of the four base populations included brood stock originating from eight to 24 river strains.

- Collect genetically diverse strains from different riverine environments and wild stocks.
- Include strains adapted to various temperature, salinity, and disease resistance profiles.

2. Formation of Broad Base Population

- Create a founder population comprising 100 males and 100 females.
- Ensure random mating to capture and maintain broad genetic diversity.

3. Tagging and Pedigree Recording

- Individually tag all fish using PIT tags or genetic fingerprinting.
- Record:
 - iv. Initial body weight
 - v. Initial body length
 - vi. Pedigree data (parental IDs)
- Maintain centralized data records for performance tracking and selection accuracy.

4. Performance Evaluation

c) Challenge Tests

- Evaluate growth performance under controlled aquaculture conditions.
- Monitor:
 - iv. Growth rate
 - v. Feed conversion ratio (FCR)
 - vi. Health and survival

d) Field-Level Tests

- Conduct performance tests in commercial-scale sea cages or freshwater farms.
- Validate performance across diverse farming environments.

5. Selection of Brooders

- Apply individual selection based on:
 - iv. Superior growth performance
 - v. Good health and survivability
 - vi. Desired body shape and market traits
- Use Estimated Breeding Values (EBVs) derived from performance and pedigree data.

6. Mating Design

- Employ a nested mating design:

- Each selected male mated with 2–3 females.
- Facilitates pedigree tracking and genetic parameter estimation.
- Helps control inbreeding and allows estimation of heritability.

7. Heterosis Observation

- Test crosses between lines or families to assess heterosis (hybrid vigor) for growth traits.
- If heterosis is significant, consider crossbreeding strategies or developing composite strains.

8. Dissemination of Genetic Gain

- Multiply selected brood stock.
- Distribute improved stock to commercial hatcheries and farms.

Expected Outcome

- Faster growth rate.
- Improved production efficiency.
- Enhanced performance in commercial aquaculture systems.

Examples of Selective Breeding Programme:

Atlantic salmon selective breeding

In 1971, AKVAFORSK began breeding experiments for Atlantic Salmon and Rainbow Trout in Norway, which eventually became a national breeding program.

Breeding Goal

To improve the growth rate of Atlantic Salmon through a scientifically designed and data-driven selective breeding program.

GIFT (Genetic Improvement Formed Tilapias) selective breeding programme

GIFT Tilapia developed by World fish Centre, ICLARM Malaysia in 1988 to 1997. The World Fish Center's GIFT (Genetically Improved Farmed Tilapia) initiative produced a tilapia strain with faster growth, greater survival rates, and improved disease resistance.

Breeding Goal

To improve the growth rate, survival rate, disease resistance of GIFT Tilapia through a structured and scientifically designed selective breeding program.

Jayanthi Rohu selective breeding programme

In India, a selection experiment was carried out at CIFA (Central Institute of Freshwater

Aquaculture) with rohu carp (*Labeo rohita*).

Breeding Goal

To improve the growth rate of the Jayanthi Rohu (*Labeo rohita*) in aquaculture systems, enhancing its marketability and production efficiency while maintaining or improving overall health and disease resistance.

GI Scampi selective breeding programme

The ICAR-Central Institute of Freshwater Aquaculture (ICAR-CIFA) has made significant advancements in freshwater prawn research, leading to the creation of CIFA-GI SCAMPI a genetically enhanced strain of *Macrobrachium rosenbergii*. Beginning in 2007, ICAR-CIFA partnered with WorldFish, Malaysia, to launch a structured selective breeding program aimed at producing a faster growing scampi variety.

Breeding Goal

This improved strain has demonstrated a cumulative growth gain of 7.2% over 16 generations. Improved traits: Growth rate and disease resistance

Amrit Catla

CIFA has launched a genetically modified Catla (*Catla catla*) called AMRIT CATLA, a Selective breeding program which began from 2010.

Breeding Goal

A 35% cumulative gain by 3rd generation for improved aquaculture productivity. Better feed efficiency, higher survival rates and better disease resistance.

Other Examples of Selective Breeding programme:

Table. 1 Examples of Selective Breeding programme

Fish Species	Countries
Coho salmon (<i>Oncorhynchus kisutch</i>)	Chile
Atlantic salmon (<i>Salmo salar</i>)	Chile, Iceland, Ireland and Scotland
Rainbow trout (<i>Oncorhynchus mykiss</i>)	Denmark, Norway, Finland, Chile, France and USA
Brown trout (<i>Salmo trutta</i>)	France
Shire tilapia (<i>Oreochromis shiranus</i>)	Malawi
Multi-species tilapia hybrid	Israel

Gilthead sea bream (<i>Sparus aurata</i>)	Greece
Mediterranean Sea bass (<i>Dicentrarchus labrax</i>)	France and Italy
Channel catfish (<i>Ictalurus punctatus</i>)	USA
Turbot (<i>Scophthalmus maximus</i>)	Norway and Spain
Rohu (<i>Labeo rohita</i>)	India
Blunt snout bream (<i>Megalobrama amblycephala</i>)	China
Tench (<i>Tinca tinca</i>)	The Czech Republic
Pacific oyster (<i>Crassostrea gigas</i>)	Australia, USA
Sydney rock oyster (<i>Saccostrea glomerata</i>)	Australia
White Pacific Shrimp (<i>Litopenaeus vannamei</i>)	Brazil, Colombia, Mexico and USA
Kuruma shrimp (<i>Penaeus japonicas</i>)	Australia
Brown tiger prawn (<i>Penaeus esculentus</i>)	Australia
Giant tiger prawn (<i>Penaeus monodon</i>)	Australia, Thailand and USA
Banana shrimp (<i>Penaeus merguensis</i>)	Australia
Abalone (<i>Haliotis sp</i>)	Australia
Common carp (<i>Cyprinus carpio</i>)	Russia, France, Vietnam and Serbia
Artic Charr (<i>Salvelinus alpinus</i>)	Sweden
Asian seabass (<i>Lates calcarifer</i>)	Australia
Red sea bream (<i>Argyrops spinifer</i>)	Japan
Crab (<i>Portunus trituberculatus</i>)	China
Red claw crayfish (<i>Cherax quadricarinatus</i>)	Australia

Applications of selective breeding program

- Selective breeding involves selecting species with desirable features as parents for future generations, increasing the incidence of those traits over time.

- This approach aims to improve the Genetic composition of aquatic organisms for aquaculture applications.
- Including genetic considerations and well-designed selective breeding programs in aquaculture can improve success rates.
- This requires careful planning. Implementation of breeding strategies to attain desired characteristics.
- Selective breeding involves human intervention in adaptation, replacing natural selection with controlled breeding methods.
- This modification of the natural evolutionary process can result in both. Aquaculture can have both beneficial and harmful results depending on the qualities used.
- Selective breeding programs inside the aquaculture business may be more efficient and aligned with commercial goals, notwithstanding academic institutions' contributions to genetic data collection and research.
- Selective breeding aims to assist the aquaculture business adapt to changing market needs by developing superior stocks with desirable features.
- Increased production: Selective breeding can result in quicker growth rates, larger yields, and increased overall productivity, potentially lowering costs per unit of production.
- Improved disease resistance: Selective breeding can increase disease resistance, lower mortality, and improve the general health of farmed fish.
- Reduced feed costs: Breeding for features such as increased feed efficiency can greatly reduce the cost of aquaculture operations.
- Market demand: Selective breeding allows fish to be tailored to certain market demands such as size, color, and nutritional content.
- Adaptability: Breeding for features that make fish more adaptable to specific situations can boost their resilience and reduce stress.

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FUTURE FRUITS FOR URBAN AND VERTICAL FARMING SYSTEMS

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Manuj Awasthi

Teaching Associate, Chandra Shekhar Azad University of Agriculture & Technology,
Kanpur (U.P.), India

Abstract

Rapid urbanization, shrinking arable land, and climate uncertainty have intensified the search for innovative food production systems. Urban and vertical farming offer promising solutions for sustainable fruit production in cities. However, conventional fruit crops are often unsuitable for these systems due to their long juvenile phase, large canopy, and high resource demand. This article explores the concept of future fruits—fruit crops and cultivars specifically suited for urban and vertical farming systems. Key traits, suitable species, technological integration, and research priorities are discussed, highlighting the role of fruit science in shaping resilient urban food systems.

Keywords: Urban agriculture, vertical farming, dwarf fruit crops, controlled environment agriculture, future fruits.

1. Introduction

Urban areas are projected to house nearly 70% of the global population by 2050. Ensuring access to fresh, nutritious fruits in cities is a growing challenge due to land scarcity, transportation losses, and environmental concerns. Urban and vertical farming systems—rooftop gardens, hydroponic units, indoor farms, and building-integrated agriculture—are emerging as viable alternatives. While leafy vegetables dominate these systems, fruits represent the next frontier. Identifying and developing fruit crops adapted to confined spaces and controlled environments is critical for future urban food security.

2. Concept of “Future Fruits”

Future fruits are fruit crops or varieties that possess traits enabling successful cultivation

in urban and vertical farming systems. These fruits differ from traditional orchard crops in growth habit, physiological behavior, and management requirements.

Key Characteristics of Future Fruits

- Compact or dwarf growth habit
- Early bearing and short crop cycle
- High harvest index
- Adaptability to container and soilless culture
- Suitability for controlled environments (light, temperature, CO₂)
- High nutritional or functional value

Vertical Farming:

Vertical farming has emerged as a **revolutionary** agricultural system designed to address the challenges posed by urbanization and limited arable land. By utilizing vertical spaces and advanced technologies such as hydroponics and aeroponics, it significantly optimizes land use, making it a viable option in urban environments where traditional farming is constrained. Studies have shown that vertical farming systems can achieve yields up to ten times higher per unit area compared to conventional farming by leveraging three-dimensional cultivation techniques. One of the standout benefits of vertical farming is its ability to sustain year-round crop production. Controlled environments equipped with artificial lighting, temperature regulation, and humidity control allow crops to thrive regardless of external weather conditions, ensuring steady production cycles and a reliable supply of fresh produce.

This is particularly beneficial for urban centers with high demand for locally grown fruits like strawberries and blueberries. Furthermore, vertical farming minimizes environmental impact by employing water-efficient systems, recycling up to 98% of water used in cultivation, and reducing the need for chemical inputs due to the controlled environment. Bringing food production closer to urban populations, it reduces transportation-related emissions, contributing to carbon footprint reduction. The method also supports water conservation through closed-loop systems, which recycle nutrients and water, addressing resource scarcity challenges. Reduced reliance on pesticides further enhances its environmental appeal, as it curtails chemical usage and promotes the cultivation of healthier, pesticide-free produce. Moreover, vertical farming's flexibility allows for its application in diverse urban settings, from rooftops to abandoned buildings. Its ability to grow crops in stacked layers maximizes yield within limited spaces,

making it an indispensable solution for cities facing land scarcity. Advanced systems also ensure consistency in crop quality and accelerated growth cycles, with some crops reaching maturity 10-15 days earlier than traditional methods, meeting urban demand more efficiently. Despite its numerous advantages, vertical farming presents challenges, including high initial investment costs and the need for specialized technical expertise. Addressing these barriers through technological innovation and policy support is essential for the widespread adoption and integration into global food systems.

Traditional Farming vs Vertical Farming:

When comparing traditional to vertical farming, there are notable differences in terms of space efficiency, resource use, crop yield, and environmental impact. Open field farming is traditional and relies on large tracts of land where crops are grown horizontally, often subject to the vagaries of weather, pests, and soil quality. While it can support large-scale production, it requires significant land area and is dependent on seasonal cycles, meaning that the supply of fresh produce is often limited by climate conditions. Additionally, open field farming typically consumes large amounts of water, fertilizers, and pesticides, leading to environmental concerns like water depletion, soil erosion, and pollution.

In contrast, vertical farming is a more modern, space-efficient approach, especially suited for urban environments where land is limited. By using stacked layers or vertical growing surfaces, it allows for the cultivation of crops in confined spaces such as rooftops or abandoned buildings. This system often uses hydroponics or aeroponics, which reduces water usage by up to 98%, compared to traditional agriculture. Vertical farming also offers year-round production by controlling environmental factors like temperature, humidity, and light, which is not feasible in open field farming due to seasonal changes and unpredictable weather. Moreover, the reduced need for pesticides and minimal land use makes vertical farming a more sustainable option, as it limits environmental degradation while also minimizing food miles, since produce can be grown close to urban markets.

Current Scenario and Market Potential of Vertical Farming:

Vertical farming has experienced significant growth since its emergence, transitioning from a niche concept in 2010 to a rapidly expanding industry by 2025. According to a report from Market Research Future, the sector is projected to grow at a compound annual growth rate (CAGR) of 20.62%, driven by increasing demand for sustainable agricultural practices,

technological advancements, and the growing need for locally sourced fresh produce. The rise in urbanization, the demand for year-round food production, and the environmental challenges associated with traditional farming methods are key factors contributing to the industry's growth. Advanced technologies like hydroponics and aeroponics, alongside precise environmental controls, have enabled vertical farms to significantly outperform conventional agricultural practices in terms of yield. Vertical farming systems now generate multiple times the yield per square meter compared to traditional farming, making them more profitable and efficient. This increase in productivity has led to vertical farming being viewed as a viable and scalable alternative to traditional farming, especially in densely populated urban environments.

3. Fruit Crops Suitable for Urban and Vertical Farming

3.1 Naturally Compact and Short-stature Fruits

- **Strawberry** – Most successful vertical fruit crop; ideal for hydroponics and aeroponics
- **Blueberry** (dwarf cultivars) – High antioxidant value, suitable for containers
- **Raspberry and Blackberry** (primocane types) – Compact varieties for protected systems
- **Cape gooseberry** (*Physalis peruviana*) – High adaptability and nutritional value

3.2 Dwarf and Genetic-modified Fruit Types

- **Dwarf banana** (tissue-culture derived) – Rooftop and greenhouse suitability
- **Columnar apple varieties** – Minimal canopy spread, high-density planting
- **Dwarf citrus** (lime, calamondin, kumquat) – Popular for urban balconies and terraces
- **Papaya** (dwarf and gynodioecious types) – Early bearing and high productivity

3.3 Emerging and Underutilized Fruits

- **Dragon fruit** (*Hylocereus* spp.) – Vertical training system, CAM physiology
- **Passion fruit (compact hybrids)** – Trellised vertical cultivation
- **Fig (low-chill, dwarf cultivars)** – Suitable for container orchards
- **Mulberry (dwarf genotypes)** – Nutritious and fast-growing

4. Role of Technology in Vertical Fruit Farming

4.1 Controlled Environment Agriculture (CEA)

- LED lighting tailored for flowering and fruiting
- Temperature and humidity optimization
- CO₂ enrichment to enhance photosynthesis

4.2 Soilless Cultivation

- Hydroponics, aeroponics, and substrate culture
- Improved nutrient use efficiency
- Reduced pest and disease incidence

4.3 Digital and Smart Technologies

- AI-based growth monitoring
- IoT-enabled irrigation and fertigation
- Automated pruning and harvesting (future scope)

5. Advantages of Urban Fruit Production

- Fresh, residue-free fruits near consumers
- Reduced postharvest losses and carbon footprint
- Year-round production
- Enhanced nutritional security in cities
- Livelihood and entrepreneurship opportunities

Potential of Vertical Farming in Fruit Crops:

Vertical farming holds considerable promise for the cultivation of fruit crops, especially in urban environments where traditional farming is constrained by limited land availability. By utilizing vertically stacked layers or integrated systems, vertical farming optimizes space, allowing for high-density planting in compact urban areas. This makes it particularly suitable for growing high-demand fruits such as strawberries, dwarf apple varieties, and even tropical fruits like bananas. The ability to create controlled environments within vertical farms ensures that fruit crops can be grown irrespective of external climate conditions, making year-round production feasible in locations with harsh or inconsistent weather patterns.

Vertical Strawberry Farming: Innovations and Future Outlook

Strawberries, known for their appealing taste and vibrant color, hold significant value in the global agricultural market. Traditional farming practices, however, face several obstacles, such as limited land availability, susceptibility to pests and diseases, and unpredictable climatic conditions. Vertical farming has emerged as an innovative solution to overcome these challenges by providing controlled growing environments that enhance productivity and optimize growth conditions. Vertical strawberry farming utilizes vertical space by cultivating strawberries in stacked layers, which significantly boosts crop yield per square meter. This method, often

integrated with hydroponic and aeroponic systems, ensures that plants receive a steady supply of nutrients while simultaneously reducing water consumption. Moreover, these systems minimize the risks associated with soil-borne diseases, a common issue in conventional farming. The use of artificial lighting in vertical strawberry farming allows for continuous production throughout the year, overcoming the limitations of seasonal variations. This controlled setting not only maintains consistent fruit quality but also accelerates the growth rate, enabling faster harvests compared to traditional farming. With the increasing global demand for fresh produce, vertical strawberry farming presents a promising solution to meet these needs while promoting sustainable agricultural practices. This technique is particularly suited for urban areas where space is limited, and it helps lower the carbon footprint associated with food transportation. Looking ahead, the future of vertical strawberry farming appears promising, with advancements in technology such as automation, the Internet of Things (IoT), and artificial intelligence (AI). These innovations are expected to further enhance production efficiency and reduce labor costs. As urbanization continues to grow and the global population increases, vertical farming systems for strawberries are likely to play a crucial role in the future of modern horticulture.

6. Challenges and Research Gaps

Despite its potential, urban and vertical fruit farming faces several constraints:

- Limited availability of fruit-specific vertical cultivars
- High initial investment costs
- Pollination challenges in indoor systems
- Limited crop-specific nutrient protocols
- Lack of region-specific recommendations

7. Future Research Priorities in Fruit Culture

- Breeding fruit varieties specifically for vertical farming
- Developing ultra-dwarf and fast-fruiting genotypes
- Exploring rootstock–scion combinations for container culture
- Optimizing light spectra for fruit quality improvement
- Integration of fruit crops into smart city planning

Conclusion

Urban and vertical farming systems represent a paradigm shift in fruit production. The development and adoption of future fruits—compact, resilient, and nutritionally rich can



transform cities into productive food landscapes. Fruit scientists, breeders, and urban planners must collaborate to harness this potential, ensuring sustainable fruit availability for future generations.

Suggested Journals / Platforms

- Indian Journal of Horticulture
- Fruits
- Scientia Horticulturae
- Urban Agriculture Magazine
- ICAR extension publications



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CARBENDEZIM APPLICATION FOR CONTROLLING ROOT ROT IN CHILLI (CAPSICUM ANNUUM L.)

Article ID: AG-VO6-I01-101**Santhanasnehavalli M**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Chilli (*Capsicum annuum* L.) is an important commercial spice and vegetable crop widely cultivated in India. Fungal diseases significantly reduce chilli yield and quality. Carbendazim, a systemic benzimidazole fungicide, is commonly used for the management of seed-borne and soil-borne fungal pathogens in chilli. This article discusses the mode of action, recommended application methods, target diseases, dosage, advantages, limitations, and safety precautions associated with carbendazim use in chilli cultivation.

Introduction

Chilli is highly susceptible to several fungal diseases such as damping-off, anthracnose, fruit rot, wilt, and leaf spot. Effective disease management is essential for achieving higher productivity. Carbendazim (methyl benzimidazol-2-yl carbamate) is a broad-spectrum systemic fungicide widely adopted by farmers due to its curative and preventive action.

Mode of Action

Carbendazim works by inhibiting fungal cell division. It interferes with the formation of microtubules during mitosis, thereby preventing fungal growth and reproduction. Due to its systemic nature, it is absorbed by plant tissues and translocated upward, providing internal protection against fungal pathogens.

Target Diseases in Chilli

Carbendazim is effective against the following fungal diseases in chilli:

Damping-off (*Pythium* spp., *Rhizoctonia solani*)

Anthracnose / Fruit rot (*Colletotrichum capsici*)

Fusarium wilt (*Fusarium oxysporum*) Cercospora
leaf spot

Powdery mildew (partial control)



Methods of Application

1. Seed Treatment

Take 2 g Carbendazim per kg of seed. Controls seed-borne fungi and improves seedling vigor.

2. Seedling Root Dip

Take 1 g per liter of water and soak 20–30 minutes before transplanting. Prevents soil-borne diseases like wilt and damping-off

3. Foliar Spray

Take 1 g per liter of water, At disease initiation, repeat at 10–15 day intervals if required. Controls leaf and fruit infections

4. Soil Drenching

Take 1–2 g per liter of water and pour in root zone area. Effective against root and collar rot diseases

Advantages of Carbendazim Systemic
and long-lasting action Effective at low
doses

Controls a wide range of fungal pathogens

Economical and easily available

Compatible with many other agrochemicals (except alkaline solutions)

Limitations

- Continuous use may lead to fungicide resistance Ineffective against bacterial and viral diseases
- Restricted or regulated in some countries due to environmental concerns
Should not be used indiscriminately

Safety Precautions

- Use recommended dose only
- Wear protective clothing during application
- Avoid spraying during windy conditions
Follow pre-harvest interval (PHI) of 7–10 days
- Do not mix with strongly alkaline pesticides

Conclusion

Carbendazim plays a significant role in managing fungal diseases in chilli when used judiciously. Proper application methods, correct dosage, and integration with other disease management practices such as crop rotation, resistant varieties, and biological control can enhance its effectiveness while minimizing environmental risks.

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CATTLE AND BUFFALO POPULATION TRENDS IN UTTAR PRADESH: EMERGING ECONOMIC AND FODDER CHALLENGES

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***Sakshi Chaturvedi¹ and Saurabh Shukla²**

¹ Young Professional-II, Indian Grassland and Fodder Research Institute (IGFRI),
Jhansi, Uttar Pradesh, India

² Ph.D. Research Scholar, Department of Agricultural Economics, Institute of Agricultural
Sciences, Bundelkhand University, Jhansi, Uttar Pradesh, India

*Corresponding Author: Sakshi Chaturvedi

Abstract

In Uttar Pradesh's rural economy, livestock is vital to employment, income generation, and nutritional security. However, current patterns show significant swings and a comparatively decreasing number of native cattle and buffalo, as well as an ongoing decrease in the number of goats. This article analyzes the population trends of cattle, buffaloes, and goats in Uttar Pradesh using secondary data from 2018-19 to 2024-25 and looks at the economic and extension-related factors that caused these changes. Fodder scarcity, growing maintenance costs, and gaps in the extension system are given particular attention. In order to guarantee sustainable livestock development in the state, the study emphasizes the necessity of an integrated strategy that combines fodder development, financial incentives, and efficient extension techniques.

Keywords: Livestock population, Fodder scarcity, Dairy economics, Agricultural extension & economic, Uttar Pradesh

1. Introduction

The livestock sector of Uttar Pradesh is a major contributor to India's economy. The state is home to the highest number of cows and buffaloes in the country and, therefore, has an important role in milk production. Livestock is a key contributor to the livelihoods of small and marginal farmers. Livestock farming has been changing rapidly, with new breeds being introduced, as well as increasing concentration and commercialization. As a result, livestock

farming becomes more difficult for many farmers and therefore raises concerns about long-term viability and profitability.

The demographic dynamics of livestock populations are not simply biological but also reflect the economic viability, resource utilization and efficiency of the extension services that support them. For example, declining or stagnant numbers of livestock may imply that the costs of production are rising due to the high cost of feed and relatively limited access to scientific management practices, as well as drought and an aging population in many areas. The current article seeks to provide an analysis of both the trends in the population of livestock in Uttar Pradesh, as well as the limitations faced by the industry, with respect to both economics and extension.

2. Trends in Livestock Population in Uttar Pradesh

The data from 2018-19 to 2024-25 (Figures in '000 Nos.) reveal mixed but concerning trends in livestock population in Uttar Pradesh (Table 1).

Year	Cattle		Buffaloes	Goat
	Exotic	Indigenous		
	(Figures in '000 Nos.)		(Figures in '000 Nos.)	
2018-19	1409.68	5275.79	11759.06	4789.94
2019-20	1466.99	5461.10	12126.08	4921.15
2020-21	1762.64	5005.69	11986.55	4612.65
2021-22	1849.27	5204.19	11878.92	4444.09
2022-23	1643.34	4985.72	11958.04	4391.14
2023-24	1721.37	5046.98	12505.63	4289.54
2024-25	1710.00	4912.00	11400.00	4100.00

(Source: Basic Animal Husbandry Statistics 2025, Govt. of India, Ministry of Fisheries, Animal Husbandry & Dairying)

2.1 Cattle Population

The growth of the Exotic Cattle Population was 1409.68 in 2018-19 and increased to 1710.00, between 2024-25 in Uttar Pradesh reflecting total growth with some fluctuations. It appears that Farmers are gradually shifting towards Exotic and Crossbred higher-yielding Animals.

On the flip side, the number of Indigenous Cattle has steadily decreased from 5275.79 in Uttar Pradesh in the year 2018-19 to 4912.00 in 2024-25 because of Economic Pressures caused by the

fact that Indigenous Cattle produce lower milk volumes and increase the costs for Farmers who raise Indigenous Cattle, primarily Male and Those who do not produce Milk.

2.2 Buffalo Population

Buffalo population showed relative stability with minor fluctuations, increasing from 11,759.06 thousand in 2018-19 to a peak of 12,505.63 in 2023-24, before declining to 11,400.00 in 2024-25. Given their higher fat content milk and better market price, buffaloes continue to remain economically attractive to farmers.

2.3 Goat Population

Goat population declined consistently from 4,789.94 in 2018-19 to 4,100.00 in 2024-25. This decline is particularly concerning for landless and marginal farmers, for whom goats serve as a low-investment livelihood option.

3. Milk Production of Uttar Pradesh During 2024-25 (000tonnes)

	Buffaloes	Cattle	Goat	Total
Milk production	24249.53	13211.45	1354.37	38815.34

(Source: Basic Animal Husbandry Statistics 2025, Govt. of India, Ministry of Fisheries, Animal Husbandry & Dairying)

Despite population fluctuations, Uttar Pradesh continues to be a leading milk-producing state. The data indicate that buffaloes contribute the largest share to milk production (24,249.53 thousand tones), followed by cattle (13211.45 thousand tones) and goats (1,354.37 thousand tones), resulting in a total milk production of 38,815.34 thousand tones.

This dominance of buffaloes in milk output further explains farmers' preference for buffalo rearing over indigenous cattle and small ruminants from an economic standpoint.

4. Economic Factors Behind Declining Livestock Numbers

4.1 Rising Cost of Livestock Rearing

Feed and fodder constitute nearly 60-70 per cent of the total cost of milk production. Rising prices of concentrates, green fodder, and dry fodder have significantly increased maintenance costs, reducing net returns from livestock farming.

4.2 Low Profitability of Indigenous Cattle

Indigenous cattle often yield lower marketable surplus of milk compared to buffaloes and exotic cattle. In the absence of adequate price incentives and support systems, farmers perceive

indigenous cattle as economically unviable.

4.3 Stray Cattle Problem

The increasing number of stray cattle in Uttar Pradesh has discouraged farmers from maintaining unproductive animals. This issue has also imposed social and economic costs on crop farmers, indirectly influencing livestock rearing decisions.

5. Fodder Availability: The Central Constraint

Fodder scarcity emerges as one of the most critical constraints affecting livestock population dynamics.

5.1 Shrinking Grazing Resources

Rapid urbanization, land fragmentation, and conversion of common property resources have drastically reduced grazing lands in Uttar Pradesh.

5.2 Deficit in Green Fodder

Uttar Pradesh faces a **significant shortage of green fodder**. Estimates suggest there is about a **28.3% deficit** in green fodder availability in the state compared to the requirement. This means nearly **one-third of the needed green fodder is not available** for livestock feeding.

5.3 Rising Fodder Prices

Increased dependence on purchased fodder has raised production costs, making livestock rearing less attractive, particularly for smallholders.

6. Extension and Economic Constraints in Livestock Production

- The observed trends also reflect gaps in the agricultural extension system.
- Limited dissemination of fodder production technologies
- Low awareness of balanced ration feeding and fodder conservation practices
- Inadequate training on cost-effective livestock management
- Weak linkage between dairy development schemes and ground-level adoption
- Strengthening extension services can significantly improve productivity without increasing animal numbers, thereby reducing pressure on fodder resources.

7. Way Forward: Policy and Extension Interventions

- Fodder Development Programs: Promotion of fodder crops, fodder banks, and silage-making at village level
- Economic Incentives: Support for indigenous cattle through productivity-linked incentives

- Extension Strengthening: Capacity building of farmers through KVKs, ICT tools, and on-farm demonstrations
- Integrated Livestock Planning: Linking livestock development with land-use planning and crop–livestock integration
- Stray Cattle Management: Sustainable gaushala models and community participation

Conclusion

The changing dynamics of livestock populations in Uttar Pradesh represent deeper economic and structural factors rather than just numerical shifts, such as scarcity of feed, increasing input prices, and gaps in extension services impacting farmers' choices of livestock. The decline in indigenous breeds of cows and goats has resulted from these underlying challenges, and an integrated approach is required to resolve these issues for sustainable growth in livestock production within the State, including aspects such as economic viability, fodder security, and improved extension services.

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MANAGEMENT FOR MANGO SOOTY MOULD – MAIDA STARCH SOLUTION

Article ID: AG-VO6-I01-103

Saro S

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Sooty mold is a common fungal problem observed in many horticultural crops, especially citrus, mango, guava, and ornamental plants. The fungus grows superficially on plant surfaces and reduces photosynthesis by blocking sunlight. It develops mainly due to honeydew secretions produced by sap-sucking insects such as aphids, whiteflies, mealybugs, and scales. This demonstration explains an eco-friendly and low-cost method of removing sooty mold using a maida (refined wheat flour) solution after effective pest control. The preparation, application procedure, and benefits of the maida solution are discussed in detail.

Introduction

Sooty mold is not a true plant disease but a secondary fungal growth that appears as a black coating on leaves, stems, and fruits. Though it does not penetrate plant tissues, it severely affects plant health by reducing photosynthesis, transpiration, and overall crop yield. The main cause of sooty mold is the presence of sap-sucking insects that excrete sugary substances called honeydew, which serves as a food source for the fungus. Therefore, managing insect pests is the primary step in controlling sooty mold.

Apart from chemical fungicides, traditional and farmer-friendly practices such as maida or starch solution sprays are effective in physically removing the mold from plant surfaces. This method is economical, easy to prepare, and safe when used properly.

Sooty mould: *Capnodium mangiferae*

Symptoms

- The fungi produce mycelium which is superficial and dark. They grow on sugary

secretions of the plant hoppers. Black encrustation is formed which affect the photosynthetic activity.

- The fungus grows on the leaf surface on the sugary substances secreted by jassids, aphids and scale insects.



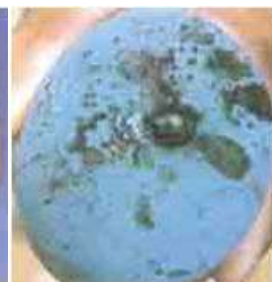
Healthy leaf



Infected leaf



Sooty mould on mature fruit



Caused by sucking pest like Jassids, Aphids or Scale insects

CONTROL USING MAIDA STARTCH SOLUTION:

Materials Required

- Maida (refined wheat flour)
- Clean water
- Measuring balance or container
- Cooking vessel (for boiling method)
- Sprayer
- Stick or ladle for mixing
- Insecticides (for controlling sap-sucking pests)

Clean water source for washing leaves



Preparation of Maida Solution



Method 1: Simple 5% Maida Solution

Take 50 g of maida Mix it thoroughly in 1 liter of water

Stir well to avoid lumps

Filter if necessary before filling the sprayer

Method 2: Boil and Dilute (Concentrated Starch Solution)

Boil 1 kg of maida in 5 liters of water

Allow the mixture to cool completely

Dilute the concentrated solution with 20 liters of water

Mix well before spraying

Procedure / Method of Application

Control the Insect Pests First

Spray recommended insecticides to control aphids, whiteflies, mealybugs, and scales.

This step is essential because sooty mold will reappear if pests are not managed.

Preparation of Maida Solution

Prepare either the 5% solution or the boiled starch solution as described.

Application of Maida Solution

- Spray the solution uniformly on affected leaves and stems.
- Ensure proper coverage, especially on the undersides of leaves.
- Washing Off the Mold
- After some time, the black fungal growth loosens.
- Use clean water or mild pressure spray to wash off the mold.
- Timing of Spray
- Spray during clear weather.
- Avoid cloudy or rainy conditions for better effectiveness.

Why Maida Solution Works

- Sooty mold is superficial and does not enter plant tissues.
- Maida or starch forms a thin film over the fungal layer.
- This film helps loosen and peel off the black fungal growth.
- Once removed, normal photosynthesis resumes, improving plant vigor.

Advantages

- Low-cost and easily available material
- Farmer-friendly and simple to prepare
- Reduces dependency on chemical fungicides
- Improves leaf cleanliness and photosynthesis
- Suitable for demonstration and extension activities

Conclusion

Sooty mold, though not a direct disease, significantly affects plant growth and yield by reducing photosynthesis. Effective management requires controlling sap-sucking insect pests followed by physical removal of fungal growth. The use of maida solution is an economical, practical, and efficient method to clean affected plant surfaces. This method is especially useful for farmers and extension demonstrations, as it promotes sustainable and eco-friendly plant protection practices.

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MICRONUTRIENT FERTILIZER IN RICE PRODUCTION: A BOOST FOR YIELD & QUALITY

Article ID: AG-VO6-I01-104**Thanuja S**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Rice, a staple food for billions, requires essential micronutrients for optimal growth and yield. This article explores the role of micronutrient fertilizers in rice production, highlighting key nutrients, application methods, and benefits. Micronutrient fertilizers enhance rice yield, quality, and resilience. Zinc, iron, manganese, and copper are crucial for rice growth. Application methods include foliar spray, soil application, and seed treatment. Benefits include improved yield, stress tolerance, and nutrient uptake.

Introduction

Rice (*Oryza sativa* L.) is a major staple crop worldwide, and its productivity largely depends on balanced nutrient management. While macronutrients such as nitrogen, phosphorus, and potassium are commonly applied, deficiencies of micronutrients have become increasingly prevalent due to intensive cropping, soil degradation, and imbalanced fertilization practices. Micronutrients including zinc (Zn), iron (Fe), manganese (Mn), boron (B), copper (Cu), and molybdenum (Mo) play vital roles in enzymatic activities, photosynthesis, nitrogen metabolism, and overall plant growth. Among these, zinc deficiency is the most widespread constraint affecting rice yield and grain quality.

The application of micronutrient fertilizers through soil, foliar, seed treatment, or integrated nutrient management practices has been shown to significantly improve crop growth, tillering, grain filling, and yield. Moreover, adequate micronutrient nutrition enhances grain nutritional quality, contributing to biofortification and reduction of micronutrient malnutrition in human populations. Proper diagnosis of deficiencies through

soil and plant analysis and site-specific application of micronutrients are essential to avoid toxicity and ensure sustainable rice production. This review highlights the importance of micronutrient fertilizers in rice cultivation and emphasizes their role in improving productivity, soil health, and grain quality.

Key Micronutrients for Rice

- Zinc (Zn): Crucial for enzyme activity, protein synthesis, and stress tolerance
- Iron (Fe): Essential for chlorophyll production and photosynthesis
- Manganese (Mn): Aids in photosynthesis, nitrogen metabolism, and stress tolerance
- Copper (Cu): Boosts disease resistance and plant defense
- Boron (B): Supports cell wall development and nutrient uptake

Deficiency Symptoms

- Zinc: Stunted growth, yellowing leaves
- Iron: Interveinal chlorosis, reduced yields
- Manganese: Brown spots, reduced tillering .

Application Methods

1. Foliar Spray: Quick correction of deficiencies, apply during critical growth stages
2. Soil Application: Long-term availability, apply before or during planting
3. Seed Treatment: Early boost for seedlings, enhances germination.

Benefits of Micronutrient Fertilizers

- Improved yield and grain quality
- Enhanced stress tolerance to drought, salinity, and temperature fluctuations
- Better nutrient uptake and utilization efficiency

Choosing the Right Fertilizer

- Soil testing to identify deficiencies
- Balanced application with macronutrients (NPK)
- Consider climate, soil type, and rice variety

The procedure for applying multinutrient fertilizer in rice typically involves the following steps:

1. Soil Testing: Get your soil tested to determine its nutrient status and identify the specific nutrient deficiencies.
2. Fertilizer Selection: Choose a multinutrient fertilizer that matches the nutrient

requirements of your rice crop, based on the soil test results.

3. **Application Time:** Apply the fertilizer at the right time, usually at planting or during the early growth stages of the rice crop (around 20-30 days after transplanting).
4. **Application Method:** Apply the fertilizer uniformly, either by broadcasting or banding, depending on the type of fertilizer and soil conditions.
5. **Dosage:** Apply the recommended dose, typically 50-100 kg/ha of NPK (Nitrogen-Phosphorus-Potassium) fertilizer, depending on the soil type and crop requirements.
6. **Split Application:** Consider split application, where a portion of the fertilizer is applied at planting and the remaining amount is applied during the crop growth stage.

Some common multinutrient fertilizers used in rice cultivation include:

- NPK (Nitrogen-Phosphorus-Potassium)
- DNP (Diammonium Phosphate)
- Urea + SSP (Single Super Phosphate) + MOP (Muriate of Potash)

The main objectives of using multi nutrient fertilizers in rice cultivation are:

1. **Improved Crop Yield:** To increase rice yield by providing essential nutrients for healthy growth and development.
2. **Balanced Nutrition:** To supply the rice crop with a balanced mix of nutrients (NPK, micronutrients) for optimal growth and productivity.
3. **Soil Fertility Management:** To maintain or improve soil fertility by replenishing nutrients removed by the crop.
4. **Enhanced Crop Quality:** To improve grain quality, nutritional value, and marketability.
5. **Efficient Resource Use:** To optimize fertilizer use, reducing waste and environmental impact.

Some achievements in multinutrient fertilizers in rice cultivation include:

1. **Increased Yields:** Multi nutrient fertilizers have contributed to yield increases of 10-20% in rice crops.
2. **Improved Nutrient Use Efficiency:** Balanced nutrient application has improved fertilizer use efficiency, reducing waste and environmental impact.
3. **Enhanced Grain Quality:** Multi nutrient fertilizers have improved grain quality, nutritional value, and marketability.

4. Soil Health Improvement: Balanced nutrient management has improved soil fertility, structure, and overall health.
5. Increased Farmer Income: By improving yields and grain quality, multinutrient fertilizers have contributed to increased farmer income and profitability.

Some notable examples include:

- In India, the use of multinutrient fertilizers has contributed to a 15-20% increase in rice yields.
- In Southeast Asia, balanced nutrient management has improved rice yields by 10-15% and reduced fertilizer use by 10-20%.

Some ways to overcome challenges associated with multinutrient fertilizers in rice cultivation include:

1. Soil Testing: Conduct regular soil tests to determine nutrient requirements and adjust fertilizer applications accordingly.
2. Balanced Fertilization: Apply multi nutrient fertilizers in a balanced ratio to avoid nutrient imbalances.
3. Split Application: Apply fertilizers in split doses to match crop demand and reduce losses.
4. Use of Organic Manures: Integrate organic manures like FYM, compost, or green manure to improve soil fertility and reduce reliance on chemical fertilizers.
5. Precision Agriculture: Leverage precision agriculture techniques like site-specific nutrient management to optimize fertilizer use.
6. Farmer Education: Educate farmers on proper fertilizer application techniques and benefits of balanced nutrition.
7. Improved Fertilizer Formulations: Develop and promote more efficient and environmentally friendly fertilizer formulations.

Some potential solutions to address specific challenges:

- Nutrient Imbalances: Use fertilizers with balanced NPK ratios and micronutrients.
- Soil Degradation: Implement conservation agriculture practices like crop rotation and cover cropping.
- Environmental Concerns: Promote sustainable agriculture practices like integrated nutrient management.

Some disadvantages of multinutrient fertilizers in rice cultivation include:

1. Nutrient Imbalances: Over application or imbalance of nutrients can lead to soil degradation and environmental issues.
2. High Costs: Multi nutrient fertilizers can be more expensive than single-nutrient fertilizers.
3. Limited Availability: Access to multi nutrient fertilizers may be limited in some regions.
4. Soil pH Impact: Some multi nutrient fertilizers can affect soil pH, potentially harming soil health.
5. Environmental Concerns: Excess nutrients can pollute water bodies, contributing to eutrophication and environmental degradation.
6. Dependence on External Inputs: Overreliance on multi nutrient fertilizers can lead to neglect of soil conservation and organic practices.
7. Lack of Awareness: Inadequate knowledge about proper application and management can reduce effectiveness.

To mitigate these disadvantages, farmers should:

- Conduct soil tests to determine nutrient requirements
- Apply fertilizers judiciously and follow recommended practices
- Integrate organic manures and conservation agriculture techniques
- Monitor soil health and adjust fertilizer applications accordingly .

RESULTS

The use of multinutrient fertilizers in rice cultivation has shown promising results, including:

- Increased crop yields by 10-20%
- Improved grain quality and nutritional value
- Enhanced soil fertility and structure
- Better nutrient use efficiency, reducing waste and environmental impact

Conclusion

Multinutrient fertilizers can be an effective tool for improving rice productivity and sustainability when used judiciously and as part of an integrated nutrient management approach. By balancing nutrient application, improving soil health, and promoting efficient fertilizer use, farmers can reap economic benefits while minimizing environmental risks.



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PREPARATION OF AMUTHA KARAISAL

Article ID: AG-VO6-I01-105**Muthuselvi.A**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Amutha Karaisal is a traditional liquid bio-stimulant widely used in natural and organic farming systems. It is prepared using locally available cow-based inputs such as cow dung, cow urine, jaggery, and water, which together serve as rich sources of nutrients and beneficial microorganisms. This indigenous formulation enhances soil microbial activity, improves nutrient mobilization, and supports better soil fertility. Regular application of Amutha Karaisal promotes healthy root and shoot growth, increases nutrient uptake, and improves overall crop vigor and yield. It can be applied through foliar spray, soil application, or seed treatment and is suitable for a wide range of crops including paddy, millets, pulses, vegetables, fruits, and plantation crops. Owing to its low cost, ease of preparation, and eco-friendly nature, Amutha Karaisal acts as an effective alternative to chemical fertilizers and plays a significant role in promoting sustainable and environmentally safe agricultural practices

Amutha Karaisal:

Introduction

Amutha Karaisal is an important liquid bio-stimulant used in natural and organic farming systems. It is prepared using cow-based products and jaggery, which act as a rich source of nutrients and beneficial microorganisms. This organic formulation plays a vital role in improving soil health, enhancing plant growth, and increasing crop productivity in an eco-friendly manner. Amutha Karaisal is widely adopted by farmers as an alternative to chemical fertilizers due to its low cost and sustainable nature.

**Composition and Importance:**

The main components of Amutha Karaisal include cow dung, cow urine, jaggery, and water. cow dung and cow urine provide essential nutrients and beneficial microbes, while jaggery serves as a food source for microorganisms, enhancing their multiplication. These microbes help in nutrient mobilization and improve soil biological activity.

Preparation of Amutha Karaisal:**Ingredients:**

Cow dung – 1 kg

Cow urine – 1 litre

Jaggery – 250 grams

Water – 10 litres

Method of Preparation:

Take 10 litres of clean water in a container. Add cow dung and mix thoroughly until it dissolves completely. Then add cow urine and stir well. Powder the jaggery and add it to the mixture. Mix continuously to avoid formation of lumps. Cover the container loosely and keep it in shade for 24 hours. The solution should be stirred occasionally during fermentation.

Benefits of Amutha Karaisal:

Improves soil fertility and soil microbial activity. Enhances root growth and overall plant vigor. Improves nutrient absorption and availability. Promotes healthy leaf and shoot development. Reduces dependency on chemical fertilizers. Increases crop yield and quality. Cost-effective and environmentally safe. Improves soil aeration and water-holding capacity.

Method of Application:

Foliar spray: Dilute 1 litre of Amutha karaisal in 10 litres of water and spray uniformly on crop leaves.

Soil application: Apply through irrigation water or drenching near the root zone.

Seed treatment: Seeds can be soaked in diluted solution before sowing

Frequency: Apply once every 10–15 days during crop growth stages

Crops Suitable for Application:**Amutha Karaisal can be used for:**

Paddy, Millets, Pulses, Vegetables, Fruits, Oilseed crops and Plantation crops

Precautions:

Use fresh cow dung and cow urine for better results. Do not store the solution for more than 2–3 days. Always dilute before application and avoid spraying during hot sunny hours. Stir the solution well before use.

Conclusion

Amutha Karaisal is a valuable organic input that supports sustainable agriculture by improving soil health and crop productivity. Its easy preparation, low cost, and eco-friendly nature make it an ideal choice for farmers aiming to adopt natural farming practices. Regular use of Amutha Karaisal helps maintain long-term soil fertility and ensures healthy crop growth without harming the environment.

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SINKING EARTH: THE GLOBAL WATER BANKRUPTCY

Article ID: AG-VO6-I01-106**A.S. Viruthikaa**

¹B.Tech Energy and Environmental Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, India

Abstract

Freshwater scarcity has emerged as one of the most serious challenges facing global agriculture. Excessive groundwater extraction, climate variability, and inefficient irrigation practices have resulted in severe water stress, land subsidence, and declining farm productivity. The concept of “Global Water Bankruptcy,” introduced by the United Nations University Institute for Water, Environment and Health, highlights that groundwater reserves are being depleted faster than their natural recharge capacity. This article discusses the impact of water bankruptcy on agriculture, with special emphasis on farmers, food security, and rural livelihoods. It also explores practical solutions such as crop diversification, efficient irrigation systems, rainwater harvesting, and the use of artificial intelligence in water management. The article emphasizes the need for sustainable farming practices to safeguard water resources for future generations.

Keywords: Water scarcity, Groundwater depletion, Agriculture, Land subsidence, Sustainable irrigation, Water management

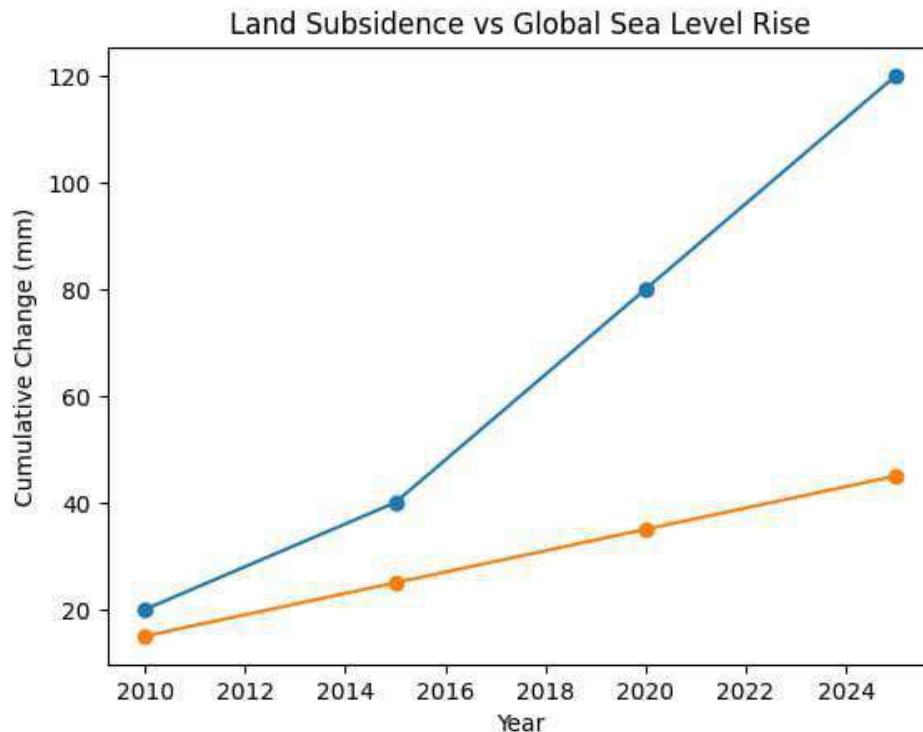
Introduction

Agriculture is the backbone of food security and rural livelihoods, yet it is the sector most vulnerable to water scarcity. In recent years, uncontrolled groundwater extraction for irrigation has led to declining water tables and sinking agricultural lands in many regions. The declaration of “Global Water Bankruptcy” serves as a warning that current water use patterns are unsustainable. For farmers, this crisis translates into dry borewells, reduced crop yields, and increased production costs. Understanding the causes and consequences of this crisis is essential for developing long-term solutions that protect both agriculture and water resources.

Contents

Groundwater acts as a hidden lifeline for agriculture, particularly during dry seasons and droughts. However, excessive pumping for irrigation has caused groundwater levels to fall rapidly. In many farming regions, wells that once supplied water at shallow depths now require deep drilling, increasing financial burden on farmers and accelerating resource depletion.

One of the most serious consequences of groundwater overuse is land subsidence



The figure highlights that land subsidence caused by groundwater over-extraction poses a more immediate threat to agricultural land stability than gradual global sea level rise.”

As water is removed from underground layers, the soil collapses, causing the land to sink. This process damages canals, farm roads, and irrigation structures, reducing the efficiency of water delivery to fields. Subsidence also permanently reduces the soil’s capacity to store water, making agriculture increasingly dependent on uncertain rainfall.

Crop selection plays a critical role in water stress. Water-intensive crops grown in water-scarce regions place enormous pressure on groundwater reserves. Shifting towards climate-resilient and less water-demanding crops can significantly reduce irrigation needs. Traditional farming knowledge combined with modern agronomic practices can help farmers adapt to changing water availability.

Efficient irrigation techniques such as drip and sprinkler systems offer practical solutions to reduce water wastage. These methods deliver water directly to the root zone, improving water-use efficiency and crop productivity. Rainwater harvesting, farm ponds, and groundwater recharge structures can further support sustainable water management at the farm level.

Emerging technologies such as artificial intelligence and satellite-based monitoring systems are increasingly being used in agriculture. AI-driven tools can help farmers schedule irrigation based on soil moisture, crop stage, and weather forecasts. Such technologies enable informed decision-making, reduce water losses, and improve long-term sustainability.

Conclusion

The sinking of agricultural lands and depletion of groundwater are clear indicators that current water use practices are unsustainable. Farmers stand at the frontline of this crisis, but they are also key to its solution. By adopting efficient irrigation systems, selecting suitable crops, and integrating modern technologies with traditional practices, agriculture can move towards water sustainability. Protecting groundwater today ensures food security, farmer livelihoods, and ecological balance for future generations.

Acknowledgement

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SPACE BREEDING AND SPACEFLIGHT MUTATIONS

Article ID: AG-VO6-I01-107**Bangaremma S. Wadeyar**

All India Coordinated Research Project (AICRP) on Pearl Millet, Regional Agricultural Research Station (RARS), Vijayapura, UAS, Dharwad, Karnataka, India

Introduction

Space Breeding is a cutting-edge science that combines astronautics with agricultural sciences aiming to grow plants in space (Space Farming) and use the variations of plants (seeds) induced in the space environment to choose new crop varieties on the ground (Space flight mutations).

Space farming refers to the cultivation of crops for food and other materials in space (space stations) or on off-Earth celestial objects like moon or other planets. Plants will play a critical role in the survival of human beings in space and on long-duration space missions, probably beginning pretty soon with a mission to Mars. NASA has built ADVASC (ADVancedASTroCulture) and VEGGIE (Vegetable Production System) plant growth chamber for space microgravity, with extensive monitoring and controlled environment facilities including temperature, relative humidity, lighting, fluid nutrient, water delivery, CO₂ and ethylene concentrations. These growth chambers provide a pick-and-eat diet of salad crops for the crew in space. (Massa *et al.*, 2016).

Plants in space provide numerous benefits to the humans. They improve the quality of indoor (space station) air by helping control humidity levels, by removing and converting the carbon dioxide from air into essential oxygen that humans can breathe. It is also axiomatic that plants can be consumed as food, providing a nutritive value to organisms throughout the food chain. Growing plants in space may also provide psychological and neurocognitive benefits to the human spaceflight crews, in the form of therapeutic people-plant interactions. (Stankovic, 2018)

The space flight mutation technique, is a crop breeding technique which uses the good variations of plants (seeds) induced in the space environment that can be reached by the recoverable spacecraft (such as recoverable satellites and space shuttles) and high-altitude balloon to choose new germplasms and new materials on the ground, then to develop new crop varieties.

The main characteristics of the aerospace environment that is far away from the earth are strong cosmic radiation, microgravity, weak geomagnetic field and super vacuum. Many morphological and physiological changes are reported in plants due to space flight, manifested as cellular and phenotypic abnormalities. These include chromosomal breakage, failure to produce seed, altered or nonviable embryos, alterations in cell wall composition and properties, increased breakdown of xyloglucans, changes in polar auxin transport and other morphological abnormalities. (Liu *et al*, 2008)

Xionget *al.* (2017) reported a spaceflight induced salt tolerant wheat mutant, named *salinity tolerance 1 (st1)*, they characterised transcriptomic sequence variation induced by spaceflight, and showed that mutations in genes associated with sodium ion transport may directly contribute to salinity tolerance in *st1*. Additionally, key genes for salinity tolerance, such as genes encoding arginine decarboxylase, polyamine oxidase, hormones-related, were not only salt induced in *st1* but also showed higher expression in salt-treated *st1* compared with salt-treated WT (wild type), indicating that these genes play important roles in salinity tolerance in *st1*.

Li *et al.* (2020) reported two dwarf mutants *short internode length1 (sil1)* and *short internode length2 (sil2)* obtained from two of 398 space flighted seeds of inbred line 18-599. A *Ty1-copia* LTR-retrotransposon, termed *ZmRE-1*, inserted in the fifth exon of *Brachytic2 (Br2)* was identified in *sil1* and *sil2* at exactly the same site, which indicated the transposition of *ZmRE-1* probably correlated with the spaceflight. This new dwarf mutant allele was named as *br2-sil* in this study, *br2-sil* reduced plant and ear height effectively in *Br2/br2-sil* genotype without negative effects on grain yield.

Zhou *et al.* (2020) reported that the fibre quality of upland cotton (*Gossypium hirsutum* L.) line Tai 8033, was improved by pedigree selection. Stable high-yield and high-quality lines obtained by space mutation were tested and compared with the control cultivar 'Sikang 1'. Eight space mutated lines fit the Chinese standard of high-quality cotton class I, were suitable for

spinning more than 40 Ne and had yields that were 12.7 per cent, 7.1 per cent and 3.5 per cent higher than the current control cultivar yield in the cotton cultivation area tested in Jiangsu Province, the fibre quality of one of the lines was very high with nepiness value of 80Ne which is a high quality yarn standard fibre.

Space agriculture is no longer a dream because it is a reality now in countries like China. Space agriculture, spearheaded by space breeding, that provides a brand-new perspective in trying to resolve food problem. Space-induced mutation technique is an effectively new way not only to develop new crop variety, but also possible to obtain rare mutants that may make a great breakthrough in important economic characters of crop, such as yield and quality, which are difficult to get using the other breeding methods on ground.

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SPEED BREEDING A POWERFUL TOOL TO ACCELERATE CROP IMPROVEMENT: RECENT ADVANCES, PERSPECTIVES AND PROTOCOLS

Article ID: AG-VO6-I01-108***Bangaremma S. Wadeyar¹**

All India Coordinated Research Project (AICRP) on Pearl Millet, Regional Agricultural Research Station (RARS), Vijayapura, UAS, Dharwad, Karnataka, India

Introduction

The growing human population and a changing environment have raised significant concern for global food security. With the current improvement rate of several important crops, it is inadequate to meet future demand. This slow improvement rate is attributed partly to the long generation times of crop plants. Methods like shuttle breeding, exerting physiological stress to trigger flowering and embryo rescue technique along with use of PGRs have found to reduce the generation times in wheat (Ortiz *et al.*, 2007), rice (Collard *et al.*, 2017) and lentil (Mobini *et al.*, 2015) respectively. These methods are labour intensive, especially with large populations, laboratory facilities are required and if species-specific protocol is not available, extensive testing would be needed to optimize these applications.

‘Speed breeding’- A technique which involves extending photoperiod and controlled growing conditions such as temperature, soil media, spacing etc. in glasshouses, enabling rapid generation advancement by shortening the breeding cycle is found to be a promising approach to increase genetic gain.

Speed breeding in fully enclosed, controlled-environment growth chambers can accelerate plant development for research purposes, including phenotyping of adult plant traits, mutant studies and transformation. The use of supplemental lighting in a glasshouse environment allows rapid generation cycling through single seed descent (SSD) and potential for adaptation to larger-scale crop improvement programmes and cost saving through light-emitting diode (LED) supplemental lighting can also be used.

Watson *et al.* (2018) reported a method called ‘speed breeding’, which greatly shortens generation time and accelerates breeding and research programmes. Speed breeding was used to achieve up to six generations per year for spring wheat (*Triticum aestivum*), durum wheat (*T. durum*), barley, chickpea and pea and four generations for canola (*Brassica napus*), instead of 2–3 under normal glasshouse conditions.

Glasshouse and growth chamber-based speed breeding approaches with supporting data from experimentation with several crops were revealed by Ghosh *et al.* (2018). They described the conditions that promote the rapid growth of bread wheat, durum wheat, barley, oat, various *Brassica* species, chickpea, pea, grass pea, quinoa and *Brachypodium distachyon*. Points of flexibility within the protocols were highlighted, including how plant density can be increased to efficiently scale up plant numbers for SSD and also provided on how to perform Speed Breeding on a small scale in a bench top growth cabinet, enabling optimization of parameters at a low cost.

Speed breeding protocol based on LEDs that allow to modify light quality, and exemplarily demonstrate its effectiveness for the shortday crops i.e., soybean, rice and amaranth. Adjusting the photoperiod to 10 h and using a blue-light enriched, far-red-deprived light spectrum facilitated the growth of short and sturdy soybean plants that flowered ~23 days after sowing and matured within 77 days, thus allowing up to five generations per year (Jahne *et al.*, 2020).

Agriculture is facing steep challenges of food, nutritional and water security, climate instability, nutrient depletion, high input costs and reduction in cultivable land. Plant breeders need to constantly develop new sustainable varieties with high yields, better quality, high resource-use efficiency, pest/disease resistance and tolerance to abiotic stresses. By integrating speed breeding with other modern crop breeding technologies such as high-throughput phenotyping and genotyping, genome editing, genomic selection and marker-assisted selection it enable plant breeders to develop a new varieties for the same.

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SUGARCANE TISSUE CULTURE: A TOOL FOR RAPID MULTIPLICATION OF QUALITY PLANTING MATERIAL

Article ID: AG-VO6-I01-109***Sai Divya G and Rakesh G**

Research Associate, RS & RRS, Rudrur, PJTAU, Telangana State, India

Scientist, Dept. of Plant Breeding, RS & RRS, Rudrur, PJTAU, Telangana, India

***Corresponding Author: Sai Divya G**

Introduction

Sugarcane (*Saccharum spp.*) is the primary global source of raw material for sugar production. Although sugarcane is cultivated in many countries, nearly 65% of the world's total sugarcane production is contributed by only six major producing nations with Brazil being the largest producer (FAO, 2022). In recent years, tissue culture has emerged as a key biotechnological approach for producing large quantities of high-quality sugarcane planting material ensuring genetic uniformity, freedom from diseases and rapid multiplication of elite varieties (Lakshmanan *et al.*, 2005).

Plant tissue culture refers to in-vitro cultivation of plant cells, tissues or organs under aseptic conditions on a nutrient medium containing a carbon source, minerals, vitamins, growth factors and plant growth regulators such as auxins and cytokinins (Murashige and Skoog, 1962; George *et al.*, 2008). This technology plays a significant role in accelerating conventional breeding and vegetative propagation especially in crops like sugarcane where traditional seed multiplication is slow and laborious (Thorpe, 2007).

Micropropagation is the true-to-type clonal multiplication of selected genotypes using tissue culture techniques (Debergh and Read, 1991). In sugarcane, micropropagation is primarily achieved through stimulation of axillary bud proliferation by culturing apical or lateral shoot meristems (Lorenzo *et al.*, 2001). This method enables rapid production of genetically uniform, disease-free plantlets on a large scale (Cheema and Hussain, 2004).

The concept of meristem culture also referred to as mericlone was first demonstrated by Morel (1960). Plants regenerated through this method known as mericlones, are genetically identical to the parent plant. Meristem explants consist of the apical dome with or without a few leaf primordia (Morel and Martin, 1955). The apical meristem is generally free from systemic viral infections due to its rapid cell division which outpaces viral replication, thereby enabling the production of virus-free planting material (Cassells and Long, 1982; Panattoni *et al.*, 2013).

Modern sugarcane varieties are developed through a multistage selection process extending over 8-10 years and only limited seed cane is available at the time of varietal release (Sundara, 2000). Conventional seed cane multiplication follows a three-tier system involving hot water or aerated steam therapy, fungicidal treatment of setts and multiplication through primary, foundation and commercial seed nurseries (Anonymous, 2014). However, repeated multiplication under field conditions often leads to early varietal degeneration due to systemic viral diseases such as Grassy Shoot Disease (GSD) and Ratoon Stunting Disease (RSD), which are seed-borne and lack effective curative measures (Viswanathan and Rao, 2011).

Since viral infections cannot be eliminated once established in plants, the use of virus-free planting material is the only effective strategy for preventing yield losses (Rao *et al.*, 2004). In this context, micropropagation has become the most reliable approach for rapid multiplication of healthy seed cane, ensuring full expression of varietal yield potential (Lakshmanan *et al.*, 2005). A single shoot apex can theoretically produce up to 1,80,000 plantlets within one year, sufficient to cover nearly 14 hectares of nursery area (Talaja, 2001). The micropropagation process consists of four major stages: establishment of shoot cultures, shoot multiplication, rooting and hardening and field transplantation.

Stage 1: Establishment of Shoot Cultures

Actively growing shoots are collected from healthy, field-grown sugarcane plants aged 3-4 months (Cheema and Hussain, 2004). Outer leaf sheaths are removed by wiping with rectified spirit to minimize surface contamination (George *et al.*, 2008). Shoot tops containing actively growing apical meristems are excised to a length of 7-8 cm along with a few leaf whorls (Lorenzo *et al.*, 2001).

The explants are initially washed in a mild detergent solution for about five minutes followed by thorough rinsing with water to remove debris and microbial contaminants (Thorpe, 2007). Surface sterilization is achieved by treating the explants with 70% ethyl alcohol for one

minute followed by repeated rinsing with sterile distilled water (Murashige and Skoog, 1962; Cassells, 1991). The explants are then treated with a sodium hypochlorite solution and agitated for effective sterilization before inoculation (George *et al.*, 2008; Panattoni *et al.*, 2013).

Under aseptic conditions in a laminar airflow cabinet, the apical dome along with two leaf primordia is excised and placed on shoot apex culture medium (Murashige and Skoog, 1962; Lakshmanan *et al.*, 2005). Cultures are incubated at 26 ± 1 °C under a 16-hour photoperiod with a light intensity of about 2500 lux, conditions optimal for meristem survival and growth (Lorenzo *et al.*, 2001).

Stage 2: Multiplication of Shoots

After 45-60 days of initial establishment, regenerated shoot apices are transferred to a shoot multiplication medium containing suitable cytokinins to promote axillary bud proliferation (Cheema and Hussain, 2004; George *et al.*, 2008). Within 40-45 days, multiple shoots develop from the axillary regions of primary shoots, indicating successful multiplication (Lorenzo *et al.*, 2001). These shoots are separated into small clumps and repeatedly subcultured onto fresh multiplication medium to achieve rapid and sustained shoot proliferation (Lakshmanan *et al.*, 2005).

Stage 3: Rooting and Hardening

Well-developed shoots are transferred to a rooting medium supplemented with appropriate auxins to induce root formation (Murashige and Skoog, 1962; George *et al.*, 2008). Groups of four to five shoots are maintained per culture vessel to ensure uniform root development (Cheema and Hussain, 2004). Root initiation generally occurs within 15-30 days, resulting in healthy plantlets with well-developed root systems (Lakshmanan *et al.*, 2005). Rooted plantlets are removed from culture vessels and transferred to polybags for acclimatization. Hardening is carried out using a potting mixture of sieved sand, silt, and organic matter in a 1:1:1 ratio to facilitate gradual adaptation to ex-vitro conditions (Rao *et al.*, 2004). This step is crucial for ensuring high survival under field conditions.

Stage 4: Field Planting

After 45-60 days of hardening, plantlets are transplanted to the field during normal planting season (Lakshmanan *et al.*, 2005). Tissue culture-raised plants exhibit a field survival rate of 85-90% under proper management practices (Lorenzo *et al.*, 2001). A spacing of 45 cm between plants and 90 cm between rows is recommended to ensure optimal growth and ease of

intercultural operations (Sundara, 2000; Anonymous, 2014). The transplanted canes reach harvest maturity within 8-10 months and are suitable for seed multiplication purposes.

Advantages of micropropagation

- Enables very rapid multiplication, allowing quick and large-scale spread of newly released sugarcane varieties.
- Produces uniform, true-to-type planting material with consistent growth and development.
- Ensures disease and pest-free seed cane, preventing the spread of systemic infections through planting material.
- Restores varietal vigour to its original level, leading to improved cane yield and quality.
- Allows better control over seed production and varietal scheduling under regulated conditions.
- Improves ratoon performance due to the use of healthy and high-quality planting material.
- Facilitates replacement of old, degenerated varieties, contributing to higher productivity and sustainability.

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RICE SPECIES AND FLORAL DIVERSITY

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^{*1}S. Saravanan, ²K. Gowtham and ³KaviyaSri¹Rice Research Station, TNAU, Ambasamudram, ²PhD Scholar, CPBG, TNAU, Coimbatore³PG Scholar, DG&PB, VOC AC & RI, Killikulam, Tamil Nadu, India

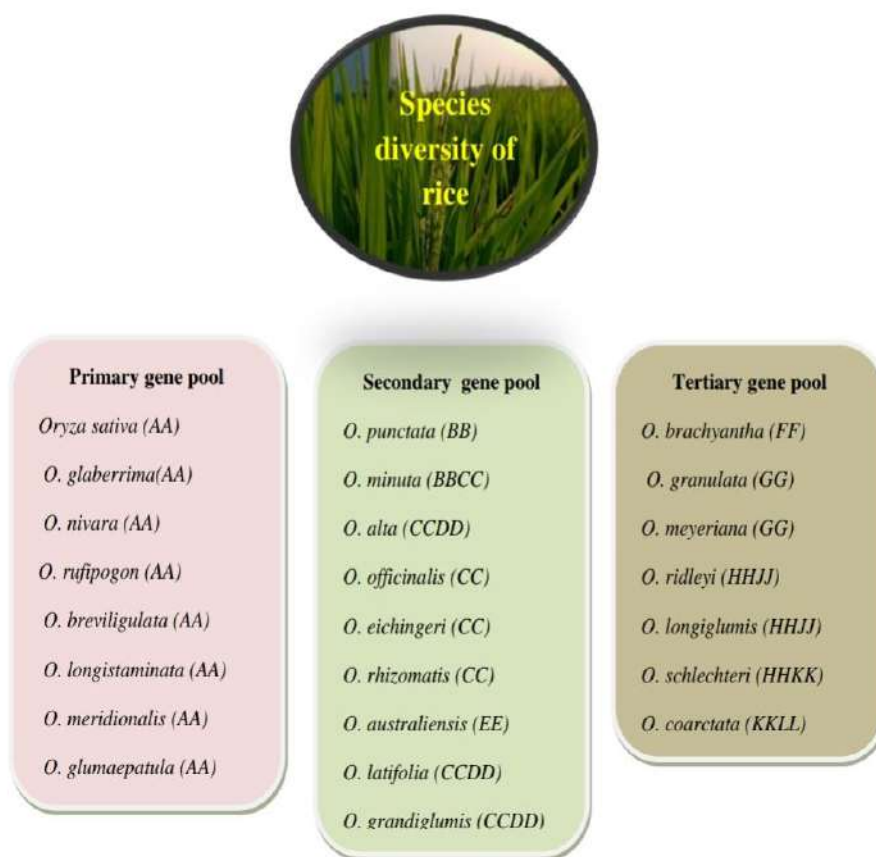
*Corresponding Author: S. Saravanan

Introduction

Cultivated rice has been affiliated to the genus *Oryza* under sub tribe *Oryzinae*. Twenty four species have been grouped under this genus categorizing 22 as wild and two viz., *Oryza sativa* and *Oryza glaberrima* as cultivated. Rice varieties from Asia, Europe and America belong to high yielding *Oryza sativa* while many of the cultivated varieties in Africa belong to low yielding *Oryza glaberrima*. Rice wild species are grouped under four complexes namely the *sativa* complex with eight species, the largest *officinalis* complex with 10 species, the *ridleyanae* complex and *granulata* complex each with two species and yet other two species remain unclassified. In spite of continuous crop domestication, genetic crossing, uncontrolled genetic assortment involving traditional and classical crop breeding techniques, rice varieties have been developed from its wild progenitors (Vaughan *et al.*, 2003).

The Asiatic rice, *Oryza sativa* is believed to be secondary balanced allotetraploid. Reports tinted six diploid ($2n = 2x = 24$) genome types (AA, BB, CC, EE, FF, and GG) have been allocated to fifteen of 22 wild *Oryza* species, while rest of seven species by three (BBCC, HHJJ, CCDD) tetraploid species types ($2n = 4x = 48$) (Solis *et al.*, 2020). These categorizations are done based on cytogenetic assessments, jumping genes effect (Kanazawa *et al.*, 2000), rDNA spacers (Cordesse *et al.*, 1992), genomic DNA hybridization (Aggarwal *et al.*, 1997) and inter-allelic assessments of two *Adh* genes (Ge *et al.*, 1999). The cultivated species of rice have been classified as *indica*, *japonica* and *javanica* in view of their ecological and morphological adaptation.

Advent to genotypic diverseness, the genus *Oryza* is categorized into three gene pools *vide* the primary gene pool includes *Oryza sativa* (AA), *Oryza glaberrima*, *Oryza nivara*, *Oryza meridionalis*, *Oryza breviligulata*, *Oryza rufipogon*, and *Oryza glumaepatula*; the secondary gene pool consisted of *Oryza punctata* (BB), *Oryza minuta* (BBCC), *Oryza alta* (CCDD), *Oryza officinalis* (CC), *Oryza eichingeri* (CC) , *Oryza rhizomatis* (CC), *Oryza australiensis* (EE), *Oryza latifolia* (CCDD) and *Oryza grandiglumis* (CCDD); while the tertiary gene pool include *Oryza brachyantha* (FF), *Oryza granulata* (GG), *Oryza meyeriana* (GG), *Oryza ridleyi* (HHJJ), *Oryza longiglumis* (HHJJ), *Oryza schlechteri* (HHKK) and *Oryza coarctata* (KKLL) (Solis *et al.*, 2020).



Intuition into the features of florets that regulate the consistency of autogamy in rice may aid rice breeders to improve the tolerance of florets to temperature stresses. High temperatures during anthesis could cause shrinkage in cell elements of pollen grains (Ramakrishnan *et al.*, 2005), but low temperature at the booting stage impede pollen growth (Shimazaki *et al.*, 1964). Hence, temperature with more than 35 °C but low than 20 °C temperature may lead poor

pollination resulting significant yield loss. The molecular mechanism of rice inflorescence has been extensively studied by Chun *et al.* (2022).

Species diversity of Rice (Solis *et al.*, 2020)

Larger and branched inflorescence with greater number of spikelets may result of delayed conversion. *Arabidopsis* model had shown numerous genes linked to meristem conversion and reported as *LEAFY (LFY)*, *APETALA1 (AP1)* and *CAULIFLOWER (CAL)*. These are used to acquire unique floret structure that discern into flower organs (Pelayo *et al.*, 2023). The expression of gene *OSH1* heralds organ disparity extending till organs formation (Serrano-Mislata *et al.*, 2017). Gene '*FZP*' facilitates the transition from branch meristem to shoot meristem and its expression signifies the terminal acquisition of the meristem. Also, *IPA1*, or *WFP/OsSPL14*, is a key regulator of rice yield that impacts identity conversion and meristem activity (Chun *et al.*, 2022).

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THE ROLE OF THE RUDDER SYSTEM IN SAFETY AND EFFICIENT FISHING VESSEL NAVIGATION

Article ID: AG-VO6-I01-111***G. Vamsi kalyan¹, Durai .V², Ganesh patil¹, Jeleena .J¹**

¹PG Scholor, Department of Fishing Technology and Fisheries Engineering,
Fisheries College and Research Institute, Thoothukudi

²Assistant Professor, Dr. MGR. Fisheries College and Research Institute,
Thalainayeru, Nagapattinam, Tamil Nadu, India

*Corresponding Author: G. Vamsi kalyan

Abstract

The rudder is a fundamental component of marine vessels, providing directional control through hydrodynamic forces. In fishing vessels, which often operate at low speeds, in confined waters, and under variable loading conditions, the rudder plays an amplified role in ensuring safe and efficient operations. This article reviews scholarly literature on rudder design and performance specific to fishing vessels, highlighting its contributions to maneuverability, stability, propulsive efficiency, and overall safety. Key findings indicate that optimized rudder geometries, such as airfoil sections (e.g., NACA series), appropriate area ratios (~5.5%), wake-adapted features (twisted or Costa bulb rudders), and flap configurations, significantly improve turning performance, reduce tactical diameters, enhance roll stabilization, mitigate cavitation, and lower fuel consumption by up to 12%. Advanced topics including shallow water effects, propeller-rudder interactions, intelligent control systems, materials durability, real-world validation via AIS data, and environmental sustainability are also addressed. Advanced designs offer substantial benefits for specialized operations like purse seining and trawling, supporting both new builds and retrofits.

Keywords: fishing vessel, rudder design, manoeuvrability, energy efficiency and hydrodynamic performance

Introduction

The rudder serves as the primary steering mechanism in most marine vessels, generating lateral forces by deflecting propeller-induced water flow to alter the vessel's heading. While essential for all ships, its importance is particularly pronounced in fishing vessels due to their unique operational profiles: frequent low-speed maneuvering in harbors, precise positioning during gear deployment and retrieval, navigation in rough seas, and maintenance of course stability under asymmetric loads from caught fish or towed nets.

Poor rudder performance can lead to increased fuel consumption, higher accident risk, and reduced operational effectiveness. Scholarly research has focused on optimizing rudder parameters—such as profile shape, aspect ratio, area ratio, and integration with propeller flow—to address these challenges. This review synthesizes findings from hydrodynamic studies, CFD simulations, and experimental methods to underscore the rudder's critical role in fishing vessel performance, covering enhancements in manoeuvrability, stability, efficiency, cavitation mitigation, shallow water operations, intelligent controls, and sustainability.

Manoeuvrability Enhancement

Fishing vessels require exceptional low-speed manoeuvrability for tasks such as pursuing fish schools (e.g., in purse seining), avoiding obstacles, and docking in crowded ports. Rudder design directly influences turning circle diameter, tactical diameter, and yaw response.

Computational fluid dynamics (CFD) studies on small fishing vessels have shown that air foil-section rudders (e.g., NACA series) outperform traditional flat-plate rudders by generating higher lateral forces. Among NACA profiles, thinner sections like NACA 0012 or NACA 0015 provide superior turning performance. Rudder area relative to the vessel's immersed lateral area (AR/A) is a key parameter: an optimal ratio of approximately 5.5% yields the best results, reducing tactical diameter by up to 16.78% compared to lower ratios, while meeting International Maritime Organization (IMO) standards for turning and zig-zag manoeuvres.

For larger fishing vessels like tuna purse seiners, high-performance flap rudders with NACA 0030 profiles and optimized aspect ratios ($\lambda \approx 2$) enable tighter turns (diameter < 4.5 –5 ship lengths), improved yaw checking ability (Norrbin number > 0.275), and reduced stall angles, critical for rapid pursuits and net operations. These designs minimize hysteresis in lift curves, enhancing course stability during high-speed chasing.

Shallow Water Effects on Rudder Performance and Manoeuvrability

Many fishing vessels, especially trawlers and small coastal boats, frequently navigate shallow or restricted waters where hydrodynamic interactions with the seabed significantly alter rudder effectiveness. Shallow water increases squat, reduces under-keel clearance, and induces bank suction effects, leading to degraded turning ability and yaw response.

Computational fluid dynamics (CFD) studies have quantified these impacts on fishing trawlers, predicting larger tactical diameters (up to 20–30% increase) and slower yaw rates in water depths less than 1.5 times the draft compared to deep water. Optimized rudder designs—incorporating higher aspect ratios or flap configurations—can partially mitigate these effects by generating sufficient lift at lower speeds. These findings underscore the importance of shallow-water-specific testing in rudder optimization to ensure compliance with IMO manoeuvrability standards and safe operations near coasts or in harbours.

Stability Enhancement and Rudder Roll Stabilization

Fishing vessels are particularly susceptible to roll motions in beam seas and rough weather, due to wave action, off-centre loads from caught fish or towed gear, and their operational profiles. Excessive rolling endangers crew safety, damages equipment, and disrupts fishing operations such as trawling or purse seining.

Traditional “barn door” rudders—large, flat-plate designs commonly found in fishing fleets—provide robust low-speed stability and control in heavy weather through their simplicity and high lift at large angles. However, for more effective roll mitigation, especially at low speeds where passive stabilizers like bilge keels are limited, active rudder roll stabilization (RRS) systems offer significant advantages. These systems leverage the existing rudder to generate counteracting forces by coordinating steering inputs with wave-induced roll motions, without requiring additional appendages.

Alarçin and Gülez (2007) pioneered neural network-based control for RRS in fishing vessels, demonstrating through simulations substantial roll reduction—up to 60–70% in moderate sea states—compared to conventional autopilots. The neural controller adapts in real time to nonlinear hydrodynamic effects and variable loading conditions typical of fishing operations, while minimizing interference with course-keeping. Later studies have extended this approach with fuzzy logic, gain-scheduling PID, or other intelligent methods for greater

robustness. These retrofit table smart control systems enable upgrades for older vessels, enhancing safety and operational continuity during gear handling in adverse conditions.

Propulsive Efficiency and Rudder-Propeller Interaction

The efficiency and effectiveness of a rudder in fishing vessels are significantly influenced by its interaction with the propeller wake. Operating directly behind the propeller, the rudder benefits from accelerated and rotated flow, which increases lift generation at low speeds—a critical advantage during precise manoeuvring for net deployment or fish pursuit. However, mismatched designs can lead to energy losses, increased cavitation, vibration, and higher drag. Fuel costs represent a significant operational expense for fishing vessels. Rudder modifications can recover energy from the propeller wake, reducing drag and power requirements. Wake-adapted geometries, such as twisted leading-edge or Costa bulb rudders, align with the non-uniform propeller inflow, yielding notable efficiency gains.

Recent studies emphasize multidisciplinary optimization of propeller-rudder systems, incorporating features such as rudder bulbs (e.g., Costa-type) or twist adaptations to recover rotational energy from the slipstream and improve inflow uniformity. These modifications enhance propulsive efficiency—achieving power savings of up to 12% in some configurations—while also reducing vibration and cavitation risk, thereby extending component lifespan in demanding fishing operations. Integrated propeller-hub and rudder optimizations offer cost-effective, retrofit table upgrades for existing fleets, with tailored CFD analysis ensuring compatibility. Such integrated design approaches, which consider hull appendage interactions, are increasingly recommended for both new builds and retrofits.

Materials Selection and Durability

Fishing vessels operate in harsh marine environments characterized by saltwater corrosion, biofouling, mechanical impacts from fishing gear, and occasional grounding risks. Rudder material selection and construction therefore play a vital role in ensuring long-term reliability and minimizing maintenance downtime.

Common choices include nickel-aluminium bronze or stainless steel for blades due to superior corrosion and cavitation resistance, while high-strength forged carbon or duplex stainless steels are used for rudder stocks to withstand high torque and bending moments. Emerging composite materials (e.g., carbon-fiber-reinforced polymers) offer weight reduction and excellent fatigue resistance, particularly suited to smaller vessels. Protective measures such

as sacrificial anodes, specialized coatings, and anti-fouling paints further extend service life. Classification society requirements (DNV, ABS, etc.) mandate detailed strength calculations and periodic inspections to prevent structural failures that could compromise vessel safety.

Integration of Real-World Data for Rudder Performance Validation

While CFD and model tests provide valuable insights, validating rudder designs against full-scale operational data ensures practical relevance. Automatic Identification System (AIS) records offer a rich source of real-world trajectories for analysing manoeuvrability under actual conditions, including variable loads and sea states. Asmara et al. (2018) combined mathematical manoeuvring models, simulations, and AIS data from small Indonesian coastal fishing vessels (3 GT class) to assess operability, revealing that simulated turning circles often underestimate real-world performance due to unmodelled factors like wind, currents, and asymmetric loading from nets. This hybrid approach identified rudder deficiencies in course stability and stopping ability, recommending enlarged rudder areas or twist adaptations for improved low-speed control. Similar methodologies, extended to larger fleets, enable data-driven refinements that bridge the gap between theoretical predictions and operational reality, supporting cost-effective retrofits.



Rudder with propeller

Design Considerations Specific to Fishing Vessels

Rudder design for fishing vessels must balance hydrodynamic performance with practical constraints like stern shape, propeller clearance, and cavitation risk.

Key recommendations includes:

- Preferring air foil profiles (e.g., NACA 00-series) over flat plates for higher lift-to-drag ratios.
- Selecting area ratios around 5.5% for small vessels and larger balanced/flap configurations for specialized types.

- Incorporating flow-straightening features (e.g., twisted blades) to minimize cavitation and vibration.
- Compliance with classification society and regulatory rules (e.g., DNV, IMO) ensures structural integrity under torque and bending moments.

Environmental and Sustainability Aspects

As the fishing industry faces growing pressure to reduce environmental impact, rudder optimization contributes meaningfully to sustainability goals. Fuel-efficient rudder designs lower overall propulsion power requirements, directly reducing CO₂ emissions and operational carbon footprint amid rising regulatory demands for greener fleets. Additionally, wake-adapted and flow-aligned rudders can decrease underwater radiated noise by minimizing cavitation and turbulence, reducing disturbance to marine ecosystems and fish behaviour—an important consideration for sustainable catch practices. Retrofit table energy-saving appendages also support the transition toward lower-emission operations without requiring full vessel replacement. Prioritizing environmentally conscious rudder designs aligns technical performance improvements with broader goals of ecological responsibility and long-term viability of fishing operations.

Emerging Technologies and Future Trends

Ongoing advancements in rudder technology promise further gains for fishing vessels. Active control systems, including integrated rudder roll stabilization with modern autopilots and dynamic positioning, are gaining traction for enhanced safety and precision in rough seas and confined waters. Hybrid and electric propulsion integration opens opportunities for electrically actuated high-lift rudders with rapid response. Artificial intelligence and machine-learning approaches are being explored for adaptive rudder control that optimizes angle in real time based on sea state, load, and operational mode. Composite materials and additive manufacturing may enable more complex, customized geometries at lower cost. As fuel costs and environmental regulations intensify, these innovations—supported by continued CFD validation and full-scale trials—will drive the next generation of rudder systems tailored to the unique demands of sustainable commercial fishing.

Conclusion

The rudder is indispensable for the safe and efficient operation of fishing vessels, far beyond basic steering. Optimized designs enhance manoeuvrability for precise fishing tasks

(e.g., purse seining and trawling), improve stability and roll reduction in adverse conditions, contribute to propulsive efficiency and fuel savings amid rising operational costs, mitigate cavitation and shallow water effects, and support environmental sustainability through reduced emissions and noise. Ongoing research using CFD, experimental methods, real-world data validation, and emerging technologies (e.g., intelligent controls, composite materials, and adaptive systems) continues to refine these systems, offering practical improvements for both new builds and retrofits. Vessel designers and operators should prioritize rudder optimization—balancing hydrodynamic performance with practical constraints like materials durability, propeller interaction, and regulatory compliance to achieve superior performance, safety, and long-term viability in the fishing industry.

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ADVANCES IN SOFTWARE-BASED DESIGN OF SHIPS AND FISHING GEAR MODELS

Article ID: AG-VO6-I01-112***Patil Ganesh Digambar¹, Durai. V², Jeleena J¹ and Vamsi¹**

¹PG Scholor, Department of Fishing Technology and Fisheries Engineering, Fisheries College and Research Institute, Thoothukudi

²Assistant Professor, Dr. MGR. Fisheries College and Research Institute, Thalainayeru, Nagapattinam

*Corresponding Author: Patil Ganesh Digambar

Abstract

Computer-based tools, including CAD, CFD, and specialized fishing-gear simulation software, have revolutionized fishing vessel design, gear development, and maritime operations. These technologies enable accurate 3D modeling, virtual prototyping, and real-time prediction of underwater gear behavior, such as purse seines and trawls, as well as assessments of hydrodynamic performance and gear selectivity. Their adoption offers significant advantages, including reduced design time and costs, early detection of design flaws, improved operational efficiency and fuel economy, and enhanced vessel safety and stability. In addition, simulation-based design supports bycatch reduction and promotes sustainable fishing practices. Under growing regulatory, environmental, and economic pressures, CAD and simulation-driven approaches have become essential tools for developing efficient, safe, and environmentally responsible fishing vessels and gear.

Introduction

The drawing board to the open sea software has really changed the way ships are designed and built. We used to do this work by hand in rooms called design lofts. Now we use computer tools to do the job. These tools help engineers make ships that're stronger, safer and more efficient. Ship design and construction software is very important, in the industry today. There are a lot of rules that ships have to follow. These rules are getting tougher. Ships are also getting

bigger and more complicated. Companies are trying to make a profit but it is not easy because their profit margins are very small. Ship design and construction software helps with all of these things. By improving accuracy, reducing errors, and saving both time and cost, these software tools have become indispensable in shaping the next generation of well-built ships.

Computers have quietly revolutionized fishing, turning an age-old craft into a high-tech endeavour. Traditionally, fishers relied on experience, trial and error, and physical prototypes to design and fix nets, trawls, purse seines, and other gear. Today, powerful simulation software and computational tools allow experts to spot defects, predict behaviour underwater, and invent better designs—all before a single knot is tied or a boat hits the water

Software has impacted the full spectrum of the maritime industry – design, construction and ship management. From the design side its primary benefit is to enable the ship designers to optimize ships both from the perspective of efficiency, and to optimize the weight, speed and power of the vessel as well as reliability and safety.

R. Keith Michel said that software has influenced every stage of the maritime industry, including ship design, construction, and ship management. He explained that in the design phase, computer software plays a crucial role by allowing ship designers to optimize vessels for greater efficiency. According to him, software tools help in balancing key factors such as vessel weight, speed, power requirements, reliability, and safety, making modern ships more efficient and dependable than those designed using traditional methods.

Fishing-gear Simulation Software

Recent advances in computer software and numerical simulation have made it possible to understand and monitor the complex behaviour of large fishing gears such as purse seines, which was earlier considered extremely difficult under real sea conditions. Purse seine fishing involves rapid enclosure of surface-swimming fish like sardine, mackerel, and tuna using large belt-shaped nets, and the success of this operation traditionally depends heavily on the experience of the vessel's headman. Factors such as ocean currents, wind, waves, gear geometry, mesh size, sinker weight, and hydrodynamic resistance strongly influence the sinking behaviour and shape of the net, often leading to gear distortion and reduced catch efficiency. Because direct underwater observation of such large gear systems is limited and physical model experiments are expensive and difficult to replicate accurately, computer-based numerical simulation has emerged as an effective alternative. Modern simulation software can calculate net geometry and

gear dynamics in real time by using essential operational parameters such as vessel speed, current direction, and wire length. These digital tools allow fishermen and engineers to visualize underwater gear behaviour, identify causes of fishing failure, improve operational decisions, and reduce dependence on experience alone. As a result, computer-assisted real-time simulation systems are becoming powerful platforms for improving fishing efficiency, enhancing safety, and supporting sustainable resource management in modern fisheries.

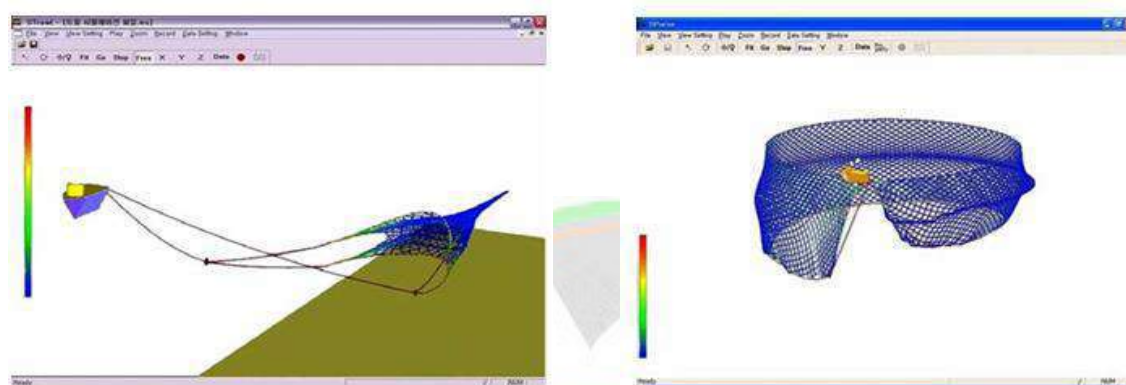


Fig. Underwater shape of the midwater trawl and purse seine gear simulated on a computer.

Source: Lee et al. (2011), Fish Aquatic Sciences. Source: Lee et al. (2011), Fish Aquatic Sciences.

Importance Of Fishing Gear Simulation Software

1. Accurate Prediction of Gear Behaviour Underwater

Fishing gear doesn't behave the same way in real oceans as it does on paper or in calm conditions. Currents, waves, boat speed, and water depth constantly deform nets, affecting their shape, opening, sinking speed, and overall performance. Simulation software creates virtual "digital twins" of gear to predict these changes precisely.

- Tools like NaLA (Net shape and Load Analysis), developed by researchers including Tsutomu Takagi and team at Hokkaido University, model the 3D shape and forces on nets in real time. They use lumped-mass models to calculate drag, tension, and deformation.
- Advanced versions integrate data assimilation (e.g., extended Kalman filters) to compare simulations with real measurements and auto-adjust parameters like mesh size or bar lengths to achieve desired shapes—even dynamically underwater.

2. Cost and Time Savings in Design and Testing

Building physical prototypes and running sea trials is expensive, time-consuming, and weather-dependent. Simulation software lets engineers test hundreds of variations virtually—before spending money on materials or risking gear damage at sea.

- For purse seines (curtain nets for encircling tuna or sardines), Japanese teams (e.g., Norio Tanada et al.) created real-time simulators that predict sinking behavior, pursing tension, and deformation under currents. This helps optimize mesh size, twine strength, and rigging for better catch efficiency and less escape.
- CFD (Computational Fluid Dynamics) analyses reveal hydrodynamic forces on net panels, otter boards (trawl doors), and ropes—leading to lower-drag, higher-spread designs that reduce fuel burn and seabed impact.

These tools cut development costs dramatically while speeding up innovation for new or improved gear.

3. Enhancing Sustainability and Selectivity

Overfishing, bycatch (unwanted species like juveniles or turtles), and habitat damage are major challenges. Simulations help design gear that targets specific fish while minimizing harm.

- By modelling mesh openings, square panels, or escape windows, software predicts selectivity—e.g., excluding small juveniles in pair trawls (as in studies by T. Endo et al.).
- Tools estimate "fished space" more accurately, improving effort calculations for stock assessments and reducing overexploitation.
- Real-time simulators train crews safely (e.g., on purse seine operations) to avoid accidents, gear loss, or bycatch incidents.

This supports eco-friendly practices, like lower seabed penetration for ground gear or designs that release protected species.

4. Better Decision-Making and Risk Reduction

Simulations provide insights into dynamic forces e.g., transverse loads on ropes, scour around structures, or net deformation in full-scale cages (relevant for aquaculture too). They help avoid failures that could lead to lost catches, damaged equipment, or safety risks.

Role of Computers in Fishing Gear Design

- **Precise Scale Drawing:** CAD software allows engineers to create precise 2D drawings and 3D models of fishing gear and its components (nets, trawl doors, lines) in a digital

environment. This replaces manual drafting, ensuring accuracy and consistency in design specifications.

- **Virtual Prototyping and Simulation:** Instead of relying solely on physical model testing in flume tanks, computer simulations (such as those using Computational Fluid Dynamics or Finite Element Analysis software like ANSYS or CATIA) can model how the scaled-down or full-size gear behaves dynamically in the water. This helps predict the gear's shape, movement, and performance under various conditions (current, depth, vessel power).
- **Defect Identification and Analysis:** Computer simulations can highlight potential design flaws or inefficiencies (defects) early in the development stage, such as excessive drag, incorrect spread of the net mouth, or issues with how different components interact. This allows for virtual adjustments and re-testing, which is faster and less expensive than building and testing multiple physical prototypes.
- **Design Optimization and Innovation:** Designers can rapidly iterate and test a large number of design variations using software, exploring different materials, mesh sizes, and configurations to optimize the gear's efficiency and selectivity (reducing bycatch). This leads to the development of innovative and sustainable fishing gear designs, such as those with Turtle Excluder Devices (TEDs) or rigid grids for size selection.

Fishing craft design Software

Design and development efforts-based fish behaviour, engineering studies, system analysis and model studies taking into consideration resource conservation, ecological and economic issues have been taking place in the recent decades. Design process for fishing gear has been greatly influenced in the recent years by the resource management and conservation, environmental safety and energy efficiency imperatives.

Computer-Aided Design (CAD) Software:

Computer-aided design (CAD) software is a vital tool in marine drafting and ship design, enabling the creation of accurate 2D and 3D digital models of vessels such as hull forms, interior layouts, and engine rooms. It improves visualization, allows easy modification of designs, and supports digital prototyping and simulations. By enhancing efficiency, precision, and safety, CAD software plays a key role in the successful design and performance optimization of modern marine engineering projects.

The Role of CAD Software in Modern Marine Drafting:

Computer-Aided Design (CAD) software plays a crucial role in modern marine drafting, offering significant benefits in terms of efficiency and precision. Marine drafting involves the creation of detailed drawings and plans for various components of a marine vessel, such as hulls, propulsion systems, navigation equipment, and more. Here are key aspects highlighting the role of CAD software in this context:

Digital Prototyping:

CAD software allows for the creation of digital prototypes of marine structures and components. Designers can create 3D models of ships, ensuring a comprehensive and accurate representation of the vessel.

Digital prototypes enable designers to visualize the entire vessel and its individual parts, facilitating better design evaluation and decision-making.

Efficient Design Iterations:

CAD software enables quick and efficient design iterations. Designers can easily modify and refine designs, test different configurations, and assess the impact of changes in real-time. This iterative design process helps in optimizing the performance, stability, and other critical aspects of marine vessels.

Precision in Measurements:

CAD tools provide precise measurement capabilities, ensuring accuracy in the drafting process. This is essential for meeting safety standards, regulatory requirements, and ensuring that components fit together seamlessly.

The ability to work with precise measurements also helps in minimizing errors and reducing the likelihood of costly rework during the construction phase.

Integration with Analysis Tools:

CAD software can be integrated with various analysis tools, such as Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD). This integration allows designers to simulate and analyze the structural integrity, stress distribution, and fluid dynamics of marine structures.

By performing virtual tests and simulations, designers can optimize the design for strength, durability, and performance without the need for physical prototypes.

Collaboration and Communication:

CAD facilitates collaboration among team members, including naval architects, engineers, and other stakeholders. Design files can be easily shared and accessed by multiple team members, leading to better communication and coordination.

The ability to collaborate in a digital environment streamlines the review and approval process, reducing the time it takes to finalize designs.

Documentation and Revision Control:

CAD software automates the creation of documentation, including drawings, specifications, and bills of materials. This helps in maintaining a comprehensive record of the design process. Revision control features ensure that changes to the design are tracked, making it easier to manage versions and ensuring that everyone is working with the latest information.

Cost and Time Savings:

The efficiency gained through the use of CAD software contributes to significant cost and time savings. Designers can complete tasks more quickly, and the ability to detect and address issues early in the design phase helps avoid costly modifications during construction.

What is a Marine drafter?

A Marine drafter, also known as a Naval Architectural drafter or Marine CAD drafter, is a professional who specializes in creating technical drawings and plans specifically for marine vessels and structures. This role involves using computer-aided design (CAD) software to produce detailed diagrams, blueprints, and specifications for various maritime projects.

marine drafting and shipping design involve a multidisciplinary approach, combining engineering principles, regulatory knowledge, and advanced technologies such as CAD software to create safe, efficient, and compliant vessels. The field continues to evolve with advancements in materials, technology, and sustainability practices.

CAD drafting services

CAD drafting services involve the creation, modification, and optimization of technical drawings and plans using computer-aided design (CAD) software. CAD drafting services are commonly used in various industries such as architecture, engineering, construction, manufacturing, and product design.

These services typically include:

- **2D Drafting:** Creating two-dimensional technical drawings such as floor plans, elevation views, site plans, and construction details.
- **3D Modeling:** Developing three-dimensional digital representations of objects, buildings, or products. This allows for a more realistic visualization and analysis of designs.
- **Rendering:** Applying textures, materials, lighting, and other visual effects to 3D models to create photorealistic images or animations.
- **Conversion:** Converting hand-drawn sketches, PDFs, or physical blueprints into digital CAD formats for easier storage, sharing, and modification.
- **Modification and Optimization:** Making changes to existing CAD drawings based on client feedback, design revisions, or regulatory requirements. Optimization involves refining designs for better functionality, efficiency, or cost-effectiveness.

Conclusion

Rapid advances in computer software have brought about a paradigm shift in the maritime and fishing industries, fundamentally transforming traditional approaches to ship design, marine drafting, and fishing gear development. Modern software tools—such as computer-aided design (CAD), simulation, and real-time modeling—have largely replaced the time-consuming processes of manual calculations, drafting, and design across maritime applications. These technologies support the development of **safer, regulation-compliant vessel designs**, while significantly reducing construction costs and shortening design and production timelines. Within the fishing industry, specialized fishing-gear simulation software has become an invaluable tool for analyzing complex underwater gear behavior, identifying design deficiencies, optimizing catch performance, and encouraging environmentally responsible fishing practices. By enabling virtual prototyping, advanced analysis, and design optimization prior to physical testing, computer software reduces operational risks, lowers development costs, and supports more informed decision-making. The role and application of computer software in ship design and fishing gear development therefore cannot be overstated, as these tools are essential to fostering innovation, sustainability, and competitiveness in the modern maritime sector.

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VERTICAL HARVEST: GROWING MORE IN LESS SPACE

Article ID: AG-VO6-I01-113**Shweta Soni* and Udham Singh**

Banda University of Agriculture and Technology, Banda (U.P.) 210001, India

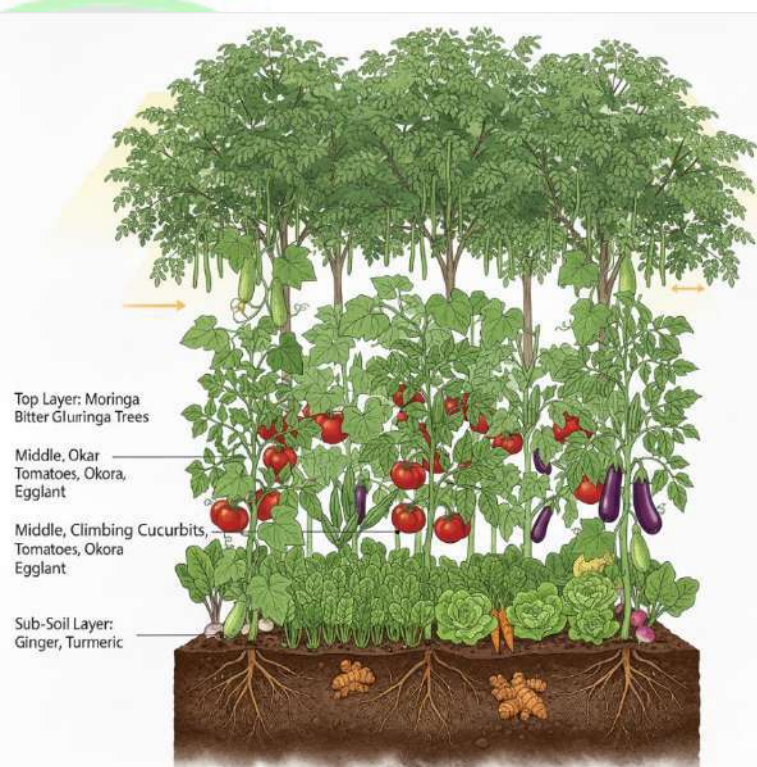
*Corresponding Author: Shweta Soni

Introduction

A farm that doesn't sprawl across acres of land but instead reaches for the sky, a verdant skyscraper brimming with fresh produce. As global populations soar and arable land diminishes, traditional farming methods are facing unprecedented challenges. Vertical farming, with its innovative use of vertical space, offers a compelling solution, promising higher yields, reduced environmental impact, and a more sustainable food future. It's a concept that moves

beyond the conventional horizontal plane, transforming agriculture into a multi-dimensional endeavor that's as efficient as it is visually striking.

At its core, vertical farming is the practice of growing crops in vertically stacked layers, often within controlled indoor environments. This can range from sophisticated, high-tech indoor farms utilizing artificial lighting and hydroponics to more natural, outdoor multi-layered systems. While the image illustrates an example of multi-layer outdoor vertical farming, the



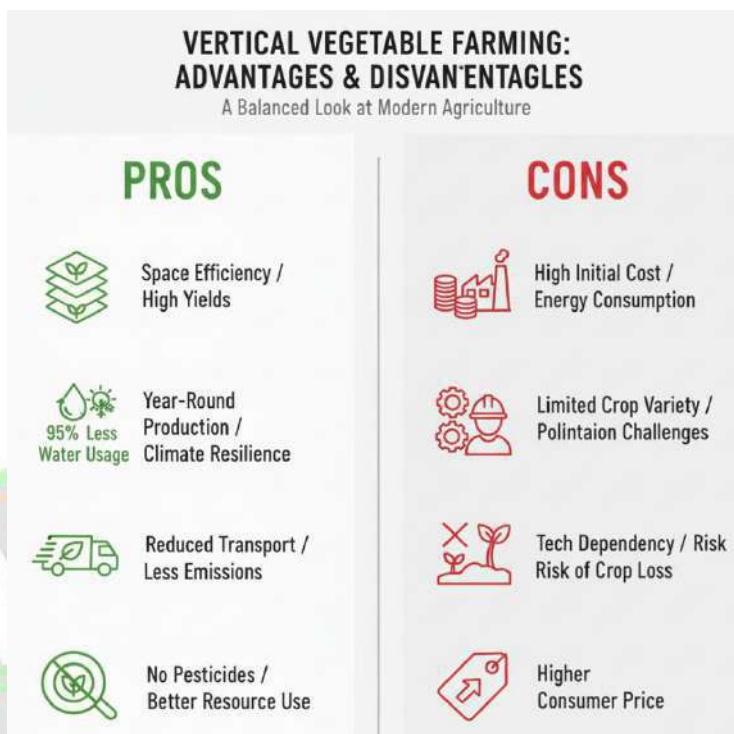
principles of maximizing vertical space and integrating compatible crops are central to the broader vertical farming movement.

Levels of green

The beauty of vertical farming lies in its ability to mimic and optimize natural ecosystems, creating distinct levels or “layers” where different plants can coexist and thrive well supporting each other.

1. **Sub-Soil Layer:** Even in a vertically oriented system, the soil remains the fundamental anchor. Crops like ginger and turmeric reside in this deepest layer. These root vegetables are perfectly suited for the sub-soil, as they primarily require fertile ground and consistent moisture rather than direct sunlight. Their presence at this level allows for efficient nutrient absorption from the deeper soil profiles and helps to anchor the entire system, contributing to soil health and aeration. This layer is crucial for the overall stability and nutrient cycling within the multi-tier system. It reminds us that even with vertical ambition, the earth beneath our feet remains vital.
2. **Ground Layer:** Above the sub-soil, we find the ground layer, home to leafy greens like spinach, lettuce, and radishes. These vegetables generally have shallower root systems and often prefer partial shade, making them ideal for the under-story of taller plants. This strategic placement not only maximizes space but also creates a microclimate that can deter pests and conserve moisture, vital for their tender leaves. This layer provides quick-growing, nutrient-dense crops, offering frequent harvests and a continuous supply of fresh greens.
3. **Middle Layer:** This layer, as depicted, is a bustling hub of productivity, featuring vegetables like tomatoes, okra, and eggplant. These plants require a good amount of sunlight but can also tolerate some dappled shade, especially during the hottest parts of the day. Their placement in the middle allows them to receive adequate light while also providing some shade to the ground layer below. The ingenious integration of climbing cucurbits (like bitter melon or other vine vegetables) in this layer, utilizing the trunks of the Moringa trees as natural trellises. This exemplifies ingenious space utilization, where a plant that would otherwise sprawl horizontally is guided vertically, increasing overall yield from the same footprint. This integration of diverse crop types in the middle layer truly maximizes the use of light, air, and structural support, leading to a highly productive zone that contributes significantly to the overall harvest.

4. **Top Layer:** The uppermost layer is dominated by Moringa trees. These remarkable trees, known for their rapid growth and exceptional nutritional value, serve multiple purposes. They utilize the maximum available sunlight, acting as the primary solar energy converters for the entire system. Crucially, their canopy provides essential shade for the layers below, protecting them from intense sun and reducing water evaporation. The image shows bitter gourd vines not just integrated into the middle layer but also extending into this top layer, trellised along the moringa canopy. This demonstrates how even within the highest tier, additional climbing vegetables can be incorporated to further enhance productivity and diversity. This top layer is not just about its own harvest; it plays a critical role in shaping the microclimate for the entire vertical system, acting as a living umbrella and a natural support structure for other climbing plants.



Applications of multi-layer farming

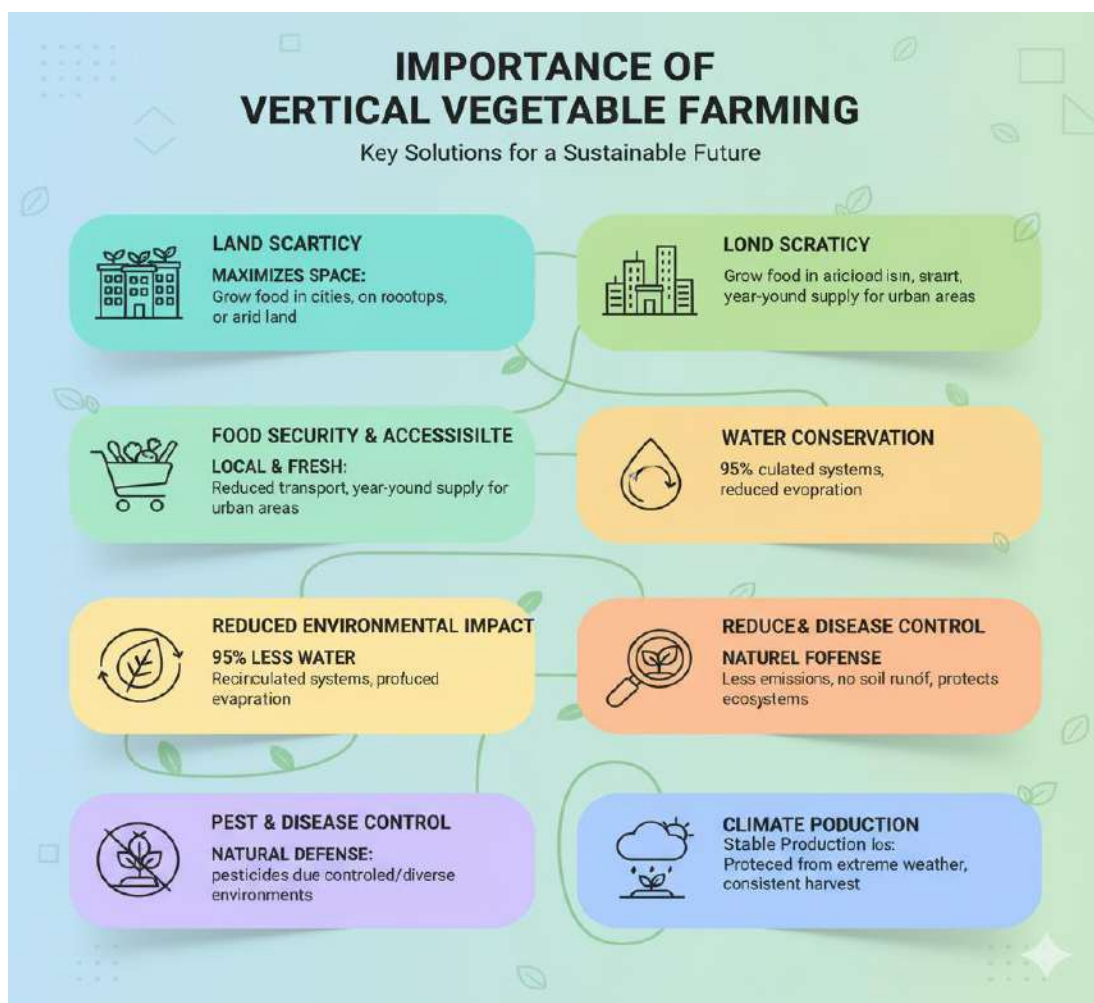
The multi-layer vegetable production system illustrated in our image, with its integrated moringa trees and diverse vegetable layers, offers a prime example of vertical farming principles applied in a more accessible, often low-tech context. Its applications are particularly relevant in specific scenarios:

Smallholder farming and homesteads:

For individuals or families with limited land, particularly in densely populated or rural areas, this type of multi-layer system can dramatically increase food production from a small plot. It allows for a diverse diet and potential surplus for local markets, enhancing livelihoods and food security.

Urban and peri-urban agriculture: In cities where space is at a premium, this model can be replicated in community gardens, backyard plots, or even along property lines. The vertical

nature minimizes footprint while maximizing yield, bringing fresh, local produce closer to urban consumers. The aesthetic appeal of such a system can also contribute to greening urban spaces.



Sustainable permaculture designs:

The system aligns perfectly with permaculture principles, which emphasize working with natural ecosystems to create self-sustaining agricultural systems. The symbiotic relationship between the different layers – where taller plants provide shade and support for climbers, and diverse root systems optimize nutrient uptake – embodies ecological intelligence.

Resource-scarce regions:

In areas with poor soil quality, limited water, or challenging climates, this multi-layered approach can be adapted. For instance, in sunny tropical regions, the shading provided by taller layers becomes crucial for heat-sensitive crops. The efficient use of water, even without sophisticated hydroponics, makes it suitable for regions facing water stress.

Educational and research settings:

The visual clarity of such a layered system makes it an excellent model for teaching sustainable agriculture, plant compatibility, and efficient resource management. It provides a living laboratory for understanding inter-cropping and ecological farming principles.

Food forests and agroforestry:

This model is a micro-version of a food forest, where perennial food-producing plants are arranged in multiple layers, mimicking a natural forest ecosystem. It contributes to biodiversity, soil health, and long-term sustainability within a smaller agricultural footprint.

Conclusion

Vertical vegetable farming represents a paradigm shift in how we approach agriculture, moving beyond the traditional flat expanse of fields to embrace the vertical dimension. From the high-tech, climate-controlled towers of urban centers to the ingeniously layered outdoor system, the core principle remains the same: to maximize space, optimize resources, and cultivate food more sustainably. The careful integration of moringa trees providing shade and support for climbing cucurbits, alongside middle-layer vegetables and ground-level greens, with root crops anchoring it all, is a masterclass in agricultural efficiency. This model is particularly powerful because it doesn't always require significant technological investment, making it accessible to a wider range of farmers and communities. While vertical farming, especially its indoor, high-tech iterations, faces hurdles such as high initial costs and energy consumption, its benefits are compelling. It offers a robust solution to food security, environmental sustainability, and the challenge of diminishing arable land. As technology advances and farming techniques become more refined, vertical farming is poised to play an increasingly crucial role in feeding our planet.

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BLUE-GREEN ALGAE: BOON FOR PADDY FARMING

Article ID: AG-VO6-I01-114**Pratibha Kumari¹, ReenaKumari^{2*}, Babloo Sharma³**

¹Krishi Vigyan Kendra Aurangabad (Bihar Agricultural University), Sirish Agricultural Farm,
Aurangabad, 824112, Bihar, India

² N.M. College of Agriculture, Navsari Agricultural University, Navsari 396450, Gujarat, India

³KrishiVigyan Kendra Jaisalmer-1 (Swami Keshwanand Rajasthan Agricultural University)
Jaisalmer 345001, Rajasthan, India

*Corresponding Author: ReenaKumari

Abstract

Blue-green algae (BGA), also known as cyanobacteria, are among the earliest recognized biological agents capable of fixing atmospheric nitrogen in flooded rice ecosystems. Under waterlogged conditions, BGA can contribute 20–30 kg N ha⁻¹ per season and, in some cases, up to 80 kg N ha⁻¹, thereby reducing the dependence on inorganic nitrogen fertilizers by nearly 30%. In addition to nitrogen fixation, BGA enhance soil health by increasing organic matter, improving soil structure, water-holding capacity, and microbial activity. They also aid in phosphorus solubilization, produce plant growth–promoting substances such as vitamins and phytohormones, reduce sulfide toxicity, and suppress aquatic weed growth by forming a dense surface mat. Application through broadcasting or seedling root dip methods, coupled with adequate phosphorus supply and reduced chemical nitrogen input, ensures effective establishment and performance. Overall, BGA represent a vital biofertilizer for rice-based cropping systems, supporting sustainable agriculture, environmental protection, and enhanced productivity.

Keywords: Paddy, Blue-green algae, biofertilizer, Soil health

Introduction

Blue-green algae (BGA) known as Cyanobacteria (CB) was first agents acknowledged to

fix atmospheric nitrogen in flooded paddy field. It reported that BGA provide up to 80 kg N/ha per season in the rice ecosystem, Blue Green algae plays a crucial role in improving soil fertility and crop productivity even in the absence of any added chemical fertilizers under water logged conditions of rice fields. BGA is an important biofertilizer to renovate the soil health, is a eco-friendly, cost efficient and imperishable supply of soil nutrient which play a essential role in preserving a long term sustainability and fertility of soil. The biofertilizer intact the soil fertility cost by using in the yield is assured with biofertilizer and perpetual use of biofertilizer makes the soil very fertile for improved yield.

Ecology of BGA

BGA are prokaryotic, photosynthetic microorganisms, various of which are able of nitrogen fixation. Their main photosynthetic pigments include carotenes, chlorophyll a, and xanthophylls together with phycobiliproteins, c-phycocyanin (blue) and c-phycoerythrin (red). Due to the presence of these latter pigments and mucilage, the color of BGA in nature may range from dirty yellow, through various shades of blue-green, to brown or black. Some BGA contain nitrogenase that can fix nitrogen because they, an O_2 -sensitive enzyme. This capacity was first associated to the existence of specialized non O_2 -evolving cells called heterocysts in which the enzyme is preserved from O_2 . Ecology tells that in paddy field BGA are more ample than in other tilled soils; although the frequency ratio of N_2 -fixing BGA ranges within large limits and they are not every time exit in rice soils. BGA appear to be more resistant compare to other algae to pesticides. Most BGA are efficient of tolerating pesticide levels recommended for field application. Insecticides are generally less poisonous to BGA than other pesticides and have the secondary positive impact. BGA are basically photoautotrophic. They can also express heterotrophic growth.

Application Methods in Paddy Field

There are basically two methods to apply BGA in paddy field .

1. Broadcast Method : This is the most common method to apply BGA in rice field.

- a) **Preparation:** 10 kg of dried BGA flakes mixed with 4 kg of sieved farm soil or can use pre-mixed soil-based culture.
- b) **Application:** Disperse uniformly atop the surface of water.
- c) **Timing:** After 3-6 days of transplanting of rice seedlings when water in the field is in standing condition.

d) **Post-Application:** Keep up 5-7.5 cm deep water logging for 10-12 days to assist the growth of algae to form a mat.

2. **Seedling Root Dip Method:** In this practice, rice seedlings are soaked before transplanting.

a) **Preparation:** construct a superficial bed in a corner of the field owing water and incorporate endorsed amount of BGA.

b) **Application :** Before transplanting, roots of rice seedlings immersed in prepared solution for 8-10 hours. Application of BGA in paddy field depicted in figure 1.



Figure : 1 Application of BGA in paddy field (Lee, M.A., 2010)

Important points for Success

- a) **Soil Type:** Perform effectively in loamy to clayey soils.
- b) **Nitrogen (N):** Excessive nitrogen levels obstruct BGA, it performed better when chemical nitrogen fertilizers are decreased, permit BGA to fix atmospheric nitrogen.
- c) **Phosphorus (P):** BGA required phosphorus to worked well. So, incorporate superphosphate (around 2 kg/ha) with the culture or apply it into seedbed or at a time of field preparation.
- d) **Consistency:** For best results it should be applied for 3-4 successive seasons in the same field.
- e) **Pest Control:** Use moderate insecticides like Neem Oil, Insecticidal Soap, Bacillus thuringiensis (Bt) etc during production or application to control insect grazers if required.

Main functions of BGA in Rice Farming

In Rice Farming, BGA play many important roles which are describe below and also systematic diagram is mentioned in figure 2.

1. **Nitrogen Fixation:** The chief advantage of BGA is it has capacity to fix atmospheric nitrogen in the form which rice plants can easily utilize. Through this process it can provide considerable amount of the nitrogen needs of crop, commonly 20–30 kg of N per hectare per season, in addition to some cases till 80 kg N/ha, which assist to keep inorganic fertilizers use by substantially 30%.
2. **Soil Health Buildup:** soil enriched by them with increasing of organic matter as well as microorganism, hence soil structure, water holding capacity and on the whole soil fertility.
3. **Nutrient Accessibility:** It play important role in solubilizing phosphorus and liberate plant growth regulators (vitamins, hormones like auxins, gibberellins), vivifying root and overall plant growth.
4. **Yield Increment:** In paddy fields, BGA remarkably boost grain along with straw yield by furnishing requisite minerals and growth factors.

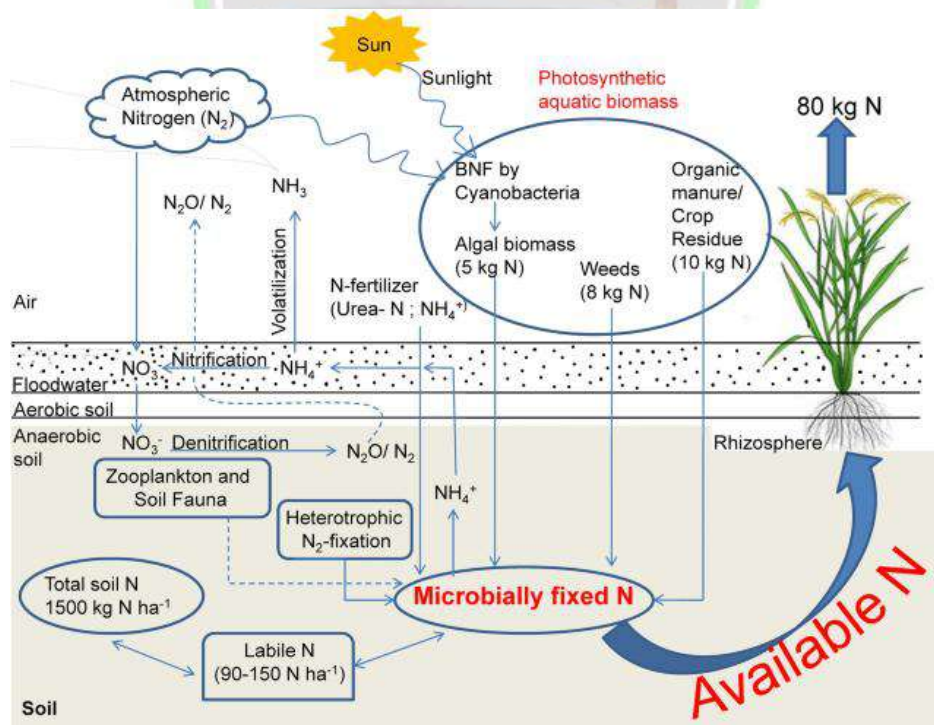


Figure 2: Systematic diagram on Role of BGA in paddy field (Kaushik et al. 2019)

5. **Ecological Advantages:** They generate guarded agricultural ecosystem by lowering dependency on resource-intensive chemical inputs, not just this it also assist to demote some pollutants, bestowing to sustainable agriculture.
6. **Sulfide Toxicity Reduction:** They can minimize sulfide damage in rice seedlings, defending them from detrimental impacts under wet conditions.
7. **Weed Control:** In a paddy field a dense layer of BGA growing on the water surface can prevent the aquatic weeds through impeding sunlight.

Conclusion

Blue-green algae (cyanobacteria) represent a vital and sustainable biofertilizer for rice-based ecosystems, particularly under flooded paddy field conditions. Their unique ability to fix atmospheric nitrogen, improve soil fertility, enhance nutrient availability, and promote plant growth makes them an effective alternative or supplement to chemical fertilizers. Beyond nitrogen fixation, BGA contribute to long-term soil health by increasing organic matter, improving soil structure, reducing sulfide toxicity, and suppressing weed growth. Their tolerance to commonly used pesticides and adaptability to waterlogged environments further support their suitability for rice cultivation. Consistent application over successive seasons can significantly improve crop yield while reducing input costs and environmental pollution. Therefore, the integration of BGA into rice farming systems offers an eco-friendly, cost-effective, and sustainable approach to maintaining soil fertility, ensuring food security, and promoting environmentally responsible agriculture.

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DUCK VIRAL HEPATITIS – AN EMERGING DISEASE

Article ID: AG-VO6-I01-115**R.Ramya^{1*}, Neha Kumari², Mahesh Thirugnanam² and D. Jaya Senthil Nathan¹**

¹ Central University Laboratory, ² Internship scholar, Tamil nadu Veterinary and Animal Sciences University, Chennai-51, Tamil Nadu, India

*Corresponding Author: R.Ramya

Introduction

Duck viral hepatitis (DVH) is an acute, highly contagious viral disease typically affecting ducklings less than six weeks old (often under 3 weeks old). DVH is characterized by a short incubation period, sudden onset, high mortality with characteristic liver lesions.

Traditionally, DVH has been classified into types I, II, and III. DVH type I is caused by three distinct genotypes of the duck hepatitis A virus (DHAV).i.e. DHAV-1, DHAV-2 and DHAV-3. DHAV belongs to the Avihepatovirus genus within the Picornaviridae family (Ramya *et al.*, 2023).

Epizootiology

- It is associated with high mortality of upto 100% and produces characteristic liver lesions in the affected birds (Woolcock, 2008). Transmission of the disease takes place by feco-oral route and direct contact.
- DVH type 1 is extremely contagious with infected ducklings continuing to excrete the virus for up to 8 weeks post-infection. Susceptible ducklings can contract the virus through direct contact with infected individuals or their contaminated surroundings. The virus can persist for up to 10 weeks in contaminated brooders and for 37 days in feces.
- Wild birds have been suspected of acting as mechanical carriers of virus over short distances. There are no known vectors for the disease.
- It should be noted that DVH is different from Duck Hepatitis B virus, which is hepadnavirus infection affecting mainly older ducks.

Clinical signs

- Incubation period ranges from 12-48 hours. It causes highly contagious disease in ducks. Affected ducklings shows signs like lethargy, loss of balance, spasmodic paddling and death within few minutes to hours in case of severe and acute infections. Ducklings lose their balance, fall on their sides and kick spasmodically prior to death. Whole flock can vanish within 3-4 days of outbreak, most deaths seen within first two days. Other clinical signs shown by affected birds are typical opisthotonus (Ramya *et al.*, 2023) and paralysis, sudden death (Fig-1).

Fig-1 Signs of opisthotonos (Arched back position) in affected duckling



Lesions :

- Typical gross lesions include hepatomegaly with multiple petechial and ecchymotic hemorrhagic foci on liver (Fig.2). Splenomegaly with mottling may be observed in spleen (Fig.3). Congested renal vessels and enlarged kidneys may be observed. Microscopic lesions observed in the liver are extensive hepatocyte necrosis and bile duct hyperplasia along with various degrees of hemorrhages and inflammatory changes.

Fig.2 DVH infected ducklings showing Liver enlargement with Multifocal petechiae , Ecchymosis and Pale-pink /pale-yellow colour discoloration.

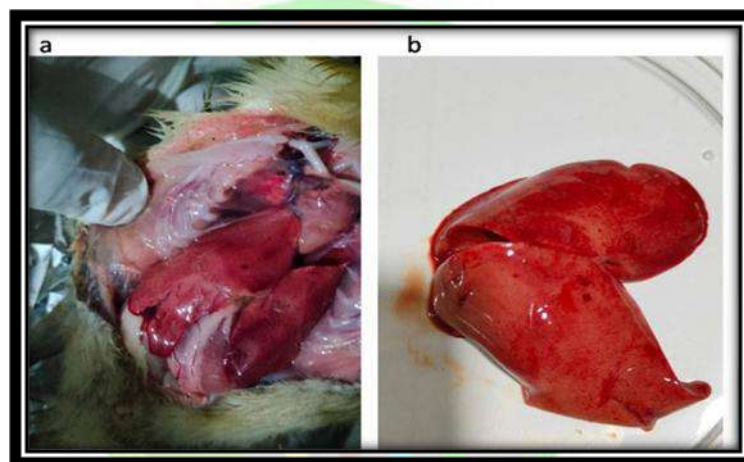
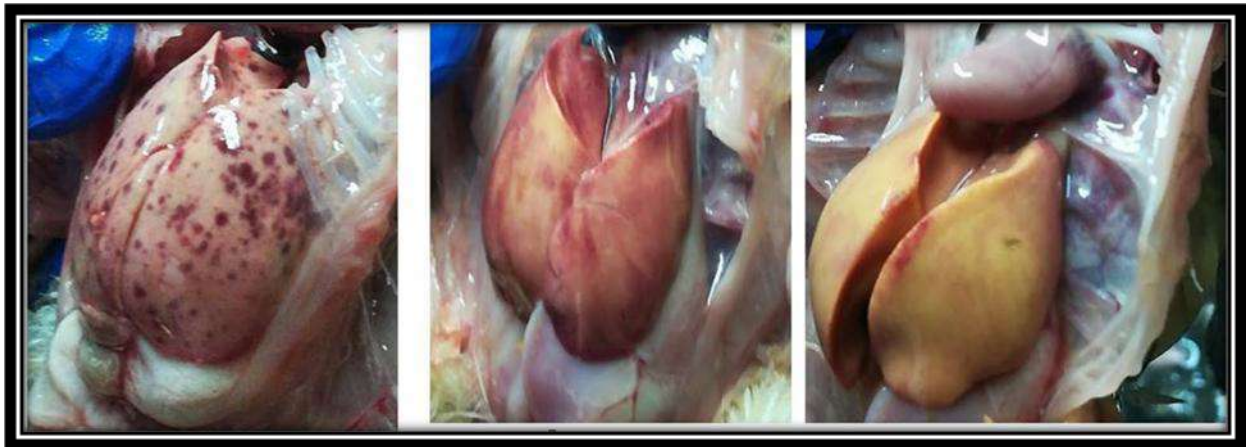


Figure 3 : Congested spleen



Diagnosis :

- Sudden onset, typical clinical signs along with characteristic liver lesions suggestive of the disease.
- Based on clinical findings and gross pathology it is difficult to differentiate the three genotypes of DHAV, alternatively serological tests in vitro may help in this.

- DHAV can be isolated in chicken and duck embryos and it does not produce haemagglutinins. DHAV can readily be recovered from liver tissue of the affected ducklings.
- By inoculation of the liver homogenate into the allantoic sac of embryonated duck eggs (10–14 days) or chicken eggs (8–10 days), the resultant embryos die between 24 and 72 hours after inoculation, whereas chicken embryos are more erratic in their response and death usually occurs 5–8 days after inoculation. Gross pathological changes in the embryos include stunting and subcutaneous hemorrhages over the whole body with edema of the abdominal and hind limb regions. The embryo livers may be red and yellowish, swollen and may show some necrotic foci. In live inoculated embryos, a greenish-yellow colored allantois is noticed and both the liver lesions and stunting become more evident (Fig – 4).

Figure -4 : Gross pathology in embryonated chicken eggs inoculated with DHAV positive tissue supernatant A. Liver of dead embryo showing greenish-yellow discoloration (arrow head). B. Uninfected control embryo. C. Dead embryos showing stunted growth (arrow head) compared to uninfected control embryo. D. Dead embryos showing edema and cutaneous haemorrhages.



- DHAV can be isolated in primary cells. In duck embryo liver (DEL) cells DHAV type 1 cause a cytopathic effect (CPE), which is characterized by presence of round cells and necrosis. When given with maintenance medium having 1% agarose (w/v) the CPE gives rise to plaques of approximately 1 mm in diameter.
- Disease confirmation may be done via virus isolation and PCR (RT-PCR and Multiplex PCR) assay. Multiplex PCR used to identify various genotypes of the virus. DHAV RNA can be detected by single-step RT PCR (Reverse Transcriptase PCR) from duckling liver,

allantoic fluid and embryo liver from inoculated duck eggs. Real time PCR can also be used for diagnosis.

- Various serological tests like virus neutralization, agar gel immunodiffusion test (AGID) and ELISA have also been used in identification of the virus. ELISA and VNT being more sensitive. These serological tests cannot give appreciable results in initial stages of infection with acute onset. Neutralization test with no or minimum cross-neutralization amongst DHAV 1, 2 and 3. But these neutralization tests are not used extensively in routine identification of the disease. These tests are useful in epidemiological studies, virus identification and titration of antibody in vaccination cases.

Treatment

There is no specific treatment protocol available for the disease. So, early identification and isolation may help in control of the disease. Vaccination and biosecurity plays vital role in preventing the disease

Prevention and Control

- DHAV can be prevented by strict isolation during the first 4 to 5 weeks of life. In areas where the disease is prevalent, achieving the necessary degree of isolation may be very difficult and vaccination may be required. Avoid contact with wild waterfowl. Minimize exposure to rodents, especially rats.
- Injection of immune serum (IgY) in day-old ducklings for passive immunization.
- A modified live vaccine can be used for early vaccination of progeny of non-immune breeders. However, immune response in ducklings is not induced until 3–5 days after vaccination; meanwhile ducklings have a high potential risk of DHAV infection at 1–3 days old. Hence, immunization of breeders 1 month before laying to ensure high level of maternal antibodies in hatched ducklings is advised. Currently, no vaccine is available in India for Duck Viral Hepatitis.

Acknowledgements

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INTEGRATED FARMING SYSTEM FOR SMALL AND MARGINAL FARMERS

Article ID: AG-VO6-I01-116**Keerthika .M**

Undergraduate Student of B.Sc., (Hons) Agriculture, S.Thangapazham Agriculture College,
(Affiliated to TNAU), Vasudevanallur, Tenkasi- 627760, Tamil Nadu, India

Abstract

The Integrated Farming System (IFS) is a sustainable agricultural approach that combines different farming enterprises such as crops, livestock, poultry, fisheries, and agroforestry on a single farm. This system aims to maximize resource utilization, increase farm income, and reduce production risks, especially for small and marginal farmers. By recycling farm wastes and by-products, IFS improves soil fertility, enhances productivity, and ensures environmental sustainability. This article discusses the concept, importance, and benefits of integrated farming systems in improving the livelihoods of small and marginal farmers.

Introduction

Small and marginal farmers constitute a major portion of the farming community in India. Due to limited land holdings, low capital investment, and dependence on monsoon rainfall, these farmers often face economic instability and production risks. Traditional monocropping systems alone may not provide sufficient income or employment throughout the year.

The Integrated Farming System (IFS) offers a practical solution by integrating multiple agricultural enterprises within a single farming unit. In IFS, the output of one enterprise becomes the input for another, thereby reducing waste and input costs. For example, crop residues can be used as livestock feed, animal manure can improve soil fertility, and farm ponds can support fish culture and irrigation. This interlinked approach ensures better resource use efficiency, income diversification, and sustainability, making it ideal for small and marginal farmers.

What Is an Integrated Farming System?

IFS is a **holistic and sustainable farming approach** that combines different agricultural

enterprises such as crops, livestock, poultry, fishery, and agroforestry into a **synergistic system**. The idea is to **optimize resource use, reduce risk, and improve farm income**.



Importance for Small & Marginal Farmers

Small holdings often lack scale for high profits through just one enterprise. Integrated systems:

- Diversify income sources
- Reduce input costs (by recycling wastes)
- Enhance soil fertility
- Improve nutrition security at the household level+

Concept of Integrated Farming System

Integrated Farming System is a holistic farming approach that involves the judicious combination of crops, animals, and allied enterprises to achieve higher productivity per unit area and time. The primary objective of IFS is to maintain ecological balance while increasing farm profitability and ensuring food and nutritional security.

For example:

- Crop residues are used as fodder for livestock
- Animal dung is used for compost or biogas production
- Farm pond water is used for irrigation and fish culture

- Poultry droppings serve as manure for crops and fish ponds

Thus, IFS works on the principle of **recycling farm resources**.

Components of Integrated Farming System

Common components of IFS include:

- **Crop production** (cereals, pulses, oilseeds, vegetables)
- **Livestock farming** (cattle, goats, sheep)
- **Poultry farming**
- **Fish culture**
- **Horticulture and agroforestry**
- **Vermicomposting and biogas units**

Components of Integrated Farming System

1. Crop Production

Crops form the base of the IFS. Cereals, pulses, oilseeds, vegetables, and fodder crops are selected based on climate, soil, and market demand. Crop diversification reduces pest and disease incidence.

2. Livestock Farming

Dairy, goat rearing, sheep, and piggery are common livestock components. Livestock provides milk, meat, manure, and draft power, significantly contributing to farm income.

3. Poultry Farming

Backyard poultry is ideal for small farmers. It requires low investment and provides eggs, meat, and manure for crops and fish ponds.

4. Fisheries

Fish farming in farm ponds or tanks enhances income and nutritional security. Fish feed can be supplemented with farm waste and poultry droppings.

5. Agroforestry and Horticulture

Fruit trees, timber species, and fodder trees improve land use efficiency and provide long-term income, fuelwood, and fodder.

6. Allied Enterprises

Beekeeping, mushroom cultivation, vermicomposting, and biogas units further add value and income.

Importance of IFS for Small and Marginal Farmers

- Provides **diversified income sources**
- Reduces **risk of crop failure**
- Enhances **employment opportunities** throughout the year
- Improves **soil fertility** through organic recycling
- Ensures **food and nutritional security** for farm families

Benefits of Integrated Farming System

- ✓ Efficient use of land, water, and labor
- ✓ Reduced dependency on chemical fertilizers
- ✓ Increased farm income and profitability
- ✓ Sustainable and eco-friendly farming
- ✓ Better resilience to climate variability



Constraints in Adoption of IFS

Despite its advantages, adoption of IFS faces certain challenges:

- Lack of technical knowledge and training
- Limited access to credit and inputs
- Initial investment requirements
- Poor market linkages
- Inadequate extension support

ADDRESSING these constraints through policy support, farmer training, and institutional backing is essential.

Role of Government and Institutions

Government schemes, Krishi Vigyan Kendras (KVKs), agricultural universities, and NGOs play a vital role in promoting IFS by:

- Providing training and demonstrations
- Offering subsidies and credit facilities
- Supporting market access and value addition
- Encouraging climate-resilient farming practices

Conclusion

The Integrated Farming System is a viable and sustainable approach for small and marginal farmers to enhance productivity and income while conserving natural resources. Adoption of IFS can significantly improve farm resilience, reduce poverty, and promote sustainable agricultural development. With proper planning, training, and support from extension agencies, IFS can play a key role in strengthening rural livelihoods and achieving long-term agricultural sustainability.

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SEED PROCESSING AND ITS STORAGE TECHNIQUES

Article ID: AG-VO6-I01-117**Thanga Priya.S**

Undergraduate Student of B.Sc., (Hons) Agriculture, S.Thangapazham Agriculture College,
(Affiliated toTNAU), Vasudevanallur, Tenkasi- 627760, Tamil Nadu, India

Abstract

Seed processing and storage are crucial operations in seed production systems that ensure the availability of high-quality seeds for agricultural use. Proper seed processing improves seed purity, germination, and vigor, while appropriate storage techniques help maintain seed viability and health over time. Efficient seed processing removes impurities and damaged seeds, and scientific storage practices protect seeds from moisture, pests, and diseases. This article highlights the importance, steps, and techniques involved in seed processing and storage to ensure quality seed supply and sustainable crop production.

Introduction

Seed is the primary input in agriculture, and its quality determines the success of crop production. After harvest, seeds must undergo proper processing and storage to preserve their quality until the next planting season. Seed processing involves a series of operations that prepare seeds for safe storage and sowing by improving their physical purity, germination potential, and overall quality.

Improper processing and storage can lead to seed deterioration, loss of viability, pest infestation, and reduced crop yields. Therefore, adopting scientific seed processing and storage techniques is essential for farmers, seed producers, and seed agencies to ensure the availability of quality seeds at the right time.

Importance of Seed Storage

Seed storage refers to the preservation of seeds under controlled conditions to maintain their **viability and vigor** for future use. The main objectives of seed storage are:

- To maintain high germination capacity
- To preserve seed vigor and genetic purity
- To protect seeds from insects, pests, and diseases
- To ensure availability of quality seed during planting time
- To minimize post-harvest losses



Factors Affecting Seed Storage

1. Moisture Content

Moisture is the most critical factor affecting seed longevity. High moisture content accelerates respiration and microbial growth, leading to rapid seed deterioration.

2. Temperature

Higher storage temperatures reduce seed life. Lower and stable temperatures help prolong seed viability.

3. Relative Humidity

High relative humidity encourages fungal growth and insect infestation, causing seed damage.

4. Seed Quality

Well-matured, healthy, and mechanically undamaged seeds store better than poor-quality seeds.

5. Storage Period

Seed viability declines with increasing storage duration, depending on species and storage conditions.

Principles of Good Seed Storage

- Store seeds at **low moisture and low temperature**

- Use clean, dry, and pest-free storage structures
- Protect seeds from insects, rodents, and fungi
- Regularly monitor seed condition during storage

Seed Processing Techniques

Seed processing is the **post-harvest operation** that improves seed quality by removing impurities and enhancing physical and physiological characteristics. Proper processing ensures uniform, healthy, and marketable seeds.

Steps in Seed Processing

1. Seed Drying

Drying reduces seed moisture to a safe level for storage.

- **Sun drying:** Common, low-cost method but weather-dependent
- **Mechanical drying:** Controlled and efficient, used in commercial seed production

Safe moisture levels generally range from **8–12%**, depending on crop type

2. Seed Cleaning

Cleaning removes inert matter, chaff, broken seeds, weed seeds, and dust.

Methods include:

- Winnowing
- Sieving
- Air screen cleaners
- Gravity separators

3. Seed Grading

Grading separates seeds based on **size, weight, and density**.

Benefits:

- Uniform germination
- Better field establishment
- Higher market value

4. Seed Treatment

Seed treatment protects seeds from pests and diseases and enhances seed performance.

Types of seed treatment:

- **Chemical treatment** (fungicides, insecticides)
- **Biological treatment** (Trichoderma, Rhizobium)

- **Physical treatment** (hot water treatment)

5. Seed Coating and Pelleting

- **Seed coating:** Application of protective chemicals or nutrients
- **Seed pelleting:** Enlarging small seeds for easy sowing and precision planting

These techniques improve handling, sowing efficiency, and seedling vigor.



Seed Storage Structures

1. Traditional Storage Structures

- Earthen pots
- Bamboo bins
- Mud bins

2. Modern Storage Structures

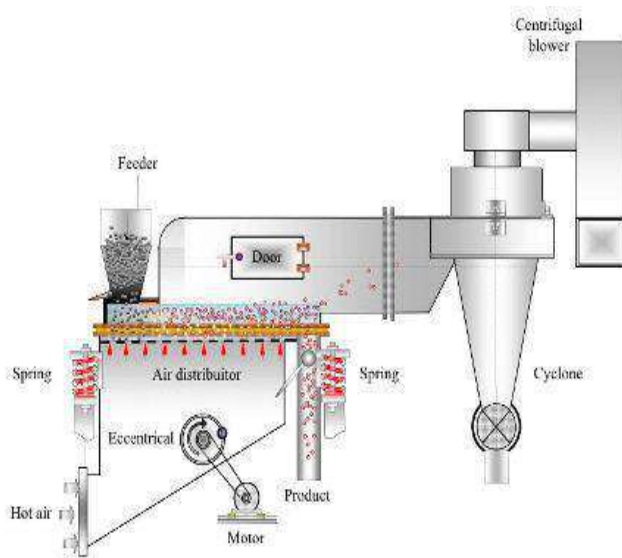
- Metal bins
- HDPE bags
- Cold storage facilities
- Seed warehouses with temperature and humidity control

Types of Seed Storage

- **Open storage:** Short-term, prone to losses
- **Closed storage:** Airtight containers, better protection
- **Controlled storage:** Temperature and humidity controlled, ideal for long-term storage

Role of Seed Storage in Sustainable Agriculture

- Ensures timely availability of quality seed
- Reduces dependency on external seed sources
- Enhances crop productivity
- Supports seed security at farm and national levels



Seed Storage Techniques

Seed storage aims to maintain seed viability and vigor from harvest to planting. The effectiveness of storage depends on controlling environmental factors such as temperature, moisture, and pests.

Factors Affecting Seed Storage

- **Moisture content**
- **Temperature**
- **Relative humidity**
- **Seed health**
- **Storage pests and pathogens**

Traditional Storage Methods

- Earthen pots sealed with mud or cow dung
- Jute or cloth bags with neem leaves
- Bamboo bins and granaries

Modern Storage Techniques

- Metal bins and silos
- Airtight or hermetic storage bags
- Cold storage for high-value and vegetable seeds

Best Practices for Seed Storage

- ✓ Store seeds in a cool, dry place
- ✓ Maintain low moisture content
- ✓ Use pest-resistant containers
- ✓ Periodically inspect stored seeds

Importance of Proper Seed Processing and Storage

- Maintains high germination and vigor
- Reduces seed losses during storage
- Ensures availability of quality seeds
- Improves crop establishment and yield
- Supports sustainable agriculture

Conclusion

Seed processing and storage play a vital role in maintaining seed quality and ensuring successful crop production. Proper cleaning, grading, drying, and treatment enhance seed performance, while scientific storage techniques preserve seed viability and protect against pests and diseases. Adoption of improved seed processing and storage practices is essential for achieving higher agricultural productivity and food security.

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SEED QUALITY AND ITS ROLE IN CROP YIELD

Article ID: AG-VO6-I01-118**Varshini .V**

Undergraduate Student of B.Sc., (Hons) Agriculture, S.Thangapazham Agriculture College,
(Affiliated to TNAU), Vasudevanallur, Tenkasi- 627760, Tamil Nadu, India

Abstract

Seed quality plays a crucial role in determining agricultural productivity and crop yield. High-quality seeds ensure better germination, uniform crop establishment, vigorous plant growth, and resistance to pests and diseases. The use of good quality seeds reduces the risk of crop failure and increases the efficiency of inputs such as water, fertilizers, and plant protection chemicals. This article highlights the importance of seed quality and explains how it directly influences crop yield and farmers' income. Seed quality is one of the most critical factors influencing crop productivity and agricultural sustainability. High-quality seeds ensure better germination, uniform plant population, vigorous growth, and resistance to biotic and abiotic stresses. The use of quality seeds leads to efficient utilization of inputs such as water, fertilizers, and plant protection measures, resulting in higher crop yields and improved farm income. This article discusses the concept of seed quality, its components, and its significant role in achieving higher crop yield and food security.

Introduction

Seed is the basic and most essential input in agriculture. The success of a crop largely depends on the quality of seed used for sowing. Even when all other agricultural practices such as irrigation, fertilization, and pest management are properly followed, poor-quality seeds can drastically reduce crop yield. Hence, seed quality forms the foundation of successful crop production.

Seed quality refers to the overall characteristics of a seed that determine its ability to germinate, establish, and produce a healthy and productive plant under field conditions. Quality

seeds possess high genetic purity, good germination capacity, physical purity, seed vigor, and freedom from pests and diseases. The use of certified and quality seeds is especially important for small and marginal farmers, as it reduces production risk and enhances crop performance.

What Is Seed Quality?

Seed quality refers to the **genetic purity, physical soundness, physiological vigor, and health status** of seeds. High-quality seeds show:

- High *germination rates*
- Uniform *plant stand*
- Genetic purity for desired traits
- Resistance to pests and diseases



Why It Matters for Crop Yield

High-quality seeds are the foundation of productive agriculture because they:

- Ensure **better crop establishment**
- Promote **robust plant growth**
- Improve **resource use efficiency (nutrients, water)**
- Lead to **higher and stable yields**
- Reduce the need for re-sowing

In contrast, poor-quality seeds result in uneven crop stands, increased crop failures, and lower farmer profitability.

Indicators of Good Seed Quality

- ✓ High germination percentage
- ✓ Optimal seed weight
- ✓ Free of physical impurities
- ✓ No pest or disease contamination

Role of Seed Quality in Crop Yield

Seed quality affects crop yield in several ways:

- **High germination percentage** ensures better plant establishment.
- **Seed vigor** helps seedlings withstand adverse environmental conditions.
- **Genetic purity** maintains desired crop characteristics and productivity.
- **Healthy seeds** reduce the incidence of seed-borne diseases.

By using quality seeds, farmers can achieve higher yields, improved crop uniformity, and better economic returns.



Components of Seed Quality

1. Genetic Purity

Genetic purity ensures that the seed belongs to the correct variety and expresses desirable traits such as high yield potential, disease resistance, and adaptability to local conditions.

2. Physical Purity

Physically pure seeds are free from inert matter, weed seeds, broken seeds, and other crop seeds. High physical purity improves uniformity in sowing and crop establishment.

3. Germination Capacity

Germination percentage indicates the proportion of seeds capable of producing normal seedlings. Higher germination ensures adequate plant population in the field.

4. Seed Vigor

Seed vigor refers to the seed's ability to germinate rapidly and establish strong seedlings even under adverse environmental conditions such as drought or poor soil fertility.

5. Seed Health

Healthy seeds are free from seed-borne diseases and insect damage, reducing early-stage crop losses.

Role of Seed Quality in Crop Yield

Seed quality directly and indirectly influences crop yield in the following ways:

- **Uniform Crop Establishment:** Quality seeds ensure even germination and uniform plant growth, which is essential for effective crop management.
- **Higher Yield Potential:** Genetically superior seeds express their full yield potential under proper management practices.
- **Efficient Resource Use:** Healthy seedlings utilize water, nutrients, and sunlight more efficiently.



- **Reduced Pest and Disease Incidence:** Disease-free seeds minimize early pest and pathogen attacks.
- **Lower Cost of Cultivation:** Reduced need for resowing and plant protection measures saves input costs.

Importance of Certified Seeds

Certified seeds are produced under strict quality control and tested for germination, purity, and health. Their use ensures reliability, better crop performance, and increased farmer confidence. Adoption of certified seeds plays a vital role in improving national agricultural productivity.

Conclusion

Seed quality is a foundation of agricultural productivity. The use of high-quality seeds results in improved crop establishment, higher yields, and sustainable farming practices. Promoting awareness among farmers about the importance of seed quality can significantly

enhance agricultural production and food security. Seed quality is the cornerstone of crop production and agricultural development. High-quality seeds lead to better germination, vigorous crop growth, and higher yields. Promoting awareness about seed quality, encouraging the use of certified seeds, and adopting proper seed handling practices can significantly enhance crop productivity and farmers' income. Ensuring seed quality is therefore essential for achieving food security and sustainable agriculture.

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WATER MANAGEMENT PRACTICE IN RAINFED FARMING

Article ID: AG-VO6-I01-119**¹Dr.Reeba Jacob, S.Meenaja, G.Nanthini, M.Rohini Pon Vinisha*, K.Sumithra,**

¹Assistant professor (Agricultural Extension), UG Students B.Sc.(Hons)Agriculture,
S.Thangapazham Agricultural College (Affiliated toTNAU), Vasudevanallur, Tenkasi- 627 758,
Tamil Nadu, India

***Corresponding Author:** M.Rohini Pon Vinisha

Abstract

Rainfed agriculture plays and will continue to play a dominant role in providing food and livelihoods for an increasing world population. We describe the world's semi-arid and dry sub-humid savannah and steppe regions as global hotspots, in terms of water related constraints to food production, high prevalence of malnourishment and poverty, and rapidly increasing food demands. We argue that major water investments in agriculture are required. In these regions yield gaps are large, not due to lack of water per se, but rather due to inefficient management of water, soils, and crops. An assessment of management options indicates that knowledge exists regarding technologies, management systems, and planning methods. A key strategy is to minimise risk for dry spell induced crop failures, which requires an emphasis on water harvesting systems for supplemental irrigation.

Introduction

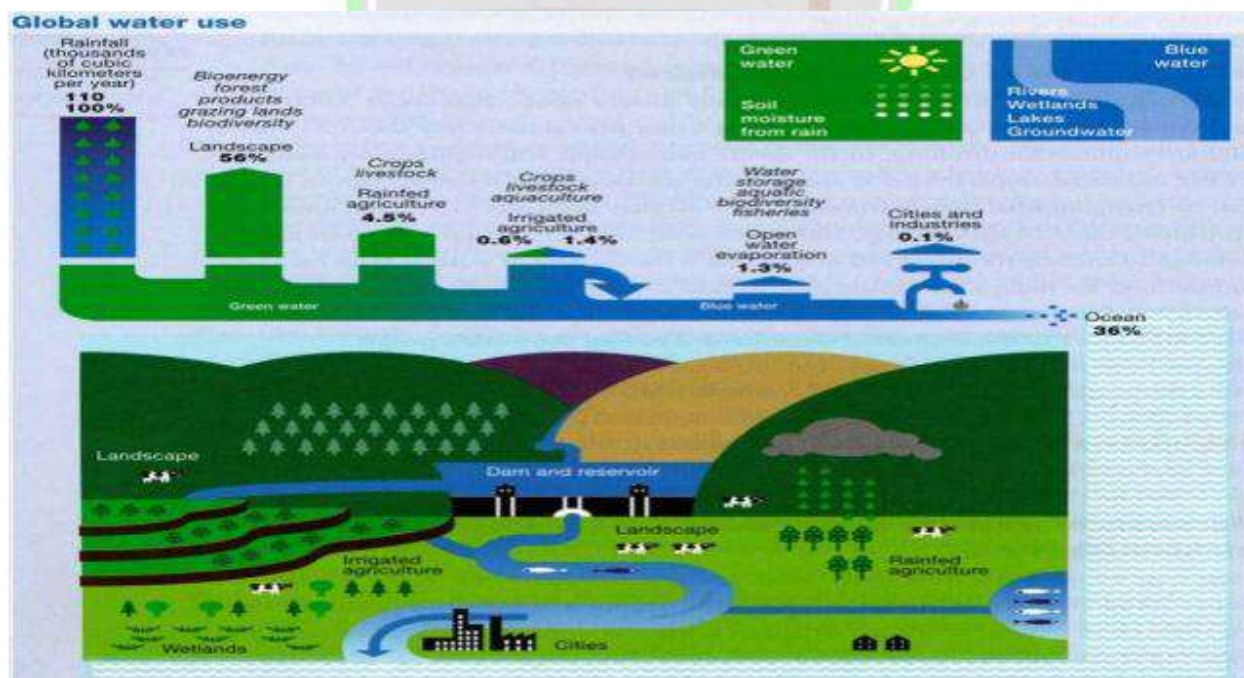
Almost eighty percent of the world's agricultural land is rain-fed, contributing to at least sixty percent of global food production. It is out of discussion the very important role irrigation is playing in supplying foods, but for most countries facing an acute food gap, the potential for increasing water withdrawals for expanding irrigated area is quite limited. Therefore, for irrigated agriculture, increasing food production to fulfil the food gap is fundamentally depending on our capability in increasing crop water productivity to produce more biomass per unit of water already withdrawn for irrigation purpose (more crop per drop of irrigated water).

Water use in rain-fed and irrigated agriculture

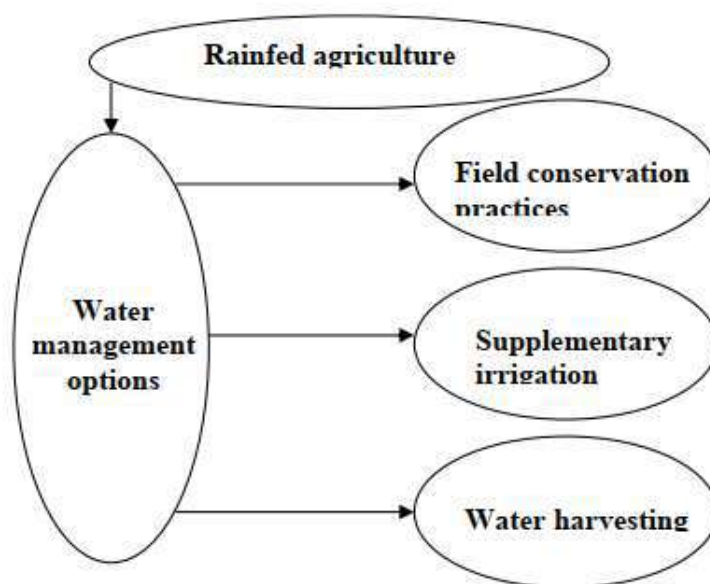
The main source of water is rainfall falling on the earth's land surface (110,000 cubic kilometres). When atmospheric precipitation reaches the ground it divides into several sections which pursue the terrestrial part of the hydrological cycle along different paths. As presented in, adapted from Shiklmano (2000), FAO (2002), Ringers et al. (2003) and Rockstrom (1999), it is estimated that out of the total annual amount of precipitation (110 km³), about 40,000 km³ is converted into surface runoff and aquifer recharge (Blue Water) and an estimated 70,000 km³ is stored in the soil and later returns to the atmosphere through evaporation and plant transpiration (green water).

Zooming in on global hotspots:

Many farming systems have adapted to hydro-climatic gradients. Examples include pastoral systems in arid environments, agro-pastoral systems in the drier semi-arid zone, and sedentary, multiple cropping systems in the savannah systems and humid agroecosystems. The challenge of upgrading rainfed agriculture through improved water management is concentrated in the world's savannah and steppe regions. These cover the semi-arid and dry sub-humid climate regions.



(Fig.1) -Water use in rain-fed and irrigated agriculture. Source: Comprehensive assessment of water management in agriculture. 2007, Water for Food, Water for Life - (eds) D. Molden



(Fig.2)- Diverse options for water management in rain-fed conditions

Most food is produced in rainfed agriculture:

The importance of rainfed agriculture varies regionally, but most food for poor communities in developing countries is produced in rainfed agriculture. Some 93% of farmed land is rainfed in Sub-Saharan Africa, 87% in Latin America, 67% in the Near East and North Africa, 65% in East Asia, and 58% in South Asia (FAO 2002). Most countries depend primarily on rainfed agriculture for their grain food.

Upgrading rain-fed agriculture: the constraints

The point which is under continuous bargaining by both politicians and professionals is mainly related to the simple question: why water management investments in rain-fed agriculture have been neglected over the past 50 years in spite of the well stated fact that, at present, rainfed agriculture dominates world food production and it will continue to produce the bulk of the world's food? There are several reasons resulted in such situation.

However, to answer this question we have to return back with our memory to the few past years where all the efforts were directed to the development and management of the blue water with a major focus on developing and allocation of such water particularly to large scale irrigation, expanding the irrigated areas and, thereby, increasing food production. Furthermore, large investments have historically tended to go to high potential irrigated areas, keeping most rain-fed areas with very poor infrastructure facilities

Water management to upgrade rain-fed agriculture:

Water management to upgrade rain-fed agriculture encompasses a wide spectrum from water conservation practices for improving rainwater management on the farmers' field to managing runoff water (surface and sub-surfaces) for supplying supplemental irrigation water to rain-fed food production. Improving water management in rain-fed agriculture is a long term process and requires learning by doing using an adaptive approach. Such adaptive management approach should be responsive to the variability within systems as well as to the long term and slow ones changes. In addition, the management approach should carefully consider the increasing rainfall variability and frequency of extreme events such as drought, floods and hurricanes due to the emerging climatic changes.

Rainwater management strategies and options:

The work done by Critchley and Siegert (1991) indicated several rainwater management strategies to improve crop yields and green water productivity. One of these strategies is aiming at maximizing plant water availability in the root zone.

- Water harvesting strategies: external water harvesting systems
- In situ water harvesting systems, soil and water conservation
- Evaporation management strategy

Conclusion

Rainwater harvesting (RWH) is a vital, sustainable strategy for managing water scarcity, offering benefits like reduced reliance on groundwater, flood mitigation, and improved water security by capturing rainfall for various uses.

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POST HARVEST MANAGEMENT - ZERO ENERGY COOLING CHAMBER

Article ID: AG-VO6-I01-120***Dr.M.Vetrivel, T.Abinaya, S.Ilakkiya, C.Jenitha, M.Rapri Devi, G.Samyuktha**

¹Assistant professor (Agricultural Extension), UG Students B.Sc.(Hons)Agriculture,
S.Thangapazham Agricultural College (Affiliated toTNAU), Vasudevanallur, Tenkasi- 627 758,
Tamil Nadu, India

***Corresponding Author:** Dr.M.Vetrivel

Abstract

In many developing nations, the lack of adequate postharvest infrastructure leads to significant qualitative and quantitative losses of fresh produce. Most harvested fruits and vegetables are subjected to high temperatures and low humidity, causing rapid moisture loss, decay, and physiological breakdown. This study explores the efficiency of the Zero Energy Cool Chamber (ZECC)—an evaporative cooling system developed by IARI, New Delhi—as a low-cost, eco-friendly storage alternative. Constructed from locally available materials like bricks, sand, and bamboo, the ZECC utilizes the principle of evaporative cooling to maintain internal temperatures significantly lower than ambient conditions and a relative humidity above 90%. The performance of the ZECC was evaluated against other storage methods, including walk-in-coolers and traditional practices (water sprinkling, leaf covering, and open storage) across five vegetable varieties (amaranthus, bhindi, bitter gourd, brinjal, and snake gourd). Results indicate that the ZECC significantly reduces the Physiological Loss in Weight (PLW) and maintains physical attributes such as appearance, color, and texture better than other low-cost methods. By providing a stable, high-humidity environment, the ZECC effectively doubles or triples the shelf life of perishables without the need for electricity, making it a viable solution for rural farmers.

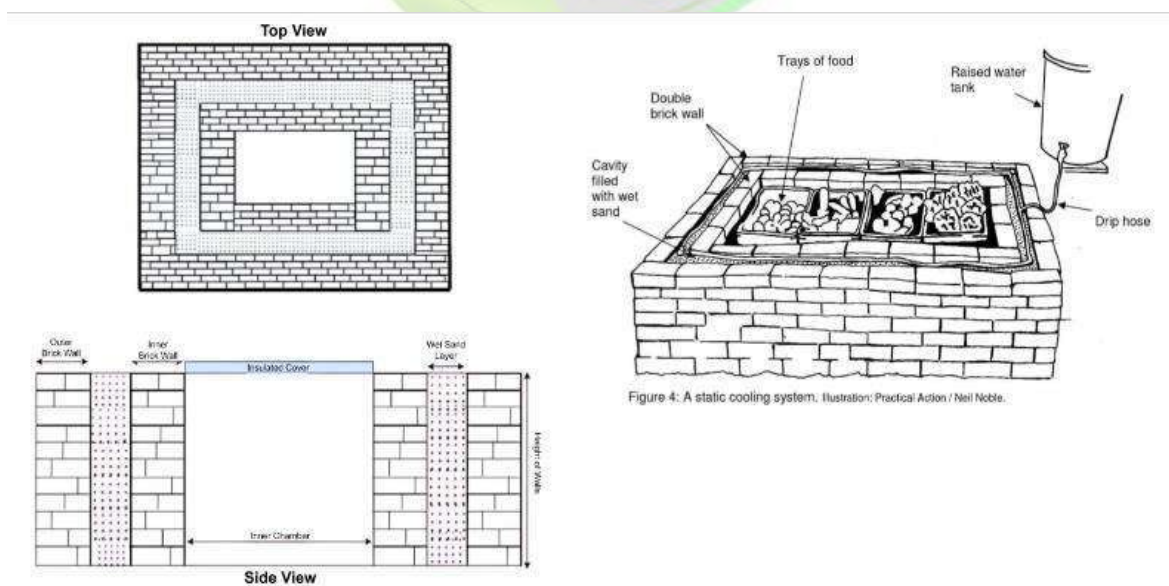
Introduction

Fresh fruits and vegetables generally need postharvest management to reduce loss and maintain quality. Today, the postharvest handling practices regarding vegetables throughout the

marketing channels in most developing countries remain inadequate. Growers have no storage facilities, while the transport and marketing channels also lack storage facilities. As a result, most harvested fruits and vegetables are usually stored in the open, exposed to high temperatures and low relative humidity conditions, until a middleman, wholesaler or retailer purchases those commodities. The quality of fruits and vegetables, and reduced shelf life are reduced by the loss of moisture, decay, and physiological breakdown, and such deterioration is directly related to storage temperature, relative humidity, air circulation, mechanical damage, and improper postharvest sanitation. The combination of higher humidity and lower temperature facilitates extended shelf life. These conditions can be achieved by using a semi-underground storage system with moistened walls. The use of a shading net is also an effective means of reducing temperature. Higher humidity and lower temperature inside the Zero [Energy Cool Chamber] offers a unique advantage for maintaining the firmness of fruits and vegetables by lowering the physiological loss in weight (PLW) and other metabolic processes.

ZERO ENERGY COOLING CHAMBER

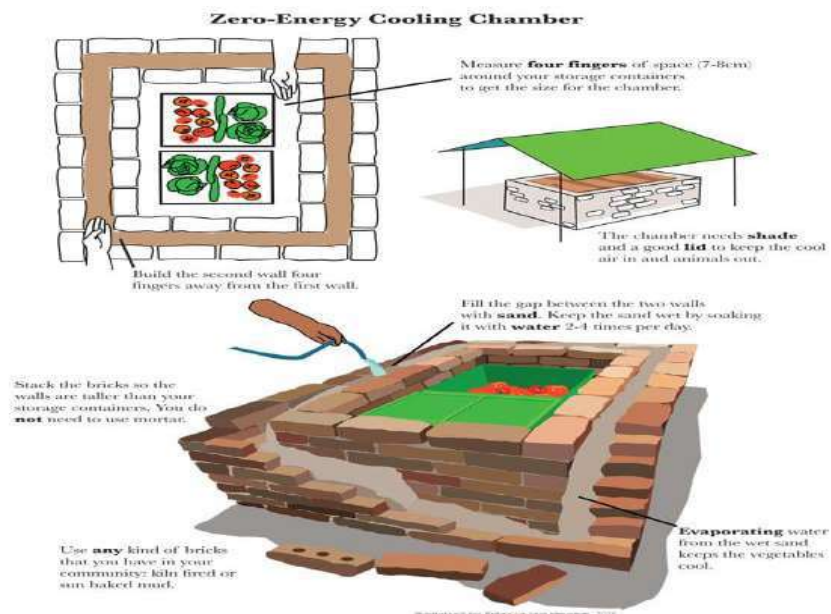
Zero energy cool chamber developed at the Indian Agricultural Research Institute (IARI), New Delhi, India, could help store the harvested fruits and vegetables for a reasonable time. Water plays a vital role in regulating relative humidity and temperature, which are important factors in the cool chamber. Too moist or too dry cool chamber will lead to unwanted growth of fungus and spoil the stored fruits. Since the moisture content in the cool chamber is regulated by



the quantity of water added to the sand, it is necessary to find the optimum quantity of water to be added for effective performance of the cool chamber.

Construction of Zero energy cool chambers (ZECC)

ZECC was made from locally available raw materials such as bricks, sand, bamboo, dry grass, jute bags etc. The [chamber is an] above-ground double-walled structure made up of bricks. The cavity of the double wall is filled with river [sand]. ZECC had a maximum efficiency during the summer season. The rise in relative humidity (90% or more) and [lower] temperature from the ambient condition could be achieved by watering the chamber twice a day.



Storage efficiency of zero energy cool chamber under local condition

The storage efficiency of zero energy cool chamber under local conditions was assessed by studying the physical, physiological, chemical and microbial changes on storage and shelf life of five vegetables viz. amaranthus, bhindi, bittergourd, brinjal and snakegourd. Storage system namely walk-in-cooler, zero energy cool chamber, sprinkling water, covering with leaves and open storage were experimented with vegetables from two sources viz. Instructional Farm (research station) and local farm at two seasons. The results obtained on physical quality changes of vegetables such as appearance, colour and texture due to storage revealed lesser rate of changes in these physical parameters with vegetables stored under walk – in – cooler followed by zero energy cool chamber compared to storage by other common methods namely sprinkling water, covering with leaves and open basket storage. Among the low cost methods of storage

zero energy cool chamber was found to be most effective and its efficiency was found at almost comparable to the refrigerated and high cost oriented method walk-in –cooler in preserving the freshness of vegetables. The physiological loss in weight was found to be minimum in vegetables stored in walk- in –cooler. Use of zero energy cool chamber was significantly effective in checking weight loss during storage.

The percentage loss in weight of vegetables was high in the other three methods particularly the open storage. In spite of increased relative humidity inside the chamber there was no microbial spoilage observed in vegetables stored under zero energy cool chamber during the study period. Fungal attack was noticed in water sprinkled vegetables. Shelf life duration of vegetables was considerably more in zero energy cool chamber as against lesser days in atmospheric temperature storage. Thus the possibility to extend the storage days of vegetables by adopting the zero energy cool chamber method is clearly indicated. The maximum and minimum temperature inside the chamber was much below the ambient conditions. The relative humidity inside the chamber was higher than atmospheric humidity. It was also observed that the seasonal fluctuation in temperature and relative humidity was very narrow in respect to fluctuation observed in the atmosphere during the two seasons, promising a fairly steady storage effect. In our country commercial cold storage are yet to make as an aid in large scale preservation of perishables because of heavy costs incurred . Thus the importance of a low cost cooking technology for horticultural crop meeting the requirements of rural conditions for prolonging the shelf- life of fresh produce is keenly felt.

Conclusion

Among all low -cost storage options, the ZECC is the most effective. Its ability to preserve freshness and texture is nearly comparable to expensive, refrigerated walk -in coolers. The chamber significantly minimizes the “Physiological Loss in Weight “(PLW), keeping vegetables firm and preventing the shriveling seen in open storage .It successfully prolongs the marketability of perishables, offering a much longer storage window than traditional atmospheric storage. Because it uses zero electricity and cheap, local materials ,it is the ideal technology for rural farmers who cannot afford commercial cold storage.

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WHY INDIA'S RICE BOOM COULD TRIGGER A WATER CRISIS

Article ID: AG-VO6-I01-121**Dr.Roohi Jan**

PhD Agriculture

Introduction

India's agricultural history is sometimes hailed as an example of resilience and magnitude. The nation has come a long way from experiencing food shortages in the decades after independence to becoming one of the world's top producers of food grains. Rice, a staple food for millions of Indians and a vital commodity in international food markets, is the key to this achievement. India has been the world's biggest producer and exporter of rice over the last 20 years, accounting for around 40% of the world's rice trade. India's food security, farmer incomes in some areas, and standing in international markets have all improved as a result of this rice boom. Beneath this success story, though, lurks a developing and sometimes disregarded problem, water scarcity. India's groundwater and surface water supplies are under unsustainable pressure due to the rapid spread of rice production, one of the most water intensive agricultural practices, in water stressed areas. Many analysts now caution that India's agricultural boom driven by rice may be jeopardizing the country's future. The rice boom has become a ticking time bomb due to declining groundwater tables, drying rivers, increased energy use, and climate uncertainty. This article examines the relationship between India's rice production success and an impending water catastrophe, the reasons why existing policies have made the issue worse, and the actions that must be taken to ensure that future generations have access to both food and water.

“The challenge is not to produce less food, but to produce it wisely, The future of Indian agriculture and the water that sustains it depends on the choices made today”

India's Rise as a Global Rice Power

Indian agriculture and culture have long revolved around rice. It sustains millions of

farmers and provides food for more than half of the nation's population. India made significant investments in high yielding rice varieties, irrigation infrastructure, fertilizers, and guaranteed procurement schemes following the Green Revolution of the 1960s and 1970s. By taking these steps, the nation went from having a shortage of food to having an abundance of it. India has become even more dominant in recent years. Indian rice exports have increased due to favorable government regulations, growing worldwide demand, and competitive pricing. In particular, non basmati rice exports have grown quickly, making India the leading supplier to West Asia, Africa, and portions of Asia. In addition to boosting rural economies and earning significant foreign income, this export increase has inspired farmers, particularly in northern areas, to keep cultivating rice year after year despite local water constraints. Over time, what started out as a strategy for ensuring food security has transformed into an export focused agricultural system that frequently disregards environmental constraints.

The Reasons Rice Requires a Lot of Water.

Because of the nature of the crop itself, rice production poses a danger to water security. Compared to most cereals, rice needs a lot more water. Long growing seasons raise the need for irrigation, particularly in hot regions, traditional paddy agriculture includes flooding fields, which results in substantial evaporation and seepage losses and producing one kilogram of rice can take 3,000 to 4,000 liters of water. Rice grows best in areas like eastern India, Assam, West Bengal, and coastal regions that have a lot of rainfall, river deltas, and naturally wet soils. However, a large portion of India's rice boom has taken place in semi arid areas, especially western Uttar Pradesh, Punjab, and Haryana, where natural rainfall is insufficient to sustain such water hungry crops. Rice almost completely thrives in these areas.

Groundwater: The Invisible Casualty

With about 25% of all groundwater extraction worldwide, India is the world's biggest user of groundwater. Increasing irrigation, maintaining harvests, and shielding farmers from unpredictable rains have all been made possible by groundwater. However, there are serious repercussions when it is overused. Groundwater is being drained more quickly than it can be replenished in rice growing states like Punjab and Haryana, and water tables are dropping by more than one meter annually in many places. It is now necessary to drill deeper than 100 to 200 feet for wells that previously reached water at short depths. Groundwater is becoming a non renewable resource due to this unrelenting extraction. Aquifers that took thousands of years to

build are being exhausted in a matter of decades. Once depleted, they are difficult to replenish, endangering agriculture's long term sustainability. Furthermore, the depletion of groundwater is not consistent. While small and marginal farmers frequently lack access to water, wealthier farmers can purchase deeper borewells and powerful pumps, which exacerbates inequality and rural hardship.

The Role of Government Policies

India's rice centric agriculture has been significantly shaped by government policies. Despite their good intentions, many of these initiatives today actually exacerbate water stress. The Minimum Support Price (MSP) scheme lowers market risk and ensures income stability by guaranteeing farmers a set price for rice. But this guarantee has also inspired farmers to cultivate rice regardless of the availability of water.

Free or Subsidised Electricity

Farmers in many states get power for free or at a very low cost. Because of this, groundwater pumping has become artificially inexpensive, which has resulted in excessive and inefficient water use, little incentive to adopt water saving technologies, rapid aquifer depletion, public procurement and storage, and large scale government procurement of rice for food distribution programs, which has created a constant demand and reinforced rice production even when storage stocks are already high. When taken as a whole, these policies have inadvertently encouraged water blind agriculture, which prioritizes short-term output over long term sustainability.

Rice Exports and the Concept of Virtual Water

India's participation in exporting virtual water is one of the most worrying aspects of its rice boom. The term virtual water describes the water that is concealed within agricultural products. India effectively sells the water necessary to grow rice when it exports it, frequently from areas that already struggle with water constraint. In other words water stressed places support global food security, local water resources are used for international markets, prices do not accurately reflect the full environmental cost of rice exports. Exporting water intensive crops from water poor areas raises significant concerns about sustainability and national resource management, even if commerce is not intrinsically detrimental.

Climate Change: A Force Multiplier

India's water problems are getting worse due to climate change, which also makes rice

farming riskier. Unpredictable rainfall patterns cause planting schedules to be disrupted and increase the need for irrigation during erratic monsoons. Farmers rely considerably more on groundwater when it doesn't rain.

Increasing Temperatures:

As temperatures rise, evaporation rates rise as well, requiring more water to produce the same results. Additionally, heat stress lowers rice output, forcing farmers to utilize more inputs and water.

Extreme Weather Events:

Heatwaves, droughts, and floods harm infrastructure and crops, further undermining agricultural systems. As a force multiplier, climate change exacerbates already existing water stress and renders current rice based farming techniques increasingly unsustainable.

Environmental Repercussions Beyond Water Scarcity:

Rice cultivation's water dilemma has wider effects on the environment, degradation of the soil as a result of ongoing flooding and chemical use, biodiversity loss as varied agricultural systems are replaced by monoculture farming, methane released from flooding rice fields causes an increase in greenhouse gas emissions. Overuse of energy because more electricity is needed for deeper groundwater pumping. Agriculture, ecology, public health, and rural livelihoods are all at risk due to these interrelated issues.

The Human Cost: Farmers at Risk

Ironically, those most at risk from the effects of India's rice boom are the farmers who are driving it. Water scarcity may eventually force farmers to give up agriculture entirely, which would result in rural migration, unemployment, and social instability. Crop failures become more common, farming costs increase due to deeper drilling and higher energy use, and small farmers face debt and financial instability.

Is Rice the Enemy? Rethinking the Narrative

It is crucial to make it clear that rice is not the adversary in and of itself. Rice is still necessary for livelihoods and food security. Where and how rice is farmed is the true issue. Using effective techniques, rice can be grown sustainably in areas with plenty of water. When policies that disregard water constraints encourage the intensive cultivation of rice in environmentally inappropriate places, a crisis arises.

Routes for a Sustainable Future

It is not necessary to completely give up rice in order to prevent a water catastrophe. Rather, India requires a forward thinking, balanced strategy.

Diversification of Crops

Encouraging farmers to switch to oilseeds, millets, and pulses can greatly cut water consumption while enhancing soil health and nutrition.

Water Saving Farming Methods

Water usage can be decreased without compromising yields thanks to technologies like direct seeded rice, alternate wetting and drying, and micro irrigation systems.

Reforming Policy, Align procurement and MSP policies with the availability of water. Reward farmers for water conservation and gradually rationalize electricity subsidies.

Regional Planning:

Rather than using standard national targets, crop choices should take into account local soil, water, and climate variables.

Investing in Education and Awareness:

In order for farmers to confidently implement sustainable practices, they must have access to information, assistance, and training.

Conclusion

The rice boom in India is at a turning point. What had represented agricultural prosperity today runs the risk of contributing to ecological deterioration. Natural scarcity is not the only cause of the nation's water crisis; legislative decisions, production trends, and development priorities that disregarded environmental constraints are also to blame. Climate stress and declining groundwater levels could jeopardize food security and farmer livelihoods, if India keeps going in the same direction. However, India can change its rice economy to one that strikes a balance between productivity and conservation with prompt reforms, technical advancement, and a renewed dedication to sustainability.

ELECTROHYDRODYNAMIC DRYING OF FOODS

Article ID: AG-VO6-I01-122**Aswathy T and Ravindra Naik***

ICAR Central Institute of Agricultural Engineering, Regional Station, Coimbatore – 641 007
Tamil Nadu, India

*Corresponding Author: Ravindra Naik

Introduction

Drying is an important unit operation in food processing. It is one of the oldest food preservation techniques, employed since ancient times through dewatering from the food material. Most conventional drying approaches are energy-intensive, accounting for around 15% of the overall production costs (Menon *et al.*, 2020). Also the energy efficiency of convective dryers is often below 50 %. Conventionally thermal-based drying techniques have remained critical disadvantages in terms of enhancing product quality and process efficiency. Recent changes in consumer demands alternative drying and processing techniques.

Electrohydrodynamic (EHD) drying is a promising non-thermal technology to better preserve the nutritional content and sensory appeal of dried fruits and vegetables. It is a novel and promising alternative drying process. Unlike conventional drying methods, EHD drying is less energy-intensive, causes the least damage to food materials and has the highest drying rates.

Mechanism of EHD

EHD is a branch of fluid mechanics, dealing with the movement of fluids under the influence of an electric field. When a high voltage electric field (HVEF) is applied between electrodes, an electric field is established that causes ionization of the surrounding fluid or air, generating charged particles. These ions migrate toward the oppositely charged electrode under the influence of the electric field and, through momentum transfer, drag neutral fluid molecules along with them, creating a bulk fluid motion known as ion wind or corona wind or electrohydrodynamic flow (Figure 1).

Figure 2 represents the flowchart of the mechanism of EHD drying.

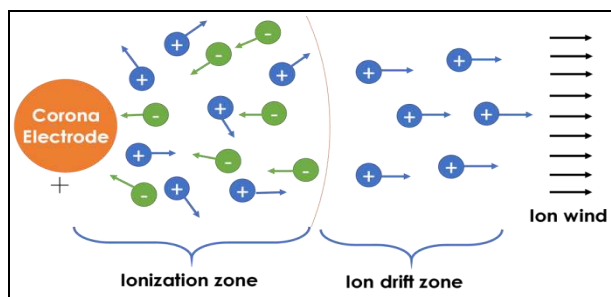


Fig 1. Generation of Ionic wind.

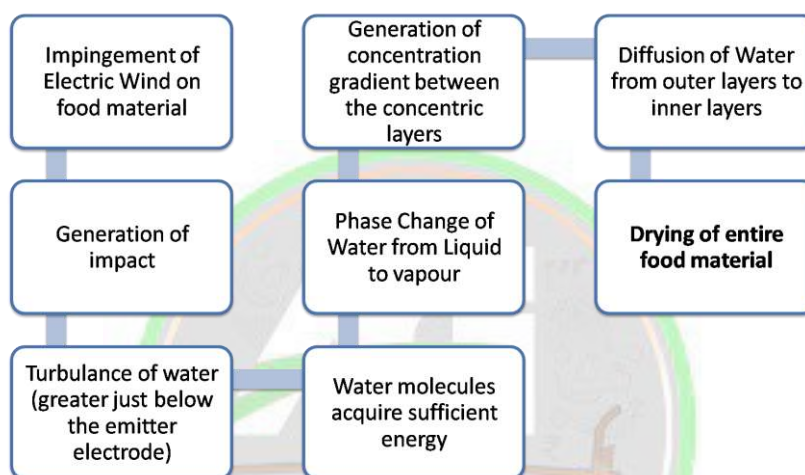


Figure 2. Mechanism of EHD Drying

EHD Drying

EHD drying refers to “removal of water from the wet material exposed to strong electric field due to aerodynamic action of the so-called corona wind, ionic wind, or electric wind”. Figure 3 depicts the schematic of EHD drying.

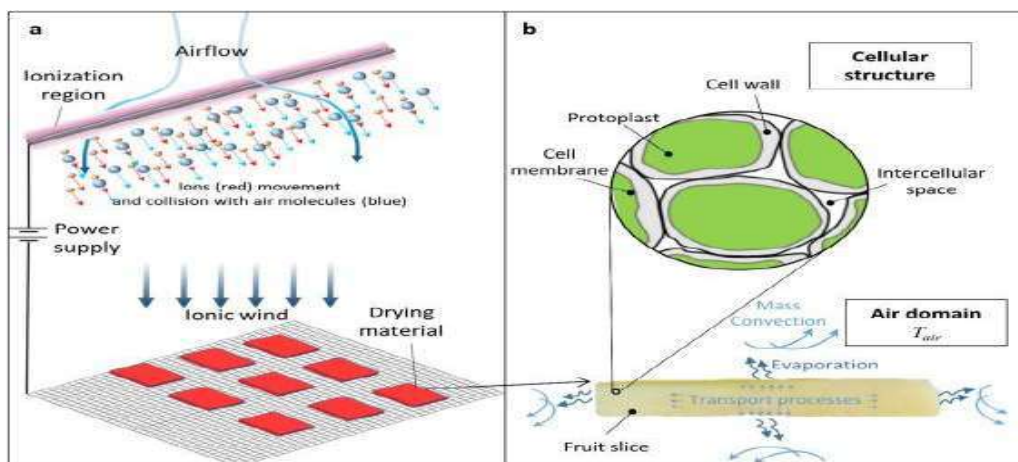


Figure 3.

- (a) Schematic of electrohydrodynamic drying setup with a wire-to-mesh configuration;
- (b) Water transport together with the different cellular environment in which the water resides (Iranshahi *et al.*, 2022)

EHD Dryer

- **Electrode material:** Copper and stainless steel are the most commonly used electrode materials for EHD drying of foods.
- **Electrode geometry:** Based on the degree of curvature of the electrode, the emitter's density varies and has a significant effect on the drying rate.
- **Number of needles:** Increment in the ionization zones with an increase in the number of needles that eventually results in increased discharge current.
- **Distance between needles/wires:** An optimal distance must be maintained between needles or wires so that the corona wind can cover the whole food surface and allow rapid drying
- **Discharge gap:** A spacing-to-gap ratio of 0.5 can result in efficient drying.

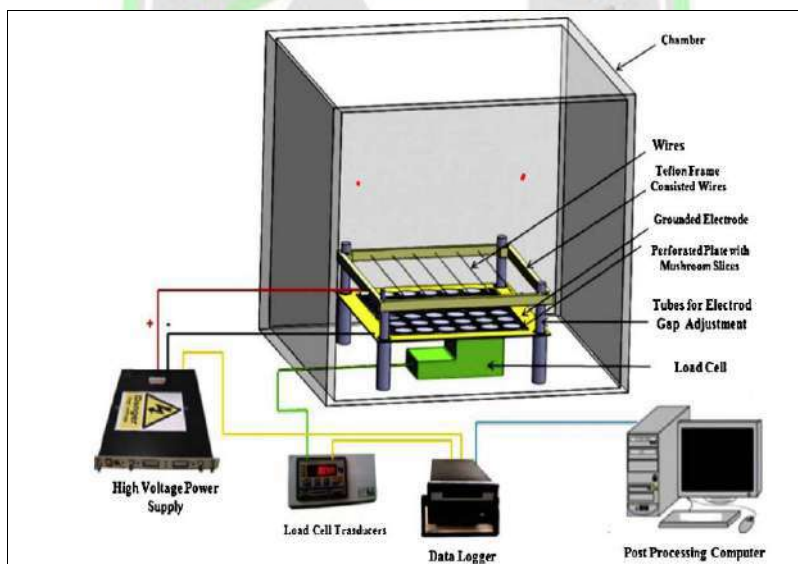


Figure 4. A schematic diagram of the EHD drying setup (H.V.–High Voltage)
(Bashkir *et al.*, 2021)

Process Variables

- ✚ **Electric field intensity:** The applied electric field is the driving force that typically ranges from 1 to 10 kV/cm

- ✚ **Air flow & Ionic flow:** It influences applied voltage, electrode gap and diameter of the wire electrode
- ✚ **Humidity & Pressure:** Formation of ionic hydrates that decrease the mobility of charged particles at higher RH, in turn resulting in reduced drying efficiency.
- ✚ **Nature of food material:** The material characteristics such as dielectric properties, texture and surface properties, diffusivity and micro structural porosity influence EHD

Effect of EHD Drying on Food Quality (Paul *et al.*, 2021)

- **Physical**

Colour: Most conventional drying methods affect colour due to thermal degradation of pigments, in addition to enzymatic and non-enzymatic browning. Researchers reported that EHD drying have better retention of colour.

Texture: Food products after EHD drying show better texture properties, such as lower hardness, better chewiness upon rehydration and softness. Unlike conventional drying, EHD drying did not create case hardening and crust formation due to more uniform volumetric shrinkage. More studies have to be taken.

Microstructure: Compared to thermal drying EHD has minimal effect on microstructure.

Shrinkage: Because of the smallest microstructural stresses due to more uniform moisture distribution in food material, those exposed to EHD drying have lower shrinkage.

- **Rehydration**

Water absorption: The EHD-dried food has better water absorption due to higher porosity.

Solid loss: The solid loss is smaller for EHD-dried foods.

- **Chemical**

pH and Acidity, Nutritional composition and Bioactive components: preserved well in EHD drying.

- **Sensory**

The evaluation of organoleptic attributes, including color, flavor, taste, texture, and overall appearance, is an essential component in the assessment of novel food products. EHD provides better sensory qualities.

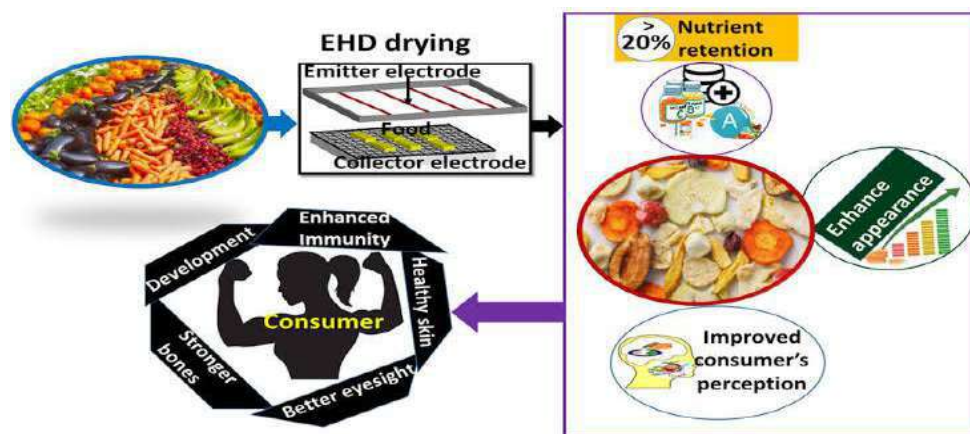


Figure 5. Impact of EHD drying process on the quality of fruits and vegetables (Onwude *et al.*, 2021)

Applications of EHD drying of foods

- ✓ **Fruits and vegetables:** suitable for drying of apples, berries, mushrooms, carrots, potatoes, mango and banana slices.
- ✓ **Aquatic products:** used for drying sea cucumber, shrimps, scallop and other sea food for maintaining quality.
- ✓ **Herbs & Spices:** suitable for drying of peppermint leaves and other botanicals.
- ✓ **Other Products:** drying of grape pomace and other agro-industrial by-products.

Advantages and limitations of EHD Drying

Advantages	Limitations
▪ Non-thermal Technology ▪ Less energy consumption ▪ Lower carbon emissions ▪ Convective heat and mass transfer ▪ Increased drying rate ▪ Reduced drying time ▪ Better retention of nutritional content, flavour and color ▪ Lower shrinkage and higher rehydration capacity ▪ Lower food production costs	▪ Drying time is more ▪ Scale-up this technology need to be done ▪ Knowledge over this drying in commercial field is less ▪ Standardization drying kinetics and drying rate ▪ A more detailed study on the nutritional value of foods after EHD drying is required

Conclusion

EHD drying is an effective non-thermal technique, especially suitable for heat-sensitive foods. It has more advantages over conventional drying methods. The EHD-dried foods have better physical qualities, such as better texture, lower shrinkage and better retention of colour. Also maintain better nutritional and sensory qualities. The EHD approach is proven to be energy-efficient and offers significant savings in drying time. But its large-scale application is still under investigation. The ultimate requirement now is to develop protocols for taking the technology from the lab to the industry. Thus, further research and collaboration are essential for the commercialisation of EHD drying technology.

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ROLE OF ARTIFICIAL INTELLIGENCE IN FOOD SENSORY ANALYSIS

Article ID: AG-VO6-I01-123**Anjana K and Ravindra Naik***

ICAR Central Institute of Agricultural Engineering, Regional Station, Coimbatore – 641 007
Tamil Nadu, India

*Corresponding Author: Ravindra Naik

Introduction

In this modern era of ever-evolving consumer demands and preferences, perspectives on food and its sensory attributes such as appearance, aroma, taste, texture, and overall acceptability have shifted, prompting the need for innovative approaches to product development and quality evaluation. Food industries now face the challenge of not only meeting consumer expectations but also predicting and adapting to changing preferences, necessitating rigorous and systematic efforts in product research and development.

Traditional sensory analysis methods were a human-centric evaluation of taste, aroma, texture, and appearance and were critical to product development, quality assurance, and consumer preference research. While human panels remain invaluable, are inherently subjective and often limited by panellist fatigue, variability, and scalability constraints. Moreover, interpreting complex sensory data and linking it to consumer preferences can be time-consuming and resource-intensive.

Artificial Intelligence (AI) is increasingly being integrated into sensory science to address these limitations. AI is rapidly enhancing the precision, speed, and scalability of sensory assessments, marking the beginning of a new era of innovation within the food industry. Adoption of Artificial Intelligence (AI) in food sensory analysis is transforming how products are developed, ensuring flavours, textures, and aromas hit the mark by decoding complex consumer preferences.

What is sensory analysis?

Sensory analysis can be defined as a scientific discipline that involves the evocation,

measurement, analysis, and interpretation of human responses to the characteristics of foods and materials as perceived through the senses of sight, smell, taste, touch, and hearing.

This evaluation can be both analytical, using trained panels to provide objective, quantitative assessments, and affective, measuring consumer preferences or acceptability. Sensory analysis plays a crucial role in product development, quality control, and consumer research, helping food industries ensure consistency, predict market success, and innovate new flavours and textures. By linking human perception with structured scientific methods, sensory analysis provides invaluable insights that guide the creation of products that meet both quality standards and evolving consumer expectations.

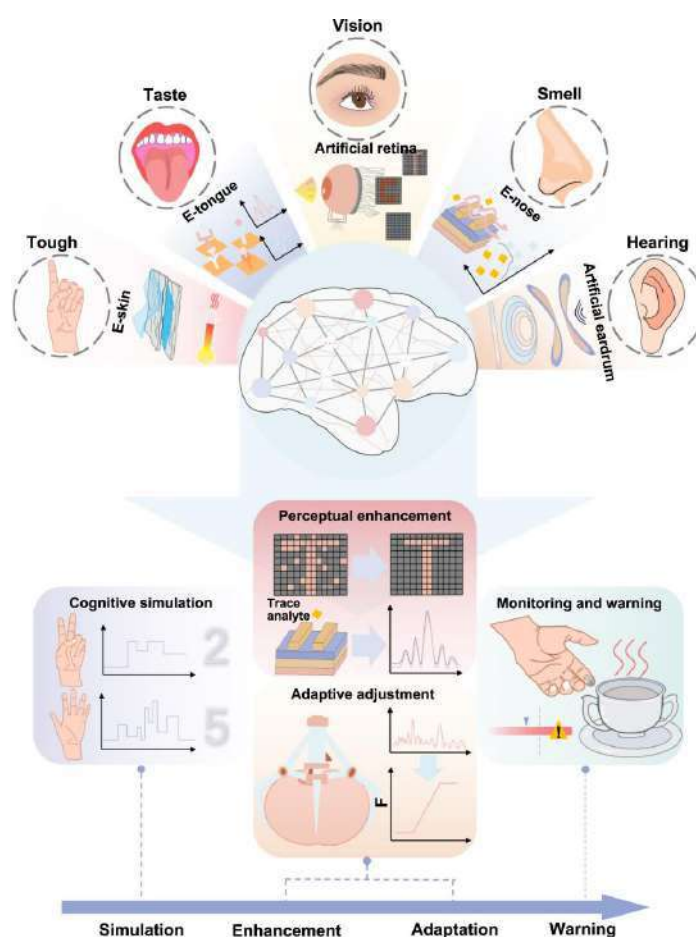


Figure 1. Schematic illustration of AI integration with artificial sensory systems for multidimensional intelligent augmentation. Five types of artificial sensory devices (touch, taste, vision, smell, and hearing) are integrated with AI to enhance cognitive simulation, perceptual enhancement, adaptive human-machine interaction, and early warning (Source: Changyu Tian *et al* 2025 *Int. J. Extrem. Manuf.* 7 042002, DOI: 10.1088/2631-7990/adbd98)

Traditional methods of sensory analysis

Food sensory analysis has historically relied on trained human panels and consumer testers. These individuals evaluate sensory attributes through structured tests such as:

- Descriptive analysis
- Hedonic (preference) tests
- Discrimination tests

While these methods offer insights grounded in human perception, they come with notable **limitations:**

- Subjectivity and variability among panelists
- Long training periods for effective panel calibration
- Time and cost constraints for large sample sets

Consequently, the food industry has sought technological solutions to augment and refine these processes.

Artificial Intelligence (AI) in sensory analysis

Artificial Intelligence (AI) in sensory analysis refers to the use of advanced computational techniques, such as machine learning, computer vision, and electronic sensing systems, to evaluate and predict human sensory responses to food products (Figure 1). AI overcomes the limitations of traditional sensory evaluation methods by processing large and complex datasets to detect patterns in flavour, aroma, texture, and appearance that correlate with consumer preferences. By integrating AI with advanced sensing technologies such as electronic noses, tongues, and computer vision systems researchers are able to quantify and predict sensory perceptions with unprecedented accuracy.

a) Electronic noses (E-Noses)

Electronic noses are sensor arrays that mimic the human olfactory system (Figure 2). When paired with AI algorithms:

- They can detect volatile compounds related to aroma
- AI models classify scent profiles and correlate them with human sensory descriptors
- Applications include spoilage detection, flavour profiling, and shelf-life prediction

b) Electronic Tongues (E-Tongues)

E-tongues use electrochemical sensors to measure taste components—such as sweetness, bitterness, and saltiness. Integrated with AI, they:

- Provide objective taste quantification
- Predict consumer preference scores
- Enable rapid comparison across product batches

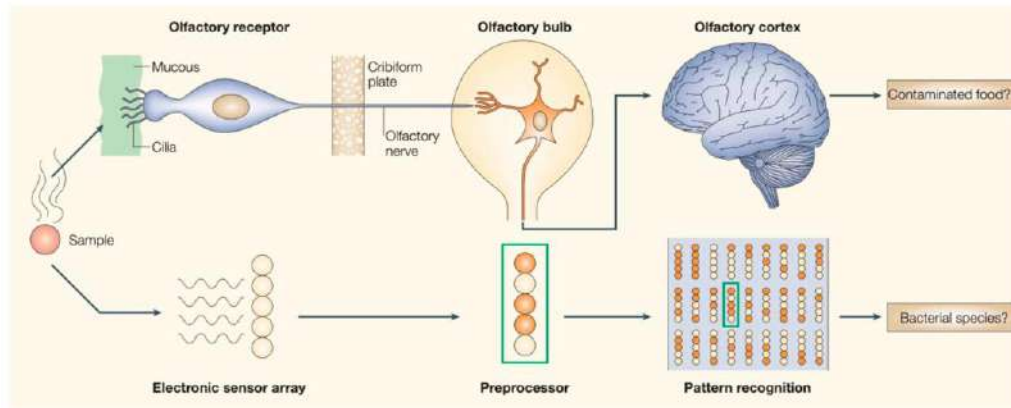


Figure 2. Schematic illustration of the biological olfactory system (A) and E-nose technology (B). (Source: Munekata *et al*, Applications of Electronic Nose, Electronic Eye and Electronic Tongue in Quality, Safety and Shelf Life of Meat and Meat Products: A Review. Sensors, 23(2), 672. <https://doi.org/10.3390/s23020672>)

c) Computer Vision and Texture Analysis

AI-driven computer vision systems analyze appearance and texture through image processing. These systems:

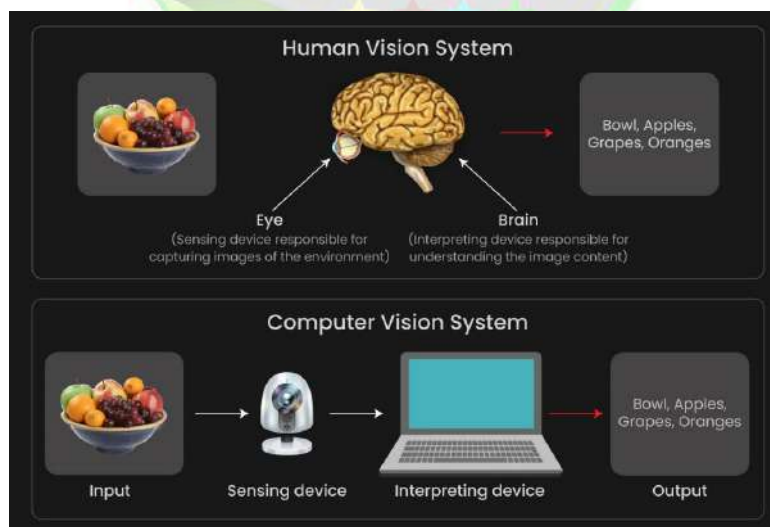


Figure 3: Diagrammatic representation of Human vision system versus Computer vision system (Source: <https://imagevision.ai/blog/understanding-computer-vision-a-technical-overview/>)

- Evaluate color, shape, surface features, and consistency
- Detect visual quality defects
- Link visual features with texture attributes perceived by humans

d) Spectroscopy

AI-integrated spectroscopy techniques are used to analyze the chemical composition of food products. These systems:

- Identify and quantify ingredients and compounds, such as proteins, fats, sugars, and flavour molecules.
- Detect chemical changes or spoilage, ensuring safety and quality.
- Correlate chemical composition with sensory attributes, such as taste, aroma, and texture, to predict consumer perception.

e) Consumer Panels

Human sensory panels remain a critical tool for collecting detailed feedback on food products. These panels:

- Evaluate taste, aroma, texture, and overall acceptability from a consumer perspective.
- Provide qualitative and quantitative data for product development and improvement.
- Serve as a benchmark for AI models, helping to train algorithms that predict sensory outcomes.

f) Social Media and Reviews

AI systems analyze consumer-generated content from social media and online reviews to understand preferences and trends. These systems:

- Mine consumer sentiments regarding flavor, texture, appearance, and overall product experience.
- Identify emerging trends and patterns in preferences and dissatisfaction.
- Integrate large-scale feedback with sensory evaluation data to guide product innovation and marketing strategies.

Machine learning models trained on large image datasets can even predict texture attributes like crispiness, graininess, or smoothness, which once required tactile human evaluation.

Applications of AI Based Sensory Analysis in Transforming the Food Industry**a) Product Development and Optimization**

AI streamlines formulation testing by rapidly identifying sensory profiles that align with target preferences. Instead of running multiple rounds of human sensory panels:

- AI models suggest optimal ingredient combinations
- Predict how changes in formulation affect sensory outcomes

This accelerates innovation while reducing development costs.

b) Quality Control and Consistency

Manufacturers maintain consistent sensory quality across production batches through AI monitoring systems that:

- Recognize deviations from standard sensory signatures
- Alert quality teams to potential issues before products reach consumers

Such real-time feedback systems are **reshaping** quality assurance protocols.

c) Consumer Insights and Market Predictions

Combining AI with consumer data enables deeper insights into how sensory attributes influence market performance. Predictive analytics can:

- Forecast which flavors are likely to succeed regionally
- Tailor products to specific demographic sensory profiles
- Reduce guesswork in launching new products

This leads to more consumer-centric innovation.

Benefits of AI in Sensory Analysis

- **Enhanced Objectivity:** AI reduces subjectivity inherent in human panels, providing standardized assessments that improve reliability.
- **Efficiency and Speed:** Automated systems process data far faster than human testing cycles, enabling high-throughput screening.
- **Scalability:** AI enables sensory analysis at scales previously impractical—hundreds or thousands of samples can be evaluated rapidly.
- **Cost Savings:** Reducing reliance on large human panel decreases expenses related to recruitment, training, and administration.

Challenges

Despite its promise, AI-driven sensory analysis faces several challenges:

- **Data Quality and Availability**

AI models require vast, well-annotated datasets that accurately represent sensory

perceptions. Acquiring such datasets is resource-intensive.

- **Model Transparency**

Complex AI algorithms (e.g., deep neural networks) can be “black boxes,” making it difficult to interpret how decisions are made in sensory prediction.

- **Human–AI Integration**

AI doesn’t replace human perception, especially for subjective qualities like cultural preference or emotional response. Effective systems integrate AI insights with expert sensory panel knowledge.

Future Outlook

The convergence of AI, advanced sensors, and big data analytics is redefining sensory science. Future directions include:

- Hybrid sensory models that combine human evaluations with AI predictions
- Use of wearable biosensors to capture real-time physiological responses to food
- Integration of AI with augmented reality (AR) and virtual reality (VR) to simulate sensory experiences

As these technologies mature, sensory analysis will become more precise, efficient, and reflective of diverse consumer experiences.

Conclusion

AI is revolutionizing food sensory analysis by bringing objectivity, scale, and predictive power to a field once dominated by subjective human judgment. Through electronic sensing technologies, predictive models, and deep data analytics, the food industry is entering a new era of sensory science one that enhances product quality, accelerates innovation, and drives consumer satisfaction. While challenges remain, the synergy between human expertise and artificial intelligence promises to continually expand the boundaries of how we understand taste, aroma, and texture.

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A SUSTAINABLE RICE-BASED FARMING APPROACH

Article ID: AG-VO6-I01-124**Nandhini V**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Bund cropping in paddy fields offers an opportunity to utilize otherwise unproductive bund areas for additional income and improved system sustainability. Blackgram (*Vigna mungo L.*), a short-duration legume, was evaluated as a bund crop in lowland rice ecosystems to assess its effects on productivity, soil fertility, and economic returns. The crop was grown on field bunds without interfering with rice cultivation, requiring minimal additional inputs and management. Results indicated that blackgram established well on paddy bunds and produced satisfactory grain yield, contributing additional income to farmers. Moreover, the leguminous nature of blackgram enhanced soil nitrogen status through biological nitrogen fixation and improved soil health. Bund cropping with blackgram also helped in reducing weed growth on bunds and minimizing soil erosion. Economic analysis revealed higher benefit–cost ratio compared to unutilized bunds, demonstrating the profitability of the system. Overall, bund cropping with blackgram in paddy fields is a viable, low-cost, and sustainable practice that enhances land use efficiency, farm income, and ecological benefits in rice-based cropping systems.

1. Introduction

Agriculture in Tamil Nadu is dominated by paddy (rice), grown extensively in irrigated and rainfed ecosystems. However, reliance on monoculture limits farm productivity and income, especially during post-monsoon and rice-fallow periods. Bund cropping — the practice of growing a secondary crop along the field bunds or in vacant spaces of a main crop field — is a promising strategy to increase productivity, improve soil fertility, and support diversified farm income. One such bund cropping practice is the integration of blackgram (*Vigna mungo L.*) with

paddy systems. Blackgram as a bund crop fits well in rice fields due to its short duration, nitrogen-fixing ability, and compatibility with residual soil moisture conditions after paddy cultivation.

2. Concepts and Definitions

2.1 What is Bund Cropping?

Bund cropping refers to the cultivation of additional crops on elevated margins (bunds) or in the interspaces of the main crop field without interfering with the primary crop production. This practice maximizes utilization of resources — light, moisture, nutrients and space — which would otherwise remain underutilized. Typically pulses, vegetables, or annual trees are chosen as bund crops depending on agro-ecology and farmer preferences.

2.2 Why Choose Blackgram as Bund Crop?

Blackgram (*Vigna mungo* L.) is a short-duration pulse crop well adapted to Tamil Nadu conditions. It is widely grown as a rice fallow crop, catch crop, and bund crop because it:

- Fixes atmospheric nitrogen, improving soil fertility.
- Requires low inputs and grows on residual moisture.
- Provides nutritional and economic benefits (high protein content).
- Fits well into rice-based cropping systems due to its adaptability and short crop cycle.



3. Benefits of Bund Cropping with Blackgram

3.1 Enhancing Farm Income

Farming rice as a sole crop often yields low returns during off-season months. Growing blackgram on bunds or in the vacant periods of paddy production can generate additional income with minimal cost. The grain and straw of blackgram can be consumed or sold, augmenting total farm profits.

3.2 Improving Soil Fertility

Blackgram, like other legumes, forms a symbiotic relationship with rhizobia, enabling biological nitrogen fixation. This process improves soil nitrogen status and reduces dependence on chemical fertilizers for subsequent crops, enhancing soil health and reducing production costs.

3.3 Efficient Resource Use

Bund cropping enables more efficient use of residual moisture, land area, and sunlight.

By exploiting the physical space around the paddy field, farmers can utilize resources that often go unutilized, thus improving overall crop productivity.

3.4 Weed Suppression and Pest Management

Dense bund cropping can act as a living mulch, suppressing weeds on bunds and field borders. Additionally, diversified cropping can interrupt pest life cycles and encourage natural biological control agents.

4. Blackgram Varieties and Suitability for Bund Cropping

Selecting appropriate blackgram varieties is crucial for successful bund cropping. TNAU agri portal lists a range of improved blackgram varieties suitable for different seasons and production conditions including rice fallows (which is analogous to bund situations):

ADT 5, VBN (Bg) 4, 5, 6, 7, and CO 6 are some recommended improved blackgram varieties, offering favorable maturity durations and yield potential.

Short-duration varieties (maturing in 60–70 days) are especially preferred for bund cropping since they complete their life cycle within the limited moisture availability windows typical of rice bund situations.

5. Agronomic Practices for Bund Cropping Blackgram

5.1 Land Preparation

Blackgram bund cropping in paddy fields requires careful planning:

- After paddy transplanting or harvesting, land should be levelled and bunds reinforced if necessary.
- Adequate bund height and width allow field access and support crop establishment without affecting rice crop roots or irrigation channels.
- For rice fallow situations, blackgram seeds can be broadcasted in standing paddy 5–10 days before rice harvest to utilize residual moisture and secure seed-soil contact for better germination.

5.2 Sowing Time and Method

- Timing blackgram sowing in relation to paddy harvest or bund preparation is vital for optimizing moisture use.
- For rice fallow planting (similar to bund cropping in rice fields), broadcast the seeds 5–10 days before paddy harvest under optimum soil moisture.

- In bunds, seeds may be sown after rice transplanting or after the paddy crop is established, depending on irrigation and soil moisture.
- Broadcasting and dibbling are common methods. Broadcasting ensures quicker soil coverage and germination under residual moisture conditions.

5.3 Seed Treatment and Rate

- Treat blackgram seeds with fungicides like carbendazim or bio-control agents (*Trichoderma viride* or *Rhizobium*) to protect against disease and improve root nodulation.
- Recommended seed rate for blackgram is typically around 20 kg/ha. For bunds, adjust proportionally based on available bund area

5.4 Nutrient Management

Blackgram requires balanced nutrition despite its nitrogen-fixing ability:

- Apply basal doses of nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O) suitable for pulses.
- Incorporate organic amendments (well-decomposed FYM) and micronutrient mixtures to enhance soil fertility and crop health.

5.5 Water Management

Blackgram relies on stored soil moisture after rice harvest. Life saving irrigation at critical stages (flowering to pod fill) can improve yield. On bunds in flooded rice fields, ensure bunds have adequate drainage and moisture for the blackgram roots without waterlogging.

5.6 Weed, Pest, and Disease Control

- Early weed control is essential for blackgram establishment, especially in bund areas prone to weed competition.
- Pulse pests such as aphids and diseases like leaf blight can be minimized with integrated management — combining timely sprays and resistant variety use.

6. Integration with Paddy Crop Management

Bund cropping should not interfere with paddy crop requirements:

Paddy irrigation schedules, nutrient applications, and mechanized operations must be adjusted so the secondary crop does not hinder primary rice productivity.

Bund crop timing should be planned around paddy field activities — like puddling,

transplanting and harvesting — to avoid physical damage. Proper synchronization ensures smooth co-existence.



7. Yield and Economic Aspects

7.1 Yield Potential

Rice fallow and bund cropping systems with blackgram have shown promising yield results when managed correctly — particularly under optimal moisture conditions or supported with life-saving irrigation. Broadcasting seeds slightly before paddy harvest ensures moisture retention and early establishment, which can increase yield compared to sowing after rice harvest.

7.2 Economic Returns

While exact returns depend on input costs and market prices, bund cropping blackgram generally enhances total farm revenue due to:

- Additional grain and fodder yield.
- Lower production costs because of reliance on residual moisture and biological nitrogen fixation.
- Improved soil fertility for subsequent crops, reducing fertilizer costs.

8. Challenges and Considerations

Despite benefits, certain challenges must be addressed:

- Poor timing or incorrect sowing depth can lead to low germination.
- Weed competition on bunds can reduce blackgram stands.
- Inadequate pest and disease control reduces overall productivity.
- Market access and price fluctuations for pulses can affect farmer profitability.

Farmers need localized extension support, weather forecasts and market insights to optimize bund cropping outcomes.

9. Conclusion and Future Prospects

Bund cropping with blackgram in paddy fields represents a sustainable, resource-efficient agricultural practice with multiple agronomic and economic benefits. Supported by TNAU's varietal and crop production recommendations, this approach can diversify cropping systems, improve soil health, and enhance overall farm profitability. Continued multidisciplinary research, farmer training, and policy support are essential for wider adoption of bund cropping practices in Tamil Nadu and similar agro-ecosystems.

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Volume: 06 Issue No: 01

NANOTECHNOLOGY-BASED ZINC AND SELENIUM SUPPLEMENTATION FOR QUALITY IMPROVEMENT OF MILK AND MILK PRODUCTS

Article ID: AG-VO6-I01-125

Rakesh Kumar^{*1}, Binita Rani¹ and Y. S. Jadoun²^{*1}Department of Dairy Microbiology, ¹Department of Dairy Chemistry and.,Associate Professor, ²Department of Dairy Extension Education,

Sanjay Gandhi Institute of Dairy Technology, Bihar Animal Sciences University, (BASU), Patna

^{*}Corresponding Author: Rakesh Kumar

Abstract

The integration of nanotechnology into dairy nutrition has emerged as an innovative and efficient strategy for improving animal health, productivity, and the quality and safety of milk and milk products. Among essential trace minerals, zinc (Zn) and selenium (Se) are of particular importance due to their critical roles in metabolic regulation, immune function, antioxidant defence, and maintenance of udder health in dairy animals. However, conventional inorganic and organic mineral supplements often exhibit limited bioavailability, higher antagonistic interactions, and substantial excretion losses, thereby reducing their biological efficiency. In this context, nanoparticle-based supplementation of zinc and selenium has gained considerable attention owing to its superior bioavailability, enhanced biological activity at lower inclusion rates, and potential for targeted delivery. Zinc and selenium nanoparticles have been reported to improve milk yield, modulate milk composition, enhance antioxidant capacity, reduce somatic cell count, and improve microbial safety and storage stability of milk and dairy products. This review critically examines the effects of nano-zinc and nano-selenium supplementation on animal physiology, milk production, milk quality, and functional attributes of dairy products. Safety concerns, dosage optimization, regulatory aspects, and future research priorities are also discussed to facilitate the responsible application of nanotechnology in dairy nutrition.

Keywords: Nanotechnology, Zinc nanoparticles, Selenium nanoparticles, Milk quality, Dairy nutrition, Antioxidant capacity

Introduction

Milk is universally recognized as a nearly complete food owing to its balanced composition of high-quality proteins, essential fatty acids, lactose, vitamins, and minerals that collectively support growth, health, and physiological functions across all age groups (Walstra et al., 2006). The nutritional value, quality, and safety of milk are not intrinsic attributes alone but are strongly influenced by animal nutrition, health status, and overall management practices adopted at the farm level (Fox & McSweeney, 2015). Among nutritional factors, trace minerals play a pivotal role in maintaining metabolic homeostasis, immune competence, reproductive efficiency, and udder health in dairy animals.

Zinc (Zn) and selenium (Se) are essential trace minerals required in minute quantities but exert profound biological effects. Zinc is involved in over 300 enzymatic reactions and is critical for protein synthesis, cell proliferation, immune modulation, and epithelial integrity of the mammary gland. Selenium, on the other hand, is a key component of antioxidant defence systems, particularly as a constituent of glutathione peroxidase, which protects cellular structures from oxidative stress and inflammation (Underwood & Suttle, 2010; NRC, 2001). Deficiencies or suboptimal utilization of these minerals can lead to impaired immune responses, increased incidence of mastitis, reduced milk yield, and compromised milk quality.

Despite their importance, the bioavailability of conventionally supplemented inorganic trace minerals remains a major challenge. Factors such as poor solubility, antagonistic interactions with other dietary components, variable absorption efficiency, and excessive fecal excretion significantly limit their effectiveness (Spears, 2003). These limitations not only reduce productive efficiency but also contribute to environmental contamination due to mineral wastage.

Recent advances in nanotechnology have provided innovative solutions to overcome these constraints by enabling the use of trace minerals in nano-sized forms (1–100 nm). Nanoparticles possess unique physicochemical properties, including a high surface-area-to-volume ratio, increased reactivity, and enhanced permeability across biological membranes. These attributes facilitate improved solubility, absorption, and cellular utilization compared with conventional mineral sources (Khan et al., 2019). In dairy nutrition, zinc and selenium nanoparticles have attracted significant attention for their potential to enhance milk yield, improve milk composition, enrich milk with functional nutrients, and ensure better microbial safety and shelf life of dairy products (Prasad et al., 2018; Singh et al., 2021).

Rationale for Using Nanoparticles in Dairy Nutrition

The application of nanoparticles in dairy nutrition is primarily driven by their superior bioavailability and efficiency at lower inclusion rates. Nano-sized zinc and selenium exhibit enhanced interaction with intestinal epithelium and cellular membranes, leading to improved absorption and systemic distribution (Khan et al., 2019). Efficient utilization of nano-minerals allows for reduced dietary inclusion levels, minimizing mineral losses through excretion and mitigating environmental pollution associated with excessive mineral supplementation (Spears, 2003).

Moreover, improved delivery of these trace minerals supports critical physiological functions such as enzymatic activity, immune responsiveness, antioxidant defence, and mammary gland health. Collectively, these benefits translate into enhanced metabolic efficiency, improved productive performance, and better quality and safety of milk produced (Prasad et al., 2018; Singh et al., 2021).

Effects of Zinc and Selenium Nanoparticles on Milk Yield and Animal Physiology

Zinc Nanoparticles (Zn-NPs)

Milk Production and Gene Expression

Dietary supplementation with zinc oxide nanoparticles has been consistently associated with increased daily milk yield and total lactation milk production, particularly in small ruminants such as dairy goats (Zhang et al., 2020; El-Saadony et al., 2021). At the molecular level, Zn-NPs have been shown to upregulate the expression of key milk-related genes, including insulin-like growth factor-1 (IGF-1) and beta-casein (CSN2). These genes play a central role in mammary gland development, cellular proliferation, and milk protein synthesis, thereby enhancing lactation efficiency and milk output (El-Saadony et al., 2021).

Rumen Microbiota and Milk Components

Zinc nanoparticles exert a positive influence on rumen microbial ecology by selectively stimulating beneficial microbial populations while stabilizing fermentation patterns (Hassan et al., 2019). Improved rumen fermentation efficiency enhances nutrient digestion and utilization, which is reflected in increased milk yield and improved milk fat content. Modulation of rumen microbiota through Zn-NP supplementation contributes to overall improvements in milk quality and productive performance (Zhang et al., 2020; Singh et al., 2021).

Somatic Cell Count and Udder Health

Somatic cell count (SCC) is a widely accepted indicator of udder health and milk hygienic quality. Nano-zinc supplementation has been shown to reduce SCC more effectively than conventional inorganic zinc sources, indicating improved udder integrity and reduced prevalence of subclinical mastitis. Enhanced immune responses and epithelial barrier function associated with Zn-NPs contribute to better udder health and superior milk quality (Spears, 2003; El-Saadony et al., 2021).

Selenium Nanoparticles (Se-NPs)

Milk Selenium Enrichment and Antioxidant Enzymes

Selenium nanoparticles have demonstrated greater efficiency in enriching milk selenium content compared with inorganic selenium supplements (Surai et al., 2018). Se-NPs significantly enhance the activity of selenium-dependent antioxidant enzymes, particularly glutathione peroxidase, which plays a crucial role in neutralizing reactive oxygen species and protecting mammary tissues from oxidative damage (Surai & Fisinin, 2016). Enhanced antioxidant status not only improves animal health but also enhances the functional and nutritional quality of milk (Singh et al., 2021).

Feed Conversion Efficiency and Lactation Performance

Several studies report that selenium nanoparticle supplementation improves feed conversion efficiency and supports sustained lactation performance (Surai et al., 2018). Although responses in milk fat and protein content may vary depending on dietary composition and physiological stage, the overall improvement in metabolic efficiency and oxidative balance contributes to better milk production and animal well-being (Underwood & Suttle, 2010).

Impact on Milk Quality and Safety

Milk Composition

Supplementation with zinc and selenium nanoparticles at appropriate levels generally maintains or modestly improves milk fat, protein, and lactose contents. Enhanced mineral bioavailability supports efficient synthesis of milk constituents without disrupting normal milk composition or technological properties.

Antioxidant and Functional Properties

Selenium-enriched milk exhibits higher antioxidant capacity due to increased activity of selenium-dependent enzymes. Improved antioxidant status enhances the nutritional value of milk

and may confer additional health benefits to consumers. Moreover, higher antioxidant levels reduce oxidative deterioration during storage, thereby improving the functional quality of milk and dairy products.

Physicochemical and Microbial Stability

Fortification of pasteurized milk with zinc nanoparticles has shown promising results in enhancing microbial and physicochemical stability during refrigerated storage. Zn-NP-fortified milk demonstrates lower total microbial counts, delayed growth of psychrotrophic bacteria, absence of coliforms, and improved pH stability compared with conventionally fortified or control milk. These characteristics indicate improved safety, extended shelf life, and better storage stability of milk and milk products.

Role in Animal Health and Bioavailability

Zinc and selenium are indispensable for immune competence, antioxidant defence, enzymatic activity, and udder health in dairy animals. Nanoparticle forms of these minerals exhibit superior absorption efficiency and tissue distribution compared with inorganic forms. Enhanced bioavailability leads to improved incorporation of zinc and selenium into biological systems and milk, supporting animal health, productive efficiency, and milk quality.

Safety and Practical Considerations

Despite their promising benefits, the application of nanoparticles in dairy nutrition requires careful attention to dosage, particle size, and duration of supplementation. Due to their high reactivity and bioavailability, excessive intake of nano-minerals may pose toxicity risks. Furthermore, long-term studies evaluating the safety of nanoparticle-fortified milk for human consumption remain limited. Regulatory frameworks governing the use of nanomaterials in animal feed and food products are still evolving, underscoring the need for standardized guidelines and comprehensive risk assessment.

Future Prospects

Future research should focus on optimizing supplementation levels, elucidating long-term health effects, and understanding the transfer, transformation, and fate of nanoparticles in milk and dairy products. Development of clear regulatory policies and robust safety evaluation protocols will be essential for the responsible commercialization of nano-mineral supplementation. Integration of nanotechnology with sustainable dairy farming practices holds substantial potential for improving milk quality, safety, and nutritional value.

Conclusion

The use of nanotechnology in dairy nutrition, particularly zinc and selenium nanoparticles, offers a promising approach to enhance animal performance and milk quality. Due to their superior bioavailability and absorption efficiency, nano-minerals effectively address the limitations of conventional inorganic mineral supplementation. Improved utilization of zinc and selenium supports immune function, antioxidant defence, enzymatic activity, and mammary gland health, resulting in improved milk yield and overall productive efficiency. Zinc nanoparticles improve rumen fermentation, lower somatic cell count, and enhance udder health, thereby improving milk yield and hygienic quality. Selenium nanoparticles strengthen antioxidant status, enrich milk with functional selenium, and support sustained lactation by reducing oxidative stress and improving metabolic efficiency. At recommended levels, nano-mineral supplementation maintains or slightly improves milk composition without compromising physicochemical properties.

In addition to production benefits, zinc and selenium nanoparticles enhance microbial safety, oxidative stability, and shelf life of milk and dairy products, improving their nutritional and functional value. However, careful optimization of dosage, particle characteristics, supplementation duration, and long-term safety evaluation is essential. Robust risk assessment and regulatory frameworks are required for safe and responsible application. Overall, zinc and selenium nanoparticles have strong potential to transform dairy nutrition by improving animal health, milk quality, and food safety. With continued research and integration into sustainable dairy farming systems, nano-minerals can significantly contribute to enhanced productivity, profitability, and nutritional security.

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Volume: 06 Issue No: 01**CLIMATE-SMART CROP MANAGEMENT PRACTICES FOR ENHANCING
PRODUCTIVITY AND RESILIENCE OF GARDEN PEA (*PISUM SATIVUM* L.)
UNDER CHANGING CLIMATIC CONDITIONS OF HIMACHAL PRADESH****Article ID: AG-VO6-I01-126****Dr. Shakuntla Rahi, Dr. Pankaj Sood, Dr. Neha Chauhan and Ranjana Thakur**

CSKHPKV, Krishi Vigyan Kendra Mandi at Sundernagar-175019, HP, India

*Corresponding Author: Dr. Shakuntla Rahi

Abstract

Climate variability poses a major threat to the productivity, profitability, and sustainability of garden pea (*Pisum sativum* L.) cultivation in Himalayan hill ecosystems, particularly in Himachal Pradesh where agriculture is highly sensitive to fluctuations in rainfall, temperature extremes, and unseasonal weather events. Recent trends in the state indicate increasing incidences of drought spells, delayed and shortened winters, frost injury, heat and cold waves, and erratic precipitation, which disrupt crop phenology by affecting germination, flowering, pod development, and final yield, while also enhancing the risk of emerging insect pests and diseases. To overcome these challenges, climate-smart crop management practices offer a viable pathway to enhance productivity and resilience of garden pea under the fragile hill ecosystems of Himachal Pradesh. This approach integrates improved and stress tolerant varieties; optimized sowing windows aligned with local agro-climatic conditions, conservation-oriented land preparation, efficient nutrient and water management, soil health enhancement, and integrated pest and disease management strategies. Adoption of these practices helps in reducing climatic risks, improving resource-use efficiency, stabilizing yields, and enhancing farm profitability while conserving the natural resource base. Climate-smart management of garden pea is therefore essential for sustaining production, strengthening resilience to climate variability, and maintaining the socio-economic and nutritional benefits of pea cultivation in Himachal Pradesh under changing climatic scenarios.

Introduction

Garden pea (*Pisum sativum* L.) is an important cool-season legume crop of high

economic, nutritional, and ecological value. It is widely cultivated for its tender green pods, dry seeds, and succulent foliage, contributing significantly to human nutrition by supplying quality proteins, carbohydrates, vitamins (A, B, and C), minerals, and dietary fiber. Being a leguminous crop, pea also enhances soil fertility through symbiotic biological nitrogen fixation, thereby improving soil health and sustainability of cropping systems. In India, and particularly in Himachal Pradesh (HP), garden pea occupies a prominent position in vegetable production owing to the state's favorable temperate and sub-temperate agro-climatic conditions. Pea cultivation provides an important source of income and employment to small and marginal farmers of mid and high hill regions of HP. Despite its importance, garden pea production is increasingly constrained by several biotic and abiotic stresses such as erratic rainfall, temperature extremes, frost injury, heat and cold waves, emerging insect pests and diseases, and gradual decline in soil fertility.

In Himachal Pradesh, the impacts of climate change are becoming more pronounced, with delayed winters, unseasonal rainfall & early onset of summer, frequent drought spells, and occasional frost events during sensitive growth stages. These climatic irregularities adversely affect crop phenology, flowering, pod setting, and ultimately yield and quality of garden pea. Moreover, shifting weather patterns favor the emergence of new pest and disease complexes, further threatening productivity in the region (Thakur et al, 2023). Under changing climatic scenarios, ensuring stable and sustainable production of garden pea in Himachal Pradesh requires the adoption of climate-smart crop management practices. These include the use of improved and stress-tolerant varieties, optimization of sowing time according to local agro-climatic conditions, efficient nutrient and water management, soil health conservation, and integrated pest and disease management strategies. Adoption of such approaches will enhance the resilience of garden pea to climate variability, safeguard farmers' livelihoods, and sustain the nutritional and economic benefits of pea cultivation in the hill ecosystems of Himachal Pradesh.

Concept of Climate-Smart Crop Management

The concept of climate-smart crop management in agriculture is focused on three core objectives: enhancing agricultural productivity and farmers' income, strengthening resilience and adaptive capacity to climate variability, and reducing greenhouse gas emissions while ensuring environmental sustainability. In garden pea (*Pisum sativum* L.) production systems, climate-smart agriculture emphasizes the adoption of climate-resilient varieties along with efficient and

precise nutrient and water management practices. It promotes improvement of soil health through the application of organic amendments, residue management, and conservation-oriented practices, as well as diversification of cropping systems to minimize climate-related risks specific to pea cultivation. Moreover, climate-smart management in garden pea integrates effective pest and disease control strategies to address climate-induced shifts in pest and pathogen dynamics. The use of weather-based agro-advisories supports farmers in making timely and informed decisions related to sowing, irrigation scheduling, fertilizer application, and plant protection measures, thereby enhancing productivity, stability, and sustainability of garden pea production under changing climatic conditions.

Climate Risks Affecting Garden Pea Production

Climate variability poses substantial challenges to garden pea production, as multiple abiotic and biotic stresses adversely influence crop growth and productivity. Terminal heat stress during the critical flowering to pod-setting stage significantly impairs pollination and pod development, resulting in poor yield formation. Conversely, frost injury at the early vegetative stage damages tender seedlings and disrupts proper crop establishment. Erratic and excessive rainfall often causes water logging, which deteriorates root function and predisposes plants to disease incidence, while drought stress in rainfed ecosystems restricts physiological processes and limits yield potential. In addition, hailstorms occurring during pod development inflict direct mechanical damage on plants and developing pods, further aggravating yield losses. Alongside these abiotic constraints, garden pea is vulnerable to major biotic stresses such as powdery mildew, downy mildew, and *Fusarium* wilt, as well as insect pests including aphids and pod borers, which collectively diminish productivity and market quality. Consequently, the adoption of climate-smart management strategies is essential to mitigate both climatic and biological risks, stabilize yields, and ensure sustainable garden pea production under increasingly variable environmental conditions (Party, *et al.* 2018).

Climate-Smart Crop Management Practices:

Selection of Climate-Resilient and High-Yielding Varieties

Climate-smart crop management in garden pea begins with the selection of climate-resilient and high-yielding varieties. Priority should be given to cultivars that are early maturing, tolerant to both heat and cold stress, and resistant to major diseases. Early-maturing varieties are particularly advantageous as they escape terminal heat stress during critical stages such as

flowering and pod development, thereby ensuring improved pod set, quality, and yield stability. Varieties possessing tolerance to temperature extremes and enhanced disease resistance help sustain productivity under fluctuating climatic conditions. Furthermore, conducting local agro-climatic evaluations and developing a diversified portfolio of well-adapted cultivars strengthens the adaptive capacity of the production system, enabling farmers to better cope with climate variability and associated production risks (Makate, *et al*, 2019).



Garden pea (Him Palam Matar-1) under protected structure



Palam Matar-1) under NICRA

Optimization of Sowing Time

Optimizing the sowing time is a key determinant of crop establishment, phenological development, and final yield. Early sowing enables the crop to avoid adverse conditions such as frost during early growth and terminal heat stress during flowering and pod formation, thereby ensuring better stand establishment and reproductive success. Timely sowing aligns critical growth stages with favorable temperature regimes, resulting in enhanced productivity and climate resilience. In contrast, delayed sowing exposes the crop to higher heat stress, greater pest and disease pressure, and moisture limitations, all of which can substantially reduce yield potential. Therefore, strict adherence to agro-climatic zone-specific sowing windows, supported by reliable weather-based advisories, is crucial for enabling informed decisions on the most suitable sowing period.

Seed Treatment and Quality Seed

The use of high-quality seed combined with appropriate seed treatment is fundamental to achieving uniform crop establishment and higher productivity. Certified, disease-free seed reduces the risk of poor germination and early-stage infections by seed-borne pathogens. Seed treatment with beneficial bio-inoculants such as *Rhizobium* and phosphate solubilizing bacteria

(PSB) enhances nodulation and improves nutrient acquisition, particularly nitrogen and phosphorus. In addition, treating seeds with *Trichoderma* spp. or suitable fungicides effectively suppresses seed- and soil-borne pathogens, thereby lowering early disease incidence. The integrated application of quality seed and scientific seed treatment practices improves seedling vigor, strengthens disease resistance, and provides a strong foundation for optimal crop growth and yield.

Soil Health and Conservation Practices

Soil health and conservation practices are essential for enhancing soil resilience and sustaining crop productivity under climate stress. Incorporation of farmyard manure or compost improves organic matter, structure, and microbial activity, thereby increasing nutrient availability. Green manuring and crop residue retention protect soil from erosion and moisture loss. In hill ecosystems, minimum or zero tillage helps conserve soil structure and reduce land degradation. Mulching with organic or plastic materials conserves moisture, suppresses weeds, and moderates soil temperature. These practices collectively improve water-use efficiency and enhance the crop's tolerance to climatic stresses.



Biomass mulching in garden pea to conserve soil moisture

Climate-Smart Nutrient Management

Climate-smart nutrient management aims to enhance crop productivity while minimizing environmental impacts through the efficient and sustainable use of plant nutrients. It emphasizes integrated nutrient management, which involves the balanced application of nitrogen, phosphorus, and potassium based on soil test values so that fertilizers match the actual nutrient requirements of crops and soils. The approach also promotes the use of organic manures,

compost, and biofertilizer to improve soil organic matter, stimulate microbial activity, and sustain long-term soil fertility. Applying nitrogen in split doses at critical growth stages increases nitrogen-use efficiency by reducing losses through leaching and volatilization while ensuring a continuous nutrient supply to plants. During stress conditions, foliar application of micronutrients helps maintain plant health by correcting hidden deficiencies and supporting essential physiological functions. Collectively, these practices improve nutrient-use efficiency, conserve soil health, lower greenhouse gas emissions associated with excessive fertilizer use, and contribute to climate-resilient, sustainable, and environmentally friendly agricultural production systems.

Efficient Water Management in Garden Pea

Efficient water management is essential for garden pea cultivation, as the crop is highly sensitive to both drought and water logging. Climate-smart water management focuses on ensuring optimum soil moisture while preventing excess water that can impair root function and reduce productivity. In high-rainfall areas, raised-bed planting improves drainage, minimizes water stagnation, and enhances soil aeration around the root zone. The adoption of drip or sprinkler irrigation systems allows precise and uniform water application, reduces evaporation and conveyance losses, and improves water-use efficiency compared with conventional flood irrigation. Providing timely irrigations at critical growth stages, particularly during flowering and pod-filling, prevents moisture stress, promotes proper pod development, and maintains yield and quality. In addition, rainwater harvesting structures and farm ponds help store surplus rainfall for supplemental irrigation during dry periods. Together, these practices conserve water, enhance water-use efficiency, stabilize yields under variable climatic conditions, and support sustainable, climate-resilient garden pea production.



Water storage tank



Rain water harvesting structure

Integrated Disease and Pest Management

Integrated Disease and Pest Management (ID&PM) is a key climate-smart strategy for garden pea cultivation, as climate change induced variations in temperature, humidity, and rainfall often intensify pest and disease incidence. ID&PM prioritizes the use of resistant or tolerant varieties as the first line of defense, reducing dependence on chemical pesticides while ensuring yield stability. Crop rotation plays an important role in disrupting the life cycles of insect pests and soil-borne pathogens, thereby preventing their accumulation in the field. The use of pheromone traps and yellow sticky traps aids in pest monitoring and mass trapping, allowing early detection and timely management in an environmentally friendly manner. Biological control agents, including beneficial insects, parasitoids, and microbial biopesticides, help suppress pest populations naturally while maintaining ecological balance. Chemical pesticides are applied only when pest populations exceed economic threshold levels, and only recommended; safer formulations are selected to minimize residues and environmental contamination. By avoiding indiscriminate pesticide use, ID&PM conserves beneficial organisms, reduces environmental pollution, delays the development of resistance in pests, and supports sustainable crop health and productivity under changing climatic conditions.

Cropping System Diversification

Cropping system diversification through the integration of pea with cereals or oilseeds via intercropping, inclusion of pea in vegetable-based crop rotations, and adoption of pea–wheat or pea–mustard sequences plays a significant role in enhancing agricultural sustainability. Such diversified systems improve resource-use efficiency, enhance soil fertility through biological nitrogen fixation, and contribute to effective pest and disease management. Diversification also minimizes production risks by reducing dependence on a single crop and helps stabilize farm income under climate variability, thereby promoting resilient and profitable farming systems.

Use of Digital and Climate Information Services

The use of digital and climate information services, including weather-based advisories, mobile applications, agro-advisory platforms, and real-time pest and disease alerts, significantly enhances farmers' capacity to make timely, climate-informed decisions. These tools deliver updated information on weather forecasts, crop management practices, and emerging pest and disease threats, enabling farmers to optimize sowing schedules, irrigation, fertilizer application, and plant protection measures. By reducing uncertainty and strengthening preparedness, digital

platforms help minimize climate-related risks, safeguard crop productivity, and promote overall farm resilience and profitability.



Weather based agro advisories provided to the farmers

Environmental Benefits of Climate-Smart Garden Pea Farming

Climate-smart garden pea farming provides multiple environmental benefits, making it an important component of sustainable agriculture. As a leguminous crop, pea contributes to biological nitrogen fixation, thereby reducing dependence on synthetic nitrogen fertilizers and minimizing associated environmental impacts. Its cultivation improves soil organic carbon through biomass addition and enhanced soil structure, which strengthens long-term soil health. Climate-smart practices in pea production further help reduce greenhouse gas emissions by optimizing fertilizer use and promoting efficient resource management. Moreover, diversified pea-based systems support biodiversity conservation by fostering a wider range of flora and fauna within the agro-ecosystem. Overall, climate-smart garden pea farming promotes sustainable use of natural resources while maintaining productivity and ecological balance.

Socio-Economic Benefits

Climate-smart garden pea cultivation delivers substantial socio-economic benefits, particularly in hill and tribal regions. The adoption of improved production practices enhances crop productivity and profitability, thereby increasing farmers' income and expanding market opportunities. The crop also generates considerable on-farm and off-farm employment through activities such as sowing, harvesting, grading, processing, and marketing, which support rural livelihoods. Garden pea is nutritionally rich and contributes to household nutritional security due

to its high protein, vitamin, and mineral content. Furthermore, climate-resilient production practices strengthen the livelihood resilience of small and marginal farmers by reducing climate-related risks and ensuring more stable returns, ultimately improving overall socio-economic well-being.



Capacity building of farmers for management of climate resilient technology in garden pea

Challenges in Adoption

The adoption of climate-smart garden pea farming faces several challenges that limit its wider implementation. Major constraints include limited awareness and technical knowledge among farmers, inadequate access to quality seed and essential inputs, and fragmented landholdings that restrict mechanization and efficient resource use. In addition, the lack of reliable irrigation infrastructure and weak market linkages further hinder productivity and profitability. Overcoming these barriers requires targeted policy support, farmer capacity building, and strengthened institutional mechanisms to ensure that farmers have the knowledge, resources, and market access needed to adopt sustainable and resilient garden pea cultivation practices.

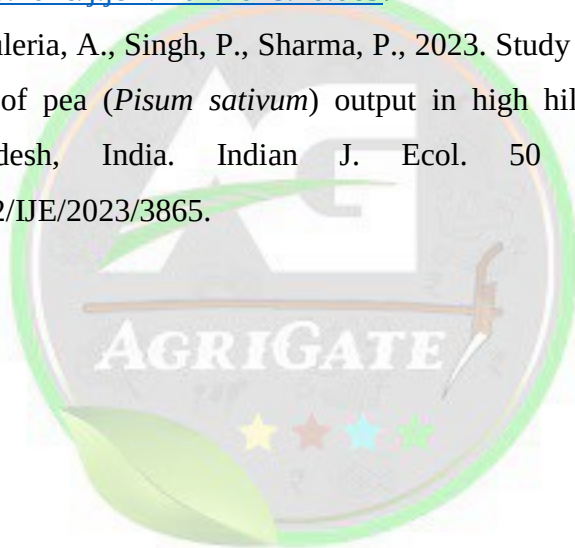
Conclusion

Climate-smart crop management strategies offer a promising pathway for the sustainable intensification of garden pea production systems. The integration of climate-resilient varieties with optimized sowing schedules, efficient nutrient and water management, soil conservation practices, and integrated pest and disease management can significantly enhance both productivity and resilience to climate variability. Furthermore, the effective dissemination of climate information services, strengthened extension support, targeted farmer capacity building,

and enabling policy interventions are essential for scaling up adoption. Together, these efforts can ensure that garden pea cultivation evolves into a more sustainable, profitable, and climate-resilient enterprise for diverse agro-ecological regions.

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DRIP IRRIGATION IN RICE: A MODERN WATER- SAVING TECHNIQUE

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**Dr.Reeba Jacob T.Abinaya, S.Ilakiya, C.Jenitha, S.Meenaja, G.Nanthini, *M.Rohini Pon
Vinisha, M.Rapri Devi, G.Samyuktha, K.Sumithra**

Asst. Prof Agricultural Extension, Undergraduate Student of B.Sc. (Hons.)Agriculture,
S.Thangapazham Agricultural College (Affiliated to TNAU), Vasudevanallur, Tenkasi-627760,
Tamil Nadu, India

*Corresponding Author: M.Rohini Pon Vinisha

Introduction

Rice is a staple food for millions of people, but traditional rice cultivation uses a lot of water. Normally, rice is grown in flooded fields, which wastes water and can increase costs for farmers. Drip irrigation is a modern method that helps save water while keeping rice healthy and productive. Rice is one of the most water-demanding crops. Traditional paddy cultivation uses flooded fields, which consumes large amounts of water. Drip irrigation is a modern technique that delivers water directly to plant roots, saving water and improving crop efficiency.

What is Drip Irrigation?

Drip irrigation is a system of pipes, tubes, and emitters that delivers water slowly and directly to the base of each plant. Unlike conventional flooding, water goes only to the roots, reducing wastage and ensuring efficient use of water.

How Drip Irrigation Works in Rice?

In rice cultivation, drip irrigation can be combined with alternate wetting and drying (AWD). This means water is supplied in controlled amounts, and fields are allowed to dry slightly between irrigations. This improves root health and reduces water use.

Benefits of Drip Irrigation in Rice: Water Conservation: Uses 30–50% less water than traditional flooded methods.

Weed Control: Only the root zone is watered, limiting weed growth.

Efficient Fertilizer Use: Fertilizers can be applied through the drip system (fertigation), enhancing nutrient absorption.

Healthy Roots: Reduces waterlogging and root diseases.

Improved Yield: Proper water and nutrient supply can increase productivity.

Energy Saving: Requires less pumping and labor compared to flood irrigation.



Suitable Fields for Drip Irrigation:

- Flat or gently sloping fields.
- Raised beds or ridge-and-furrow systems work well.
- Areas with water scarcity or irregular rainfall.

Steps to Install Drip Irrigation in Rice:

1. Prepare the field and remove weeds.
2. Lay main and lateral pipes along rice rows.
3. Place emitters near the roots of rice plants.
4. Connect the system to a water source and check pressure.
5. Monitor soil moisture and adjust water supply as needed.
6. Clean pipes and emitters regularly to prevent clogging.

Challenges in Drip Irrigation for Rice:

- Initial cost of installation is higher than traditional flooding.
- Regular maintenance is needed to avoid clogging.
- Not all rice varieties respond equally to drip irrigation.

Conclusion

Drip irrigation in rice is an innovative and sustainable method. It saves water, reduces

labor, improves fertilizer efficiency, limits weed growth, and promotes healthier plant roots. While it requires some investment and management, it is especially beneficial in water-scarce areas and helps farmers grow rice more efficiently.

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MANAGEMENT OF BROWN LEAF SPOT IN RICE

Article ID: AG-VO6-I01-128**C. S. Gopika**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Brown leaf spot is a major fungal disease of rice that affects crop productivity and grain quality worldwide. The disease is more prevalent under conditions of poor soil fertility, moisture stress, and high humidity. It is caused by *Bipolaris oryzae*, a seed-borne and air-borne pathogen. Typical symptoms include brown lesions with dark margins on leaves and discoloration of grains. Severe infection leads to premature leaf drying and significant yield loss. Effective management involves an integrated approach including use of healthy seeds, balanced fertilization, seed treatment, resistant varieties, and timely fungicide application. Proper understanding of the disease and its management is essential for sustainable rice production.

Introduction

Rice (*Oryza sativa* L.) crop (family Poaceae) is known as staple food in world (FAO, 2004) and its production have a direct impact on the poor's life (Seck et al., 2012). Its production is exaggerated with many factors (abiotic and biotic). Mostly biotic causing agents (pathogens) like fungus, nematodes, bacteria and virus are dominant in reducing the production in a qualitative and quantitative way by causing different diseases of rice crops in the world. (John and Fielding, 2014). Rice is a staple food crop for a large portion of the world's population. Among the various diseases affecting rice, brown leaf spot is one of the oldest and most widespread. Historically, the disease was associated with the Bengal famine, highlighting its potential to cause severe crop losses. Although often considered a minor disease, brown leaf spot can become destructive under unfavorable growing conditions.

Symptoms:

- Small, circular to oval brown spots appear on leaves
- Lesions have dark brown margins with gray or light brown centers
- Spots enlarge and merge, leading to drying of leaves
- Seedlings may show blight symptoms
- Infected grains show brown or black discoloration, reducing quality

**Pathogenic character:**

Brown Spot: *Helminthosporium oryzae*—FUNGAL DISEASE

(Syn: *Drechslera oryzae*) (Sexual stage : *Cochliobolus miyabeanus*)

- The fungi causing the disease occur in two states or stages. These are the asexual stage, which is called anamorph or imperfect stage and the sexual stage, which is called teleomorph or the perfect stage.
- The somatic structures of the fungus consist of black velvety mycelial mats which are made up of prostrate hyphae and erect sporophores. The hyphae are abundant, branching, and anastomosing. They are dark brown or olivaceous and measure 8-15 μm or more in diameter. The sporophores arise as lateral branches from the hyphae. The conidia measure 35-170 x 11-17 μm . Typical conidia are slightly curved, widest at the middle and tapering toward the hemispherical apex, where their width approximates half the median width. Mature conidia are brownish with a moderately thin peripheral wall.

Mode of spread and survival:

- The pathogen is both seed-borne and soil-borne.
- Primary infection occurs through infected seeds, while secondary spread occurs by fungal spores carried by wind and rain.

- Crop residues act as a source of inoculum for the next season.

Management:**Cultural Control:**

- Use certified disease-free seeds
- Maintain balanced fertilization
- Avoid moisture stress through proper irrigation
- Remove and destroy infected crop residues

Seed Treatment :

Treat seeds with Carbendazim or Thiram @ 2–3 g/kg of seed

Chemical Control :

- Spray Mancozeb 0.25% or Propiconazole 1 ml/L of water
- Repeat spraying at 10–15 day intervals if required.

Conclusion

Brown spot disease is persistent in some of the rice producing areas but not in others. There is a need to work into the epidemiological factors which initiate and increase the disease. The sources and role of primary inoculum in occurrence of the disease is poorly understood. The physical factors which influence the host physiology associated with higher brown spot incidence needs to be addressed keeping in view the recent advances made in use of various molecular tools. Brown leaf spot of rice is a significant disease that can severely affect yield and grain quality, particularly under stress conditions. Adoption of integrated disease management practices combining cultural, chemical, and varietal approaches is essential for effective control. Awareness and timely intervention can minimize losses and support sustainable rice cultivation.

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MANAGEMENT OF POWDERY MILDEW IN BLACK GRAM CAUSED BY *Erysiphe polygoni*

Article ID: AG-VO6-I01-129**P. Subathra**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Powdery mildew, primarily caused by the obligate fungal pathogen *Erysiphe polygoni*, is a widespread foliar disease that substantially reduces yield and quality of black gram (*Vigna mungo*) crops. The disease manifests as whitish powdery mycelial growth on leaves, stems and pods, particularly during warm and humid conditions, leading to impaired photosynthesis and reduced productivity. Effective management integrates cultural, chemical, biological and organic strategies to suppress pathogen development while minimizing environmental impact. Chemical fungicides such as Cyflufenamid and Propiconazole + Difenconazole combinations have shown high efficacy in reducing disease severity. Biological agents like *Ampelomyces quisqualis* and *Bacillus subtilis*, as well as botanicals and organic amendments (e.g., neem leaf extract, Panchgavya), also contribute to disease suppression and improved crop performance. Integrated approaches combining fungicides with bioagents or botanicals offer sustainable control, reduce chemical inputs, and enhance economic returns. Future research should prioritize resistant cultivars and optimized prediction models to further strengthen powdery mildew management frameworks in black gram production systems.

Introduction

Black gram (*Vigna mungo*), a major pulse crop in South Asia, suffers significant yield losses due to powdery mildew disease, especially under conducive weather conditions. The pathogen *Erysiphe polygoni* proliferates rapidly on foliage, reducing photosynthetic area and plant vigor. Yield losses of 20–30% are common in untreated crops. The black gram variety, VBN (g) 4 which is susceptible to powdery mildew was selected for this study. Sowing was

taken up during second fortnight of December at a spacing of 30 x 10 cm. The crop was grown under rainfed conditions by adopting all the agronomic practices as per the recommendation of crop production guide, Tamil Nadu except fungicides application.

Among the diseases powdery mildew caused by *Erysiphe polygoni* is one of the economically important disease in black gram which occurs at later stages of crop growth causing an yield loss of 20 per cent.

SYMPTOMS:

- Early Stage: Small, white, powdery spots appear on the upper leaf surfaces, sometimes on both sides.
- Progression: Spots enlarge, merge, and cover leaves, petioles, stems, and pods, giving the plant a greyish-white, dusty appearance. **Leaf Impact:** Leaves turn yellow, become dry, and eventually shed prematurely (defoliation).
- Pod Impact: Pods become malformed, smaller, and contain fewer, poorly filled seeds, leading to reduced yield.
- Later Stage: The white powdery mass can turn dull or dirty grayish as it matures. Finally the leaves will be shed off.



PATHOGENIC CHARACTER:

The fungus is ectophytic, sending haustoria into the epidermal cells. Conidiophores arise vertically from the leaf surface, bearing conidia in short chains. Conidia are hyaline; thin walled; elliptical, barrel shaped, or cylindrical; and single celled. Chasmothecia appear as minute, black, globose structures with myceloid appendages. Each cleistothecium contains four to eight asci, and each ascus contains three to eight ascospores, which are elliptical, hyaline, and single celled.

MODE OF SPREAD AND SURVIVAL:

Moderate temperature (22–28°C) and high relative humidity with dry weather .Cloudy

conditions and poor air circulation. Dense crop canopy and excess nitrogen application. It survives as chasmothecia in the infected plant debris. It primarily spread through ascospores from perennating chasmothecia and secondary spread through air borne conidia, tools and implement, rain splash.

FAVOURABLE CONDITION;

The disease is severe generally during late kharif and rabi seasons under warm humid weather.

DISEASE CYCLE :

The disease is severe generally during late kharif and rabi seasons under warm humid weather.

MANAGEMENT PRACTICES:

Cultural Management

- Use of disease-free and healthy seeds
- Maintenance of optimum plant spacing to improve air circulation
- Avoid excessive nitrogen fertilization

Timely sowing to escape peak disease incidence.

- Removal and destruction of infected

crop residues Host Plant Resistance

- Cultivation of tolerant or resistant varieties (where available)
- Use of locally adapted varieties with lower disease

susceptibility Biological Management

- Application of *Trichoderma viride* or *Pseudomonas fluorescens* as eco-friendly options.
- Use of botanical extracts like garlic or turmeric extract
- Spray NSKE @ 5% or neem oil @ 3% twice at 10 days interval
- Spray Eucalyptus leaf extract @ 10% at initiation of disease and 10 days later
- Spray any one of the following fungicides at initiation of disease and second spray at 15 days later.

Chemical Management

- Wettable Sulphur 0.2% (2 g/litre of water)
- Hexaconazole 0.1% (1 ml/litre of water)
- Propiconazole 0.1%
- Carbendazim 50 WP @500g/ha

- Propiconazole 25% EC @ 500ml/ha
- Azoxystrobin 5.1%w/w +Tebuconazole 9.1% w/w+ Prochloraz 18.2 % w/w EC @ 1250ml/ha
- Captan 70% + Hexaconazole 5% WP @ 750ml/ha
- Sulphur 85% DP @ 15-20 kg/ha

Conclusion

Powdery mildew is a major constraint to black gram production, especially under favorable climatic conditions. Adoption of integrated disease management practices can significantly reduce disease severity and yield losses. Emphasis on eco-friendly and preventive measures will ensure sustainable black gram cultivation while minimizing environmental risks.

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PREMATURE FLOWERING: A MAJOR CONSTRAINT TO FIBRE QUALITY IN JUTE

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Ananya Baidya^{a*}, Mohammad Anwar Ali^b, P. Lavanya^c, Tanmay Samajdar^d, Ritesh Saha^d^aScientist, ICAR-Central Soil Salinity Research Institute. Karnal, Haryana-132001^bAssistant Professor, Crop Physiology, VIAT, SAFT, Vignan University, Vadlamudi-522213^cScientist, ICAR-National Institute of Natural Fibre Engineering and Technology,
Kolkata, West Bengal-700040^dPrincipal Scientist, ICAR- Central Research Institute for Jute and Allied Fibres, Barrackpore,
West Bengal-700121, India

*Corresponding Author: Ananya Baidyaa

1. Introduction

Jute, often referred to as the “golden fibre”, occupies a unique position among natural fibres due to its biodegradability, strength, and eco-friendly nature. It plays a crucial role in sustainable agriculture, rural livelihoods, and green industries across South and Southeast Asia. India is the largest producer of jute in the world, contributing about 62.2% of global production and accounting for nearly 59% of the total area under jute cultivation worldwide. In the country, jute is grown on approximately 0.71 million hectares, with an annual production of about 9.98 million bales (FAOSTAT 2022). The crop is predominantly cultivated in the eastern states of India like West Bengal, Assam, and Bihar, which together account for nearly 98% of India’s jute area and production. Notably, almost 85% of global jute cultivation is concentrated in the Ganges Delta, a fertile agro-ecological region shared by India and Bangladesh.

Jute (*Corchorus olitorius* L. and *Corchorus capsularis* L.) is valued not only for its economic importance but also for its contribution to environmental sustainability as a renewable and biodegradable fibre crop. Fibre quality in jute is largely governed by plant height, internodal length, bast fibre development, and secondary cell wall thickening. However, these desirable traits are highly sensitive to environmental conditions and crop management practices. Among

the various biotic and abiotic factors influencing jute productivity and fibre quality, premature flowering has emerged as one of the most critical yet often underestimated constraints. Early flowering leads to premature termination of vegetative growth, resulting in shorter plants, reduced fibre length, coarser fibres, lower cellulose content, and overall deterioration of fibre quality. With increasing climate variability, rising temperatures, erratic rainfall, and changes in photothermal regimes, the incidence of premature flowering in jute has become more frequent, posing serious challenges to sustainable fibre production.

Jute is a quantitative short-day plant, and its flowering behaviour is highly sensitive to photoperiod, temperature, nutrient availability, and plant water status. Any deviation from optimum growing conditions can either delay flowering or induce untimely floral initiation, both of which have direct implications for fibre yield, quality, and seed production. From a research perspective, premature flowering is particularly important because it affects crop duration, biomass partitioning, fibre fineness, and adaptability to stress-prone environments. While uncontrolled early flowering is detrimental to fibre production, regulated induction of flowering can be beneficial for seed production, stress escape, and integration of jute into intensive cropping systems. Very early sowing window *i.e.* before middle of March may induce early flowering. Therefore, understanding the physiological and environmental drivers of early flowering in jute has become a researchable issue of strategic importance under changing climate scenarios.

2. Importance of Vegetative Growth for Fibre Development

In jute, the economic value of the crop largely depends on the quality and quantity of bast fibre, which develops from the phloem tissues of the stem. A sufficiently long and uninterrupted vegetative growth phase is essential for optimum fibre development, as it allows adequate stem elongation, increase in stem girth, and sustained cambial activity, all of which are crucial for the formation of well-developed fibre bundles. During this phase, fibre cells undergo progressive thickening of secondary cell walls with enhanced deposition of cellulose and hemicellulose, imparting strength, fineness, and uniformity to the fibre. Prolonged vegetative growth also promotes longer internodes, resulting in longer and finer fibres preferred by the jute industry. Conversely, any factor that triggers an early shift from the vegetative to the reproductive phase such as photoperiod, nutrient imbalance, or moisture deficit-interrupts cambial activity and fibre

cell maturation, ultimately leading to shorter, coarser fibres with inferior tensile strength and reduced market value.

3. Premature Flowering in Jute: Concept and Significance

Premature flowering, defined as the early initiation of floral buds before a plant achieves adequate vegetative growth, is a major constraint to fibre productivity in jute. In this crop, the onset of flowering acts as a physiological switch that redirects photosynthates and metabolic energy from stem elongation and thickening towards reproductive development. As a result, cambial activity declines, fibre cell differentiation is disrupted, and the deposition of structural carbohydrates such as cellulose is reduced, ultimately leading to inferior fibre quality and yield. This problem is particularly critical in fibre crops like jute, where economic returns depend primarily on stem growth and fibre maturation rather than seed production. Environmental factors such as photoperiod, temperature, and moisture stress often accelerate floral initiation, thereby shortening the vegetative phase and compromising fibre development. Understanding and managing premature flowering is therefore essential for sustaining jute productivity and improving fibre quality under changing climatic conditions.

4. Causes of Premature Flowering in Jute

Flowering, the developmental transition from vegetative growth to reproductive phase, represents a critical life cycle switch that determines crop reproductive success and yield potential. However, this process is concurrently modulated by a multilayered regulatory network incorporating photoperiods, phytohormones, and stress responses, enabling plants to integrate multiple signaling inputs (Osnato et al., 2022). Premature flowering in jute is strongly influenced by a combination of environmental and genetic factors. As a short-day plant, jute responds to decreasing day length by initiating flowering; therefore, early sowing under shortening photoperiods or cultivation at higher latitudes often triggers early floral initiation before adequate stem growth is achieved.

Temperature stress further aggravates this problem, as elevated temperatures-particularly during the early vegetative stage-accelerate plant development and shorten the vegetative phase, leading to early flowering. With ongoing climate change, rising temperatures have intensified this risk across major jute-growing regions. Moisture stress, whether due to drought or intermittent water availability, also promotes stress-induced flowering as a survival strategy, forcing the plant to complete its life cycle rapidly at the cost of fibre yield and quality.

Nutritional factors play an equally important role; insufficient nitrogen or imbalanced fertilization reduces vegetative vigor and hastens the shift from vegetative to reproductive growth. In addition, varietal differences significantly influence the extent of premature flowering, with traditional jute cultivars generally being more sensitive than improved, photo-insensitive varieties. Effective management of these interacting factors is therefore essential for maintaining a longer vegetative phase and ensuring superior fibre development in jute (Ghosh et al., 2013).

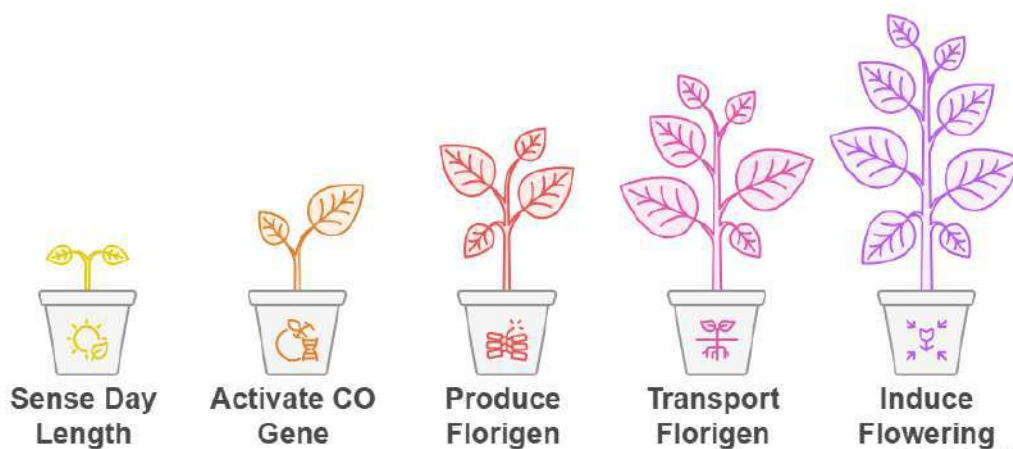


Fig.1 Regulatory Cascade of Flowering Initiation

5. Physiological and Biochemical Basis of Premature Flowering

Premature flowering in jute is governed by a complex interplay between environmental signals and internal physiological processes. Stress conditions such as high temperature, moisture deficit, and nutrient imbalance disturb the plant's hormonal equilibrium, leading to elevated levels of florigen (FT protein), which accelerates the transition from vegetative to reproductive growth (Taiz et al., 2015). Simultaneously, the activity of growth-promoting hormones like auxins and gibberellins declines, restricting stem elongation and reducing cambial activity essential for fibre development. Stress-induced increases in ethylene further hasten senescence and suppress vegetative growth, reinforcing early flowering responses. These hormonal and physiological shifts are closely linked to biochemical changes within the stem, where early floral initiation limits cellulose synthesis while enhancing lignin deposition in fibre cells. The combined effect is the production of coarse, stiff, and inferior-quality fibres, underscoring the need to manage both environmental stresses and endogenous signalling pathways to sustain fibre yield and quality in jute.

6. Impact of Premature Flowering on Fibre Quality

Premature flowering severely compromises jute fibre quality by shortening the vital vegetative phase during which stem elongation and fibre differentiation take place. When flowering begins too early, stem growth slows down, leading to poor internode development and consequently shorter fibres that are unsuitable for fine textile and diversified jute products. At the same time, early lignification of fibre cells increases fibre thickness and stiffness, resulting in coarser fibres with reduced spinnability and processing efficiency. The curtailed growth period also restricts cellulose deposition in bast fibres, while the proportion of lignin increases, adversely affecting fibre strength, fineness, and flexibility. Together, these changes reduce overall stem biomass, leading to a significant decline in fibre yield per unit area, which ultimately impacts farmer's income and disrupts the supply of quality raw jute to the jute industry.

Table 1: Effects of premature flowering in jute

Aspect	Effects
Reduction in Fibre Length	Early cessation of stem elongation restricts internode development, resulting in shorter fibres that are less suitable for high-quality textile and spinning applications.
Increased Fibre Coarseness	Premature flowering accelerates lignification, leading to increased fibre diameter and stiffness, which adversely affects spinnability and processing quality.
Lower Cellulose Content	A shortened vegetative phase limits cellulose deposition, while the relative lignin content increases, causing deterioration in fibre strength, fineness, and flexibility.
Decline in Fibre Yield	Reduced stem biomass due to early reproductive transition directly lowers fibre yield/ unit area, negatively impacting farmers' income and the raw material supply chain.

7. Agronomic and Physiological Interventions to Manage Premature Flowering

Premature flowering in jute can be effectively managed through simple agronomic and physiological interventions that help prolong the vegetative phase and ensure better fibre development. Timely sowing is one of the most critical practices; for example, farmers in the Indo-Gangetic plains who sow jute within the recommended window (late March to early April) often avoid early floral initiation triggered by short day length and low temperatures. Balanced nutrient management, particularly adequate nitrogen application, promotes vigorous vegetative growth and delays flowering, as seen in fields where split nitrogen doses resulted in taller plants with finer fibres. Proper plant spacing and irrigation during early growth stages also reduce stress-induced flowering by maintaining a favourable microclimate for stem elongation. In some cases, foliar application of growth regulators such as gibberellic acid has been reported to suppress early flowering and enhance internodal growth. Together, these interventions help farmers maintain longer vegetative growth, improve fibre length and fineness, and ultimately secure higher fibre yield and better market value.

8. Breeding Strategies for Flowering Regulation in Jute

Premature flowering in jute can be effectively managed through a combination of agronomic and physiological interventions aimed at prolonging the vegetative phase and sustaining stem growth. Timely sowing is the most critical factor, as early sowing under optimal photoperiod and temperature conditions delays floral induction and promotes vigorous vegetative development. Adequate and balanced nutrition, particularly sufficient nitrogen supply, helps maintain active cambial growth and cellulose deposition in fibre cells, while potassium supports photosynthate translocation and stress tolerance. Proper irrigation scheduling is equally important, as moisture stress during early growth can hasten flowering by triggering stress-induced hormonal signals. From a physiological perspective, practices that reduce stress-induced ethylene accumulation such as avoiding waterlogging and nutrient imbalance-help delay reproductive transition. The use of suitable varieties with lower photoperiod sensitivity and better adaptability to local agro-climatic conditions has also proven effective in minimizing premature flowering (Kar et al., 2022). Together, these interventions help sustain vegetative growth, improve fibre length and fineness, and ultimately enhance both fibre quality and yield in jute cultivation.

9. Premature Flowering under Climate Change: Emerging Concerns

Climate change has emerged as a critical driver of premature flowering in jute, posing new challenges to fibre productivity and quality. Rising temperatures, erratic rainfall patterns, and shifting photoperiod–temperature interactions increasingly expose the crop to stress during its early growth stages, accelerating floral initiation before sufficient vegetative biomass is attained. Heat waves and intermittent moisture stress, now more frequent under changing climates, trigger stress-mediated flowering as a survival response, thereby shortening the vegetative phase essential for fibre development. In addition, climate-induced uncertainty in sowing time often forces farmers to plant jute under sub-optimal conditions, further enhancing the risk of early flowering. These changes not only reduce fibre yield but also impair fibre fineness, strength, and uniformity, threatening the economic sustainability of jute-based farming systems. Addressing premature flowering under climate change therefore requires a holistic approach that combines climate-resilient varieties, adaptive agronomic practices, and improved stress forecasting to safeguard jute production in vulnerable regions.



Fig. 2: Flowering in jute plant

10. Future Research Directions

Future research on premature flowering in jute must move beyond phenological observations to a deeper understanding of its physiological and molecular regulation. Priority should be given to elucidating the key genetic and hormonal pathways that control floral induction and their interaction with environmental cues such as photoperiod, temperature, and moisture stress. Integrating classical physiological screening with modern genomics, transcriptomics, and marker-assisted selection will help identify photo-insensitive and climate-resilient genotypes suited to diverse agro-ecologies. At the field level, the development of

climate-smart agronomic packages-including optimized sowing windows, nutrient scheduling, and water management-will be essential to minimize stress-induced flowering under variable climates. In addition, emerging approaches such as nano-fertilizers and plant bio-regulators offer promising opportunities to fine-tune vegetative growth, delay floral initiation, and enhance fibre development. Together, these multidisciplinary strategies can pave the way for sustainable jute production with improved fibre quality in the face of climate change (Ghosh et al., 2013)

Conclusion

Flowering in jute is a finely regulated physiological process that begins with environmental signal perception and culminates in floral induction through a coordinated molecular cascade involving photoperiod sensing, CONSTANS (CO) gene activation, florigen (FT) synthesis, and its transport to the shoot apex. While this regulatory mechanism is essential for reproductive success, its untimely activation leads to premature flowering, which severely restricts vegetative growth and compromises fibre development. Early floral induction diverts assimilates away from stem elongation and cambial activity, resulting in shorter plants, increased fibre coarseness, reduced cellulose deposition, and ultimately lower fibre yield and quality. The problem is further exacerbated under climate change-induced stresses such as high temperature, moisture imbalance, and altered photothermal regimes. Effective management of premature flowering therefore requires an integrated approach combining optimal sowing time, balanced nutrition, stress mitigation, use of photo-insensitive varieties, and targeted physiological interventions to delay florigen activation and prolong the vegetative phase. A deeper understanding of the flowering regulatory cascade and its interaction with environmental cues will be pivotal in developing climate-resilient jute production systems, ensuring sustained fibre quality, farmer profitability, and the continued relevance of jute as a premier eco-friendly natural fibre crop.

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SERICULTURE: SMALL WORMS, BIG OPPORTUNITIES FOR SUSTAINABLE RURAL LIVELIHOODS

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***Shanmugam R., Lokeshkumar P., Jaisridhar P., Vinothkumar B., Murugesh K A and
Mohanraj P**

ICAR – Krishi Vigyan Kendra, Tamil Nadu Agricultural University, The Nilgiris, India

*Corresponding Author: Shanmugam R.

Abstract

Sericulture is a traditional agro-based enterprise that continues to play a significant role in sustaining rural livelihoods, particularly in regions dominated by small and marginal farmers. In the context of shrinking landholdings, climate variability, and limited non-farm employment opportunities, sericulture offers a resilient and inclusive livelihood option by integrating mulberry cultivation, silkworm rearing, and post-cocoon processing into a single value chain. The enterprise is characterized by low initial investment, high labor absorption, and the ability to generate regular income through multiple production cycles in a year. Sericulture also promotes gender equity, as women participate extensively in both on-farm and household-based operations, contributing directly to household income and social empowerment. From an environmental perspective, sericulture aligns well with sustainable agricultural principles through the use of perennial mulberry plantations, recycling of organic waste, and production of biodegradable natural silk fiber with a lower ecological footprint compared to synthetic textiles. Advances in mulberry improvement, disease-free silkworm seed production, rearing technologies, and extension services have further strengthened the productivity and resilience of the sector. This article highlights the economic, social, and environmental dimensions of sericulture, emphasizing its potential as a sustainable pathway for rural development and livelihood security in the modern agricultural landscape.

Introduction

Sericulture is among the oldest organized rural livelihoods, with historical roots that span

thousands of years. Despite rapid industrialization and the dominance of synthetic textiles, silk continues to retain its value due to its natural origin, elegance, and durability. Rural agriculture today faces multiple challenges, including fragmented landholdings, climate instability, rising production costs, and uncertain market returns. In this context, sericulture offers an alternative pathway that combines biological efficiency with economic resilience. It allows farmers to convert simple biological inputs into a high-value commodity. Unlike mechanized farming systems, sericulture relies more on skill and management than heavy capital investment. This makes it particularly suitable for small and marginal farmers. The activity also fits well within traditional rural lifestyles. As sustainability and livelihood security become central development goals, sericulture emerges as both a traditional and forward-looking enterprise. Its continued relevance lies in its adaptability, inclusiveness, and capacity to generate steady income.

Sericulture in the Context of Contemporary Rural Transformation

Sericulture represents one of the most enduring agro-based livelihood systems in human history, yet its relevance has not diminished in the modern era. In many developing countries, particularly in Asia, rural economies are undergoing significant stress due to shrinking landholdings, climate instability, rising input costs, and declining profitability of conventional agriculture. Under such conditions, traditional crop-based farming alone is often insufficient to ensure stable household income. Sericulture emerges as a viable alternative because it combines agricultural production with value-added processing, thereby extending income opportunities beyond the farm.

Silk continues to command a premium position among textile fibers because of its natural lustre, strength, biodegradability, and cultural value. Unlike synthetic fibers derived from petrochemicals, silk is produced entirely through biological processes that rely on renewable resources. This distinction has become increasingly important in an era where consumers are more conscious of environmental sustainability and ethical production. The persistence of demand for silk, both domestically and internationally, provides sericulture with a relatively stable market base.

Another defining feature of sericulture is its reliance on skill and biological management rather than heavy mechanization. Farmers convert mulberry leaves into cocoons through the careful rearing of silkworms, demonstrating how human knowledge and precision can add value to natural resources. This makes sericulture particularly appropriate for rural areas where capital

availability is limited but labor is abundant. Moreover, sericulture fits well within existing rural lifestyles, allowing farmers to diversify income without abandoning agriculture altogether. In this sense, sericulture acts as a bridge between subsistence farming and agro-based entrepreneurship, contributing to rural economic resilience.

Integrated Production System and Economic Stability

Sericulture functions as an integrated agro-industrial system in which each component is biologically and economically interlinked. The system begins with mulberry cultivation, which forms the foundation of silk production. Mulberry is a perennial crop capable of producing large quantities of leaf biomass when managed scientifically. Practices such as proper spacing, pruning, irrigation, and nutrient management directly influence leaf yield and quality. Since mulberry leaves are the sole food source for the silkworm (*Bombyx mori*), their nutritional status determines larval growth, cocoon weight, and silk quality.

Silkworm rearing is the most critical and sensitive phase of the sericulture system. The silkworm is a fully domesticated insect with narrow tolerance limits for environmental conditions. Temperature, humidity, ventilation, and hygiene must be carefully regulated throughout the rearing period. Feeding schedules must be precise, and rearing spaces must be kept clean to prevent disease outbreaks. The short life cycle of the silkworm—typically around 25–30 days—allows farmers to rear several crops in a year. This cyclical production pattern ensures regular income at short intervals, unlike seasonal crops that generate returns only once or twice annually.

After cocoon harvesting, sericulture extends into post-cocoon activities such as reeling, twisting, weaving, dyeing, and fabric finishing. These stages add significant value to the raw product and generate employment beyond the farm. In many regions, these activities are organized as cottage or small-scale industries, contributing to rural industrialization. The integration of farming and processing spreads economic risk across multiple activities and stabilizes household income. Thus, sericulture is not merely an agricultural enterprise but a complete rural production system that links primary production with secondary and tertiary economic activities.

Smallholder Suitability, Employment Generation, and Gender Inclusion

One of the most compelling advantages of sericulture is its suitability for small and marginal farmers. Mulberry can be intensively cultivated on small land parcels, producing high

Component of Sericulture	Key Activities Involved	Scientific/Management Requirements	Economic and Livelihood Contribution
Mulberry Cultivation	Land preparation, planting, pruning, irrigation, manuring, leaf harvesting	Selection of high-yielding varieties, soil fertility management, regular pruning cycles	Provides continuous leaf supply; generates on-farm employment; forms the biological base of the enterprise
Silkworm Rearing	Egg incubation, larval feeding, cleaning, environmental regulation	Temperature and humidity control, quality leaf feeding, strict hygiene	Converts low-cost biological input into high-value cocoons; major income-generating stage
Cocoon Harvesting	Mounting larvae, cocoon collection, grading	Timely harvesting, disease-free rearing, proper drying	Determines cocoon quality and market price; immediate cash return to farmers
Post-Cocoon Processing	Reeling, twisting, weaving, dyeing	Skilled labor, improved reeling technology, quality control	Adds substantial value; creates off-farm rural employment and cottage industries
Marketing and Trade	Auctioning, cooperative sales, private trading	Price information, quality grading, institutional support	Ensures income realization; links farmers to domestic and export markets
By-products Utilization	Use of silkworm litter, pupae, waste silk	Composting, feed processing, waste management	Enhances income through secondary products; supports circular economy

leaf yields per unit area. Even farmers owning less than one hectare can operate viable sericultural units if recommended practices are followed. Infrastructure requirements, such as rearing houses and appliances, are simple and scalable, allowing gradual expansion without heavy financial risk. This makes sericulture accessible to resource-poor households that are excluded from capital-intensive agricultural systems.

Sericulture is also highly labor-intensive, generating employment throughout the year. Mulberry cultivation requires regular labor for pruning, irrigation, and harvesting. Silkworm rearing demands continuous attention during feeding and cleaning operations. Cocoon harvesting and post-harvest handling further increase labor demand. Beyond the farm, employment is created in chawki rearing centers, grainages, reeling units, weaving clusters, transport, and marketing. Each hectare under mulberry generates significantly more labor days compared to most field crops, making sericulture an effective solution for rural underemployment.

Women play a central role in the sericulture sector, contributing significantly to both on-farm and post-cocoon activities. Many silkworm rearing operations are carried out within or near the household, enabling women to participate actively without disrupting domestic responsibilities. Tasks such as feeding larvae, cleaning rearing trays, and sorting cocoons require care, patience, and precision rather than physical strength. Income earned through sericulture often flows directly into household welfare, improving nutrition, education, and healthcare outcomes. Through participation in self-help groups and cooperative enterprises, women gain financial literacy, leadership skills, and social recognition. In this way, sericulture contributes not only to income generation but also to gender equity and social empowerment.

Biological Sensitivity, Knowledge Intensity, and the Role of Science

The success of sericulture is closely linked to the biological characteristics of the silkworm, *Bombyx mori*. As a highly domesticated species, the silkworm has lost much of its ability to survive under natural conditions. Its growth and productivity depend on carefully controlled environmental parameters, including temperature, humidity, air circulation, and sanitation. Even small deviations from recommended conditions can lead to stress, reduced growth, or disease outbreaks.

Mulberry leaf quality plays a decisive role in silkworm performance. Leaves must be tender, nutritious, and free from contaminants. Poor soil fertility, improper fertilization, or inadequate irrigation can reduce leaf quality and, consequently, cocoon yield. Diseases such as

grasserie, flacherie, muscardine, and pebrine remain major constraints in sericulture, particularly where hygiene and management practices are neglected. These challenges highlight the knowledge-intensive nature of the enterprise.

Scientific research has contributed significantly to improving sericulture productivity. The development of high-yielding mulberry varieties, disease-free silkworm seed, and improved rearing technologies has reduced risk and increased efficiency. However, the benefits of these innovations depend on effective knowledge dissemination. Extension services play a crucial role in translating research findings into field-level practices. Training programs, demonstrations, and advisory services help farmers adopt scientific rearing protocols and respond effectively to emerging challenges. In sericulture, human skill and scientific understanding are often more important than capital investment, underscoring the central role of education and capacity building.

Environmental Sustainability, Technological Progress, and Market Dynamics

Sericulture aligns closely with the principles of environmentally sustainable agriculture. Mulberry plantations provide perennial green cover, improving soil structure and reducing erosion. The deep root system of mulberry enhances soil stability and water retention. Silkworm litter and excreta are recycled as organic manure, contributing to nutrient cycling and reducing reliance on chemical fertilizers. These practices promote soil health and long-term agricultural sustainability.

Silk, as a natural protein fiber, is biodegradable and environmentally benign compared to synthetic textiles. Its production generates lower levels of pollution and greenhouse gas emissions, particularly when managed sustainably. With increasing global awareness of environmental issues, demand for natural and eco-friendly textiles has grown. This trend has renewed interest in silk products, particularly in premium fashion, handloom, and handicraft markets.

Technological advancements have modernized sericulture without undermining its biological foundation. Improved mulberry varieties, disease-free silkworm seed, low-cost rearing equipment, and efficient reeling machines have enhanced productivity and product quality. Digital advisory platforms and mobile-based extension services are improving farmers' access to timely information. Market integration, value addition, branding, and certification are increasingly important for enhancing competitiveness in domestic and export markets. India's

diverse silk varieties and rich weaving heritage provide a strong foundation for market expansion, provided quality consistency and supply chain efficiency are maintained.

Future Prospects and Policy Imperatives

The future of sericulture depends on its ability to adapt to emerging challenges and opportunities. Climate change poses new risks to mulberry cultivation and silkworm rearing, necessitating research on stress-tolerant varieties and climate-resilient management practices. Policy support in the form of subsidies, insurance schemes, and credit access can reduce risk and encourage adoption of improved technologies. Skill development programs are essential to attract younger generations to the sector and prevent the erosion of traditional knowledge.

Institutional coordination among research organizations, extension agencies, cooperatives, and market actors is critical for sustained growth. Strengthening market linkages, improving infrastructure, and promoting value addition can enhance farmer profitability. With appropriate policy interventions and continued innovation, sericulture has the potential to remain a resilient and inclusive rural livelihood system.

Conclusion

Sericulture demonstrates how a biologically simple organism can support a complex and sustainable rural economy. By providing regular income, generating employment, empowering women, and promoting environmental sustainability, it addresses multiple dimensions of rural development simultaneously. The integration of traditional knowledge with modern science has allowed sericulture to remain relevant in a rapidly changing world. Far from being an outdated practice, sericulture represents a future-ready model of skill-based, sustainable agriculture. The journey from mulberry leaf to silk fabric illustrates the power of knowledge-driven rural enterprise. Ultimately, the small silkworm creates big opportunities, reaffirming sericulture's role as a cornerstone of sustainable rural livelihoods.

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PROBLEMATIC SOIL AMENDMENTS IN AGRICULTURE: MANAGING SALINE AND SODIC SOILS FOR SUSTAINABLE FARMING

Article ID: AG-VO6-I01-132**Mohanapragash A G^{1*} and Madhupriya D¹**

¹Research scholar, Department of Soil Science and Agricultural Chemistry, Tamil Nadu
Agricultural University, Coimbatore, Tamil Nadu, India

*Corresponding Author: Mohanapragash A G

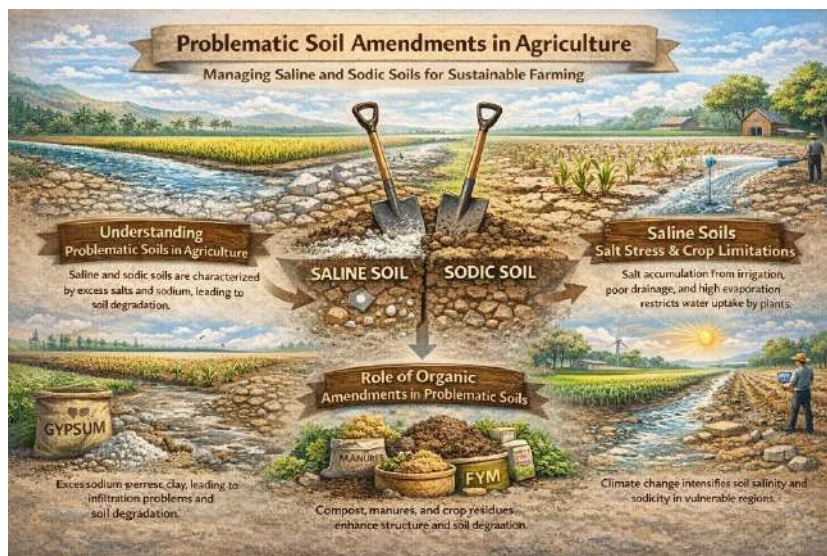
Abstract

Agricultural productivity worldwide is increasingly threatened by problematic soils, particularly saline and sodic soils, which impair soil health, reduce crop yields, and undermine long-term sustainability. These soils develop due to a combination of natural soil-forming processes, poor-quality irrigation water, climate change-induced evapotranspiration, and inappropriate soil and water management practices. Effective management therefore depends on the judicious use of soil amendments that can correct chemical imbalances, improve soil structure, and restore biological activity. This article provides an integrated overview of the nature of saline and sodic soils, the mechanisms underlying their degradation, and the role of organic and inorganic amendments in their reclamation. Emphasis is placed on mechanistic understanding, sustainable management strategies, and climate-resilient approaches for restoring productivity in salt-affected agroecosystems.

Introduction

Problematic soils represent one of the major constraints to sustainable agricultural production, particularly in arid, semi-arid, and irrigated regions. Among these, saline and sodic soils are the most widespread and economically damaging. They restrict plant growth through chemical toxicity, osmotic stress, and physical degradation of soil structure. With increasing pressure on land and water resources, coupled with climate change and expanding irrigation using marginal-quality water, the extent of salt-affected soils is expected to increase further. Addressing these challenges requires a clear understanding of soil processes and the strategic use

of amendments that act through complementary chemical, physical, and biological mechanisms.



Nature of Problematic Soils in Agriculture

Problematic soils are characterized by chemical, physical, or biological constraints that limit crop performance. Saline and sodic soils, although often grouped together as salt-affected soils, differ fundamentally in their dominant processes and therefore require distinct management approaches.

Saline soils are defined by the accumulation of soluble salts in the soil solution, which increases soil electrical conductivity and restricts water uptake by plants. In contrast, sodic soils are dominated by sodium ions on the soil exchange complex. Excess sodium disrupts soil aggregation, leading to clay dispersion, surface crusting, poor aeration, and severely reduced water infiltration. While both soil types reduce crop productivity, accurate diagnosis is critical because inappropriate amendment strategies can aggravate soil degradation.

Saline Soils: Salt Stress and Crop Limitations

Saline soils develop when salts such as sodium chloride, calcium sulfate, and magnesium salts accumulate in the root zone. This accumulation commonly results from irrigation with saline water, inadequate drainage, high evaporation rates, and rising groundwater tables. Excess salts increase the osmotic potential of the soil solution, making it difficult for plant roots to extract water even when sufficient moisture is present. As a result, crops experience physiological drought, nutrient imbalance, and reduced growth.

The primary challenge in managing saline soils lies in the removal of excess salts. Large volumes of good-quality water are often required for leaching, but poor drainage can restrict salt

removal and may even worsen groundwater salinity. Sustainable management therefore focuses on improving drainage, adopting controlled leaching practices, growing salt-tolerant crops, and incorporating organic amendments that improve soil structure and facilitate salt movement below the root zone.

Sodic Soils: Structural Degradation and Soil Toxicity

Sodic soils are generally more difficult to manage than saline soils because their primary constraint is structural rather than osmotic. Excess exchangeable sodium causes clay particles to disperse, destroying soil aggregates and leading to surface sealing and crusting. These changes drastically reduce water infiltration, aeration, and root penetration. Unlike saline soils, sodic soils may not show visible salt accumulation, making them deceptively difficult to diagnose in the field.

Reclamation of sodic soils is constrained by the high cost and limited availability of chemical amendments, the slow nature of structural recovery, and the need for precise water management. Effective strategies involve the application of calcium-based amendments, such as gypsum, which supply soluble calcium to replace sodium on the soil exchange complex. The displaced sodium can then be leached from the root zone. These practices are most effective when combined with deep tillage, organic matter additions to stabilize aggregates, and improved drainage or rainwater harvesting.

Why Amendment Strategies Differ Between Saline and Sodic Soils

Although both soil types are salt-affected, their contrasting mechanisms necessitate different reclamation approaches. Saline soils primarily require the removal of excess soluble salts through leaching, whereas sodic soils require chemical replacement of sodium with calcium to restore soil structure. Saline soils often retain relatively stable structure, while sodic soils exhibit severe dispersion and extremely poor infiltration. Consequently, the management complexity of sodic soils is considerably higher, demanding integrated and carefully planned amendment strategies.

Role of Organic Amendments in Problematic Soil Management

Organic amendments such as compost, farmyard manure, crop residues, green manures, vermicompost, and biochar play a vital supportive role in the management of saline and sodic soils. These materials improve soil aggregation, increase water-holding capacity, enhance microbial activity, and support gradual soil reclamation.



In saline soils, organic amendments improve soil structure and porosity, which facilitates salt leaching and reduces salt concentration in the root zone. The decomposition of organic matter releases organic acids and carbon dioxide, improving nutrient availability and buffering soil pH. In sodic soils, organic inputs help stabilize soil aggregates and counteract clay dispersion caused by sodium dominance. Although organic amendments alone cannot fully reclaim sodic soils, they significantly enhance the effectiveness of inorganic amendments and contribute to long-term soil resilience.

Biological Mechanisms Mediated by Organic Amendments

Organic amendments stimulate soil biological activity, which is often severely impaired in salt-affected soils. Increased microbial populations accelerate organic residue decomposition, improve nutrient cycling, and promote the formation of stable aggregates through microbial binding agents. Beneficial soil microorganisms also enhance plant tolerance to salinity stress by improving root health and producing growth-promoting substances. Over time, repeated organic inputs increase soil organic carbon, improve nutrient-use efficiency, and strengthen ecosystem resilience under climatic stress.

Inorganic Amendments in Problematic Soil Management

Inorganic amendments are indispensable for correcting the chemical constraints of saline and sodic soils, particularly where sodium-induced degradation is severe. Calcium-based amendments, especially gypsum, are widely used for sodic soil reclamation. Gypsum supplies soluble calcium that replaces sodium on the soil exchange complex, enabling the leaching of

sodium from the root zone. This process improves soil structure, enhances infiltration, and restores aeration.

Other inorganic amendments, such as sulfuric acid, elemental sulfur, and phosphogypsum, may also be used depending on soil properties and resource availability. In saline soils, inorganic amendments play a secondary role and are mainly used to correct nutrient imbalances and improve leaching efficiency rather than to alter exchange chemistry directly.

Limitations and Challenges of Inorganic Amendments

Despite their effectiveness, inorganic amendments present several limitations. High costs, uneven field application, limited availability, and the requirement for adequate water to leach displaced salts can restrict their adoption, particularly in resource-poor farming systems. Improper application without soil testing may lead to inefficient reclamation or unintended environmental consequences. Therefore, inorganic amendments must always be applied based on site-specific soil analysis and integrated with appropriate irrigation and crop management practices.

Integrated Use of Organic and Inorganic Amendments

The most effective strategy for managing saline and sodic soils is the integrated use of organic and inorganic amendments. Inorganic amendments rapidly address chemical imbalances, while organic amendments improve soil structure, biological activity, and long-term fertility. This integrated approach accelerates soil reclamation, enhances crop productivity, and ensures sustainability by reducing environmental risks. When combined with salt-tolerant crops, improved drainage, precision irrigation, and climate-smart management practices, integrated amendment strategies significantly enhance soil resilience.

Climate Change and the Growing Challenge of Salt-Affected Soils

Climate change is intensifying the problem of saline and sodic soils through increased evaporation, reduced availability of freshwater resources, and greater dependence on marginal-quality irrigation water. These pressures make adaptive and sustainable soil amendment strategies increasingly essential, particularly in arid and semi-arid regions. Long-term organic matter recycling, precision amendment application, and supportive policy frameworks will be critical for climate-resilient agriculture.

Conclusion

Saline and sodic soils represent one of the most serious challenges to sustainable

agricultural productivity worldwide. Although they share common origins, their distinct chemical and physical behaviors demand carefully tailored amendment strategies. An integrated approach that combines inorganic amendments to correct chemical constraints with organic amendments to restore physical structure and biological function offers the most effective pathway for soil reclamation. As climate pressures intensify, sustainable management of problematic soils will be central to ensuring future food security, environmental stability, and resilient agroecosystems.

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RODENTS CONTROL IN PADDY FIELDS

Article ID: AG-VO6-I01-133**Riyafa Jariya S**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Rats are one of the major vertebrate pests causing severe yield losses in rice fields at all crop stages, from nursery to harvest. Effective rat management is essential to ensure food security and economic stability for farmers. This study emphasizes an integrated rat management approach combining cultural, mechanical, biological, and chemical methods. Practices such as field sanitation, synchronized planting, destruction of rat burrows, and community-based trapping were highlighted. Mechanical methods like live traps and burrow fumigation were demonstrated, while the judicious use of rodenticides was recommended only during peak infestation periods. Farmers were also educated on identifying rat damage symptoms and adopting collective action for better control. The integrated approach proved to be environmentally safe, cost-effective, and sustainable, significantly reducing rat population and crop damage. Proper awareness and timely implementation of rat management practices can greatly improve rice productivity and farmers income. Rice is the staple food over half of the world population where majority constitute from Asian continent. In India most of the states grow rice but now-a-days pest attack plays a role in reducing the production. Rodents as a pest is one of the serious concerns felt by the farmer in rice field since it is causing more than 40 percent sometimes incurring even 100% losses in rice field. According to conservative estimate about 5-6% of the total food grains being produced are lost annually at a pre harvest stage due to rodents. Only chemical control may not serve the cause, their efficient management is only possible through practising all the rodent control measures in an integrated manner which includes environmental and cultural, physical, mechanical, chemical methods.

RAT SPECIES THAT AFFECT RICE CROP IN INDIA:

There are many rats from them the most frequently occurring species that influence the rice production in field:

Field mouse: *Mus booduga*

Indian gerbil: *Tatera indica*

Mole rat : *Bandicota bengalensis*

Grass rat : *Rattus (Millardia) meltada*

CHARACTERISTICS OF FIELD RATS:

- Rats are nocturnal animals (i.e., active at night)
They have a burrowing habit
- The teeth of rat increases 2mm every day to protect itself it sharpens and trims its teeth regularly by chewing various materials available to it.
- They are sexually active
- A female rat can produce its offsprings 3-4 times in a year Life span of a rat ranges from 6months to one year (approx.)
- This means in the same year the mother along with its offspring produce further offsprings (approx. 1 pair of rats results in production of 1200 rats a year)
- These rats also feed on frogs, small insects, weeds etc during non-cropping season.

SYMPTOMS:

- Chopped young seedlings Irregular cuttings of stem
- Patches of depressions seen in the field at early stage Chewed developing buds or ripening grains
- Tillers cut near base at 45° angle. Cut tillers may be seen in patches. At ripening stage, the ear heads are cut and stored in the burrows.
- Nature of damage:
- The rats enter the nurseries and nibble the seeds. After transplantation, the seedlings are cut.
- At the shoot blade stage, the culm is cut and At ripening stage, the ear heads are cut and stored in the burrows



MANAGEMENT

By ITK:

- Rats do not live in fields where sheep penning is being practiced.
- Planting closely notchi(*Vitex negundo*) and erukku (*Calotropis gigantea*) around the fields as a fence helps to control rat problem.
- Putting the branches of Thangarali (*Tecoma Stands*) around the fields to control rats.
- To control rats in paddy fields, Channampoo (*Cycas cercinalis*) flowers are cut in to pieces and placed in many places whose bad odour drives away the rats.
- Pieces of palmyra (*Borassus flabellifei*) leaves are tied on the poles fixed on the field.
- The sound produced by the leaves scares away the / rats
- Providing owl stands near the rat holes will help in reducing the rat damage.
- To reduce rat population, rat holes are dug and rats are killed after each harvest. To catch the rats, a trap made up of wire loops on bamboo pegs is being used.
- Big round shaped earthen pots are burried on the field at ground level. Half of the pot is filled with mud slurry on which baiting material is put on a coconut shell. Attracted rats fall inside the pot and they cannot climb up and get killed.
- Use of soaked rice as bait attracts more rats.
- Putting fresh cow dung on both the fields and bunds to reduce rat problem.

Physical control:

Includes hunting, rat drives, digging, and exclusion. Narrow bund maintenance (45 × 30 cm).

Digging burrows during the off season and killing, poison baiting with zinc phosphide

or bromadiolone 3 to 4 weeks after planting, and setting up of Thanjavur or bamboo bow traps (100 nos/ha) are to be followed in sequence.

Locate the burrows opened by the rats and insert two pellets each of 0.5 or 0.6g of aluminium phosphide per burrow as deep into the burrow as possible and plug the entrance with a mud ball.

Chemical control:

- Poison bait at 1 part zinc phosphide with 49 parts popped corn/rice/dry fish or bromodialone 0.25 w/w (1:49) at 0.005%. Mix one part of bromodialone + 49 parts of bait and keep inside the field.
- Warfarin 0.5% 1 part with 19 parts of popped corn/rice/dry fish and keep in field.
- Setting up of owl perches at 40 -50/ha.
- Wildcats, snakes, and birds are predators of rice field rats.

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ROLE OF SILICON IN SOIL–PLANT SYSTEMS FOR AGRICULTURAL SUSTAINABILITY

Article ID: AG-VO6-I01-134**Mohanapragash A G^{1*} and Madhupriya D¹**

¹Research scholar, Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

*Corresponding Author: Mohanapragash A G

Abstract

Silicon (Si), though not classified as an essential plant nutrient, has emerged as a key beneficial element contributing to sustainable agriculture and ecosystem resilience. Increasing evidence demonstrates that silicon plays a vital role in improving soil health, enhancing plant stress tolerance, boosting crop productivity, and supporting ecosystem-level processes relevant to climate change mitigation. This article provides a comprehensive overview of silicon availability and dynamics in soils, mechanisms of silicon uptake and transport in plants, and its multifaceted role in alleviating abiotic and biotic stresses. The broader impacts of silicon on plant growth, yield stability, and nutritional quality are discussed alongside the importance of silicon cycling in maintaining ecosystem resilience. Finally, recent innovations in silicon-based fertilizers and sustainable silicon management practices are highlighted as promising strategies for The broader impacts of silicon on plant growth, yield stability, and nutritional quality are discussed alongside the importance of silicon cycling in maintaining ecosystem resilience. Finally, recent innovations in silicon-based fertilizers and sustainable silicon management practices are highlighted as promising strategies for climatesmart and resource-efficient Agriculture.

Introduction

Modern agriculture faces unprecedented challenges due to climate change, land degradation, salinity, drought, nutrient imbalances, and increasing pressure to ensure food security for a growing global population (Ma *et al.*, 2006). In this context, attention has shifted

toward beneficial elements that enhance crop resilience and sustainability without imposing significant environmental costs. Silicon is one such element that has gained global recognition for its protective and regulatory functions in plants. Silicon is the second most abundant element in the Earth's crust, primarily occurring in soils as silicate minerals. Despite its abundance, plant-available silicon can become depleted in intensively cultivated systems, especially in high-yielding cereal-based agriculture. Understanding the behavior of silicon in soil–plant systems is therefore essential for designing sustainable management strategies that support both agricultural productivity and ecosystem stability.



1. Availability and Dynamics of Silicon in Soils

In soils, silicon exists mainly in crystalline and amorphous forms derived from the weathering of primary and secondary silicate minerals. The plant-available form of silicon is monosilicic acid (H_4SiO_4), which is present in soil solution at relatively low concentrations. The availability of monosilicic acid is influenced by soil pH, texture, mineralogy, organic matter content, and microbial activity.

Highly weathered tropical soils and intensively cultivated agricultural lands often show reduced levels of available silicon due to leaching, crop removal, and erosion. Continuous harvesting of silicon-accumulating crops such as rice, wheat, and sugarcane can accelerate silicon depletion. Conversely, the return of crop residues and application of silicon-rich amendments can replenish soil silicon pools and improve long-term soil fertility.



2. Mechanisms of Silicon Uptake and Transport in Plants

Plants absorb silicon from the soil solution primarily in the form of monosilicic acid through their root systems (Epstein 2009). Silicon uptake occurs via both passive diffusion and active transport mechanisms, depending on plant species. High silicon-accumulating plants such as rice, barley, and sugarcane possess specialized membrane transporters that enable efficient silicon uptake even at low external concentrations. Once absorbed, silicon is transported through the xylem along with the transpiration stream and is eventually deposited as amorphous silica in various plant tissues, including leaves, stems, and epidermal cell walls. These silica deposits form structural barriers that enhance mechanical strength and reduce susceptibility to environmental stresses. The regulation of silicon transport within plants is closely linked to transpiration rate, root anatomy, and genetic factors.

3. Role of Silicon in Stress Tolerance

Silicon plays a critical role in enhancing plant tolerance to a wide range of abiotic and biotic stresses. Under drought conditions, silicon improves water-use efficiency by reducing transpiration and maintaining leaf water status. In saline environments, silicon helps regulate ion balance by limiting sodium uptake and improving potassium retention (Liang *et al.*, 2015). Silicon also alleviates heavy metal toxicity by reducing metal uptake and immobilizing toxic ions in the rhizosphere or plant tissues. Additionally, silicon strengthens plant defense against pests and pathogens by reinforcing cell walls and stimulating the production of defensive compounds. These combined effects make silicon a valuable tool for improving crop resilience under stressful growing conditions.

4. Impact of Silicon on Plant Growth, Productivity, and Nutritional Quality

The positive effects of silicon on plant growth are reflected in enhanced photosynthetic efficiency, improved nutrient use efficiency, and stronger plant architecture. Silicon-treated plants often exhibit erect leaves, reduced lodging, and improved light interception, leading to higher biomass accumulation and yield stability (Guntzer *et al.*., 2012). Beyond yield improvement, silicon contributes to crop quality by reducing the accumulation of toxic elements such as cadmium and arsenic in edible plant parts. It can also enhance the uptake and utilization of essential nutrients, indirectly improve the nutritional quality of food crops and support human and animal health.

5. Silicon Cycling, Ecosystem Resilience, and Climate Change Mitigation

Silicon cycling is an integral component of terrestrial and aquatic ecosystems. Plants act as key mediators of the silicon cycle by taking up silicon from soils and returning it through litterfall and residue decomposition. Healthy silicon cycling contributes to soil structure, erosion control, and long-term ecosystem stability (Cooke *et al.*, 2016). Emerging research suggests that silicon interactions with carbon cycling may play a role in climate change mitigation. By supporting plant productivity and biomass accumulation, silicon indirectly enhances carbon sequestration in soils and vegetation. Thus, silicon management has broader implications beyond agriculture, contributing to ecosystem resilience under climate variability.

6. Innovations in Silicon-Based Fertilizers and Sustainable Management Practices

Recent advancements in silicon fertilization include the development of calcium silicate slags, potassium silicates, nano-silicon formulations, and silicon-enriched organic amendments. These products aim to improve silicon availability while minimizing environmental risks (savant *et al.*, 1997). Integrating silicon fertilization with residue recycling, organic farming, and precision agriculture offers a sustainable pathway to enhance crop productivity and resilience. Site-specific silicon management, supported by soil testing and crop requirement assessments, is essential for maximizing the benefits of silicon while ensuring environmental sustainability.

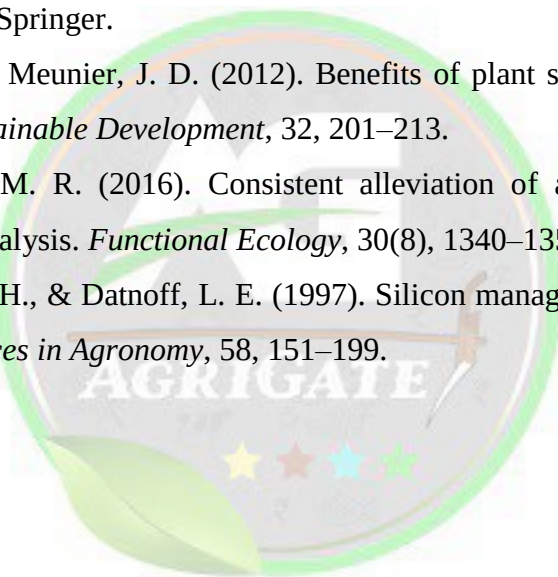
Conclusion

Silicon has emerged as a cornerstone element in sustainable agriculture and resilient ecosystems. Through its influence on soil processes, plant physiology, stress tolerance, and ecosystem-level functions, silicon provides multiple benefits that align with the goals of climate-smart agriculture. Strategic management of silicon resources, combined with innovations in

fertilizer technology and integrated soil–plant management practices, can significantly enhance agricultural sustainability. Future research and policy efforts should focus on optimizing silicon use across diverse agro-ecosystems to support food security, environmental protection, and climate resilience.

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WASTE TO WEALTH – BIOCOMPOSTING WITH WEEDS

Article ID: AG-VO6-I01-135**Subbulakshmi M**

Undergraduate Student of B.Sc. (Hons.) Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Invasive weeds and discarded coconut shells represent significant agricultural "waste" that can be strategically repurposed into soil-enriching wealth. This study outlines a rapid 60-day biocomposting procedure using a layering method: a foundational layer of coconut shells to provide structural aeration, followed by alternating layers of fresh weeds (nitrogen source) and decomposed Farmyard Manure (FYM) (microbial inoculum). The pile is repeated for six layers, thoroughly watered, and sealed with a traditional dung-mud plaster to facilitate thermophilic decomposition and kill weed seeds. Post-sealing, the heap is mixed at 14-day intervals to re-aerate the core. By maintaining a precise moisture level of 40–50%, the materials undergo rapid biotransformation. The final product is a stabilized, pathogen-free organic manure ready within 50 to 60 days, offering an eco-friendly alternative to chemical fertilizers while effectively managing farm residues.

Introduction

The "Waste to Wealth" agricultural paradigm emphasizes the circular utilization of farm residues, shifting the perception of invasive weeds and coconut by-products from liabilities to high-value resources. According to sustainable management principles, composting is the most optimal method for recycling these materials, as it stabilizes organic nitrogen and eliminates harmful pathogens through controlled aerobic decomposition. This specific 6-layer procedure leverages the structural properties of coconut shells to provide a foundational "aeration lung," ensuring the oxygen levels necessary to prevent anaerobic rot, while alternating layers of

nutrient-dense weeds and decomposed Farmyard Manure (FYM) create a synergistic microbial environment.

By sealing the pile with a traditional dung-mud plaster, farmers facilitate a thermophilic phase where internal temperatures exceed 50°C, effectively sterilizing weed seeds and achieving full biotransformation within a rapid 50 to 60-day cycle. Maintaining a precise 40–50% moisture level through bi-weekly mixing, as highlighted in current technical standards, results in a crumbly, stable organic fertilizer that enhances soil porosity and water-holding capacity, significantly reducing dependency on synthetic inputs.

MATERIAL PREPARATION AND SITE SELECTION

Selecting the Composting Site:

- ✓ The success of biocomposting is heavily dependent on environmental control. Choose an elevated site to prevent water stagnation, which causes anaerobic conditions and foul odors.
- ✓ The area should be under partial shade—either under a tree canopy or a thatched shed—to prevent the sun from drying out the microbial plaster.
- ✓ For a standard heap, a 5ft x 5ft area is prepared by leveling the soil and sprinkling a thin layer of cow dung slurry to activate indigenous earth-dwelling microorganisms.

Raw Material Pre-Processing:

- ✓ **Coconut Shells:** These must be dry and free from large fibers. Their convex shape is utilized as a natural aeration chamber.
- ✓ **Fresh Weeds:** It is critical to harvest weeds before they reach the flowering stage.
- ✓ For faster decomposition, chop them into 5–10 cm pieces.
- ✓ This increases the surface area for microbial enzymes to break down tough plant cell walls.
- ✓ **Decomposed FYM:** Use only well-aged manure (6+ months old). Fresh manure can introduce unwanted pathogens; aged FYM provides the concentrated "starter culture" of bacteria, fungi, and actinomycetes needed for the 60-day cycle.



BIOCOMPOSTING PROCEDURE :

Site Selection and Preparation:

Choose an elevated, shaded area to prevent waterlogging and conserve moisture. Level the ground and apply a cow dung slurry to create a firm, microbial-active base.

Layer 1 – Structural Aeration (Coconut Shells): Place a base layer of coconut shells. Their



convex shape creates vital air pockets, acting as a "biological lung" to maintain the 5% oxygen level required for aerobic decomposition.

Layer 2 – Nitrogen Input (Fresh Weeds): Spread a 15–20 cm layer of chopped fresh weeds (e.g., Parthenium or Water Hyacinth). Weeds are rich in Nitrogen (N) and Potassium (K), providing the primary fuel for microbial heat generation.



Layer 3 – Microbial Inoculation (Decomposed FYM): Apply a 5 cm layer of aged Farmyard Manure (FYM). This introduces a diverse community of bacteria and fungi (actinomycetes) that act as a "starter culture" to begin breaking down cellulose.

Layer 4–6 – Completing the Stack: Repeat the Weed (Layer 4) and FYM (Layer 5) sequence, finishing with a final Weed or straw cap (Layer 6) to bring the pile to a height of approximately 1 meter.

Watering and Sealing (Plastering): Sprinkle water until the pile reaches 50–60% moisture (it should feel like a damp sponge).

Apply a thick plaster of mud and cow dung over the entire exterior to seal in heat.

Thermophilic Sterilization: The seal traps heat, raising internal temperatures to 55–70°C (131–158°F). This high-heat phase is critical for killing invasive weed seeds and pathogens within 3–7 days.

The First Turn (14 Days): Open the plaster after two weeks and thoroughly mix the heap. This re-aerates the core and ensures all material, including the outer edges, passes through the hot center for sterilization.

Maintenance and Maturation: Mix the pile every two weeks to maintain a moisture level of 40–50%. Moisture below 40% halts microbial activity, while above 60% leads to anaerobic rot and odors.

Final Harvest (50–60 Days) : The compost is ready when it is dark brown, crumbly, and smells like forest floor.

BENEFITS OF BIOCOMPOSTING:

- ✓ The primary benefit of the "Waste to Wealth" biocomposting method is the total sterilization of invasive weed seeds. The mud-dung plaster creates a high-heat thermophilic environment, reaching temperatures up to 70°C. This intense heat effectively kills the embryos of resilient weeds like Parthenium, ensuring the final compost does not re-infest fields.
- ✓ By recycling nutrient-dense weeds, farmers can capture significant amounts of Nitrogen, Phosphorus, and Potassium mined from deep soil. These weeds are biological reservoirs of essential minerals that are often lost when agricultural waste is burned or discarded. This method successfully returns these vital nutrients to the topsoil in a stabilized organic form.
- ✓ Integrating decomposed Farmyard Manure (FYM) as a microbial starter introduces a diverse consortium of beneficial bacteria and fungi. These microbes act as a biological engine, breaking down tough plant fibers and converting them into available nutrients. This microbial activity also helps suppress soil-borne pathogens like Fusarium, acting as a natural plant defense.
- ✓ From an economic perspective, this method represents a zero-cost path to high-quality fertilization for modern organic farms. By utilizing free on-farm waste like coconut shells and weeds, farmers can drastically reduce their reliance on expensive synthetic NPK.
- ✓ The 60-day rapid maturation cycle ensures that farm waste is managed efficiently without long-term accumulation or storage issues. Traditional composting can take over six months, but the specific 6-layer stacking method accelerates the biological breakdown process.

- ✓ The resulting fertilizer provides a slow-release nutrient delivery system that prevents the leaching issues common with chemical inputs. Nutrients are bound within the organic matter and released gradually as the plant needs them, minimizing waste. This steady supply leads to stronger plant growth, better flowering, and higher-quality yields across various crop varieties.

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GARLIC & ONION AS THERAPEUTICS: A TRANSLATIONAL SHIFT OF KITCHEN CHEMISTRY TO NOVEL DRUGS

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Proloy Sankar Dev Roy

Assistant Professor cum Junior Scientist, Department of Biochemistry

Mewar University, Rajasthan, India

Abstract

Changing lifestyle of the human species have made them vulnerable and susceptible to a wide myriad of diseases. Various new elite diseases most of them being fatal have cropped up in recent years as witnessed in the Covid era. Drug researchers are constantly deploying their expertise in the development of drugs that have the potential to fight these pandemics. The paradigm shift towards natural alternatives to develop elite drugs has raised the adrenaline of researchers to scout out alternative bioactives for drug development. Garlic and onions form an integral part of the global cuisine and are posed to be a rich booty of active bioactive having therapeutic potential. The active molecule responsible for the kitchen tears is the allicin and other sister compounds that come under the broad umbrella organosulphur group. Elaborate chemistry is involved in the conversion of these molecules to their active counterparts and the knowledge of these pathways form the basis of incorporating these biomolecules in the development of new drug formulations. Being involved in various redox reactions these active compounds can be potentially harnessed to develop elite drugs having multifaceted roles and low side-effects. But all pros are often accompanied by various cons and addressing these cons are the need of the hour to harvest the full potential of these active biologically potent compounds for therapeutic potential. The article in a nutshell is a humble approach to summarize the chemistry behind these molecules paving a way to shift the kitchen chemistry to lab for designing novel drugs having multifaceted benefits supported by recent literatures.

Key words: alliin, allicin, thiolanes, organosulphur compounds, medicinal properties

1. Introduction

With rapid modernization and development in the human lifestyle have made the human species susceptible and vulnerable to many diseases. In the recent years, the species have encountered a wide array of life threatening and fatal pandemics that have cost a lot to the human genera. With a paradigm shift in the life style of the species various new elite diseases have cropped up that have recorded a statistically significant fatality. The recent pandemic witnessed globally, the Covid era have recorded a significant loss globally. To encounter the situation various elite drugs have evolved to offer protection to the human populace (Tudu et al., 2022). This urgent need to encounter these elite diseases have raised the eyebrows of researchers globally to design drugs to supplement the growing demand and to suffice the emergent need of elite drugs employing various strategies. Coupled with over-the-counter drugs and generic drugs development, keen interest has attained a direction to design novel drugs with less side effects as often discerned by the conventional drugs.

Globally researchers have employed strategies to manipulate the drug motifs or molecular structures to develop drugs with less visible side effects. In the recent era of drug development, researchers are keen in finding alternative sources for drug molecule discovery (Melguizo-Rodríguez et al., 2022). To suffice this emerging need of the hour various alternatives have evolved or being employed most of plant origin to develop drugs with superior combat potential coupled with less visible off target effects. Nature has gifted us with a wide plethora of medicinal plants which are mostly untapped and has been successful in gaining attention of drug researchers to develop new drug molecules to encounter new evolving diseases. With the development in drug research, various plant based secondary metabolites have gained momentum for the development of new elite drugs.

Inherently plants provide a rich booty of molecules that can be harnessed to develop drugs to combat various life threatening diseases. To supplement this wide array of molecules various culinary products have evolved or have been successful in drawing the attention of the scientists to develop new drug formulations. Notably the allium species viz. garlic and onions which pose to be the base of most global cuisine have gained importance owing to their rich array of organosulphur compounds (OSCs). Garlic (*Allium sativum*) and onion (*Allium cepa*) are a rich source of sulphur rich compounds like alliin, diallyl sulphides, ajoene and thiolanes. These untapped metabolites have a rich potential in curing many diseases owing to their medicinal

properties and can be projected as future molecules for elite drugs (Azam et al., 2025). These molecules of plant origin can be harnessed to develop drugs having antimicrobial, anticancer and cardio protective properties having less side effects. Deep understanding of the chemistry, pharmacology and pharmacokinetics of these molecules have attained a keen interest among the scientific community in the current era and can be helpful in developing drugs having anti-inflammatory, hepatoprotective, anti-cancer and antimicrobial drugs owing to their inherent chemistry and potential (Tudu et al., 2022). This article in a nutshell is a humble approach to summarize the chemistry behind these molecules paving a way to shift the kitchen chemistry to lab for designing novel drugs having multifaceted benefits supported by recent literatures.

2. The biochemistry behind onion and garlic

The allium species are a rich source of biochemically potent metabolites belonging to the organosulphur group. A wide myriad of biochemically potent or active molecules come under the umbrella of this broad group. The allium species viz. garlic (*Allium sativum*) and onion (*Allium cepa*) are a booty of these compounds as they are rich in OSCs localized in their cells. These sulphur rich organic compounds are mostly classified or nomenclature as alliin being the most prominent metabolite followed by ajoene and family of diallyl sulphides viz. diallyl sulphides (DAS), diallyldisulphides (DADS) and diallyltrisulphides (DATS) coupled with thioleues. These volatile sulphur compounds are localized in the cell and chemically bear the structures viz. $(\text{CH}_2=\text{CHCH}_2)_2\text{S}$, $(\text{CH}_2=\text{CHCH}_2)_2\text{S}_2$ and $(\text{CH}_2=\text{CHCH}_2)_2\text{S}_3$ (Pourreza et al., 2022). Garlic are a rich source of an amino acid alliin chemically S-allyl-L-cysteine sulfoxide located in the cells. The kitchen tears while chopping garlic or onion are the results of this alliin being converted to its active form allicin via the production of allyl sulphenic acid by enzymatic lysis by the enzyme alliinase when cells are disrupted.

The thiolanes of onions are a five membered ring, chemically derivatives of the umbrella group, 3,4-dimethylthiolane accompanied by various sulphoxides and are responsible for the pungency of onions. Another important sulphur compound present in garlic is ajoene bearing the chemical formula $\text{C}_9\text{H}_{14}\text{OS}_3$ released from the precursor allicin as a stereoisomer and chemically being a group of allyl polysulphides (El-Saadony et al., 2024). These sulphur compounds are highly reactive owing to their variable oxidation states and diverse chemical structures. As the name “organosulphur” compounds, these metabolites are highly reactive due to their electrophilic “S” centre present in the structural ring. Being highly reactive, they can manipulate

a diverse group of thiol structures altering the cysteine residues prominently present in many proteins having enzymatic functions to confer them with the title of being potentially viable medicinal compounds. Various redox reactions namely the oxidative thiol disulphide exchange reactions are responsible for the biological activity of these compounds. These compounds can catalyse the reactivity with thiol groups present in many enzymes producing byproducts like S-allyl-mercapto proteins via S-thioallylation, projected to be the most prominent product leading to their antimicrobial and antioxidant activity. Coupled with these products these reactions also form to be the precursor for the formation and release of H₂S having medicinal properties (Melguizo-Rodríguez et al., 2022). To summarize, this kitchen chemistry can lay the foundation for the designing of novel drugs with less visible side effects.

3. Medicinal potential of garlic and onion in drug development

The biochemical constituents of both garlic and onion have a wide myriad of medicinal properties owing to their thiol group modulation and interference in the reduction-oxidation reactions of various clinically significant pathways. These sulphur-based compounds and their derivatives are projected to show medicinal properties like being as an anti-microbial and anti-viral compounds. Moreover, they play an important role in the cardiovascular clinical pathways as a potent support to the cardiovascular metabolism. Finally, they also show proapoptotic effects showing significant cancer progenesis (Azam et al., 2025).

The diallylsulphides along with ajoene disrupt the redox reactions in various microbial pathways proving to be excellent anti-microbial compounds. They are known to inhibit the microbial biosynthetic pathway associated with the synthesis of phosphatidylcholine. Moreover, disruption of the thiol groups in microbial enzymes also confer the antimicrobial properties to these metabolites. The S-thioallylation process is also responsible for the disruption of the mitotic pathway associated with the lysis of the microbial cytoskeleton (Lu et al., 2024).

The anti-carcinogenic properties of onion and garlic are the results of the metabolic products of alliin after lyase by the enzyme alliinase. Allicin and its derivatives are known to arrest the cancer cell growth by promoting programmed cell death by stimulating the various mitochondrial pathways viz. increments in the Bax: Bcl-2 ratio etc. They also act as inhibitors of various kinases such as CDK2 stimulating apoptosis. Moreover, these compounds are also responsible for arresting the cell cycle at various crucial stages of cell division specifically the G2 & M phase of the cell cycle (Ferguson, 2024).

Allicin and its derivatives are known to provide protection to the cardiovascular system by the production of H₂S gas which has promising role in the reduction of hypertension by the mode of vasodilation and muscle relaxation. They also show their role in the reduction of LDL cholesterol and the production of nitric oxide responsible for blood pressure control. Moreover, they also have a role as an anti-thrombotic agent by acting as an inhibitor of GPIIb receptor and increasing the platelet counts significantly (Azam et al., 2025).

Finally, they also play an important role as a neuroprotective and anti-inflammatory agent by modulating various enzyme signalling cascades. These metabolites can significantly modulate the synthesis of various cytokines and antioxidant pathways conferring a role as an anti-inflammatory compound. It also acts as an oxidant by protecting enzymes involved in the Nrf2 and Keap1 systems. Moreover, they have also shown to have a role in the inhibition of prostaglandins by interfering with the COX and LOX pathways (Chen, 2025).

4. Challenges and future directions

The biochemical metabolites of garlic and onion pose to be future alternatives to generic drugs due to their lower or negligible off-target effects and pave a suitable foundation for the development of new elite drugs. But some cons also accompany the successful utilization of these bio actives as standard drug formulations. The highly reactive nature of the parent compound allicin proves to be a lacuna in drug development as it is very unstable at room temperature and often loses its biological activity. Furthermore, the pH dependent nature of the enzyme alliinase also holds to be a draw back as it is highly sensitive to the acidic environment of the stomach resulting in loss of enzymatic activity (Tudu et al., 2022). Finally, high reactivity and speedy metabolism in the blood stream also hinders its use in drug development as it interacts with natural antioxidants and fails to reach the target sites leading to low intended therapeutic potential (Mozafari et al., 2025). From the pharmacological view point allicin can reduce the efficacy of other drugs as its metabolism involves its interaction with the enzymes of cytochrome P450 posing a hinderance to its therapeutic potential. Same challenges are also encountered by its sister counterpart the thiolanes from onions and other organosulphur compounds (El-Saadony et al., 2024).

With advent in the field of pharmacological research various strategies have been incorporated or need to be addressed to develop future ready drugs and to reap the maximum potential of these bio actives in elite drug development programmes. Prodrug designing and

encapsulation of the bioactive can be used for the successful incorporation of these compounds in drug development. Developments in the field of nanotechnology have materialized the idea of encapsulation of the bioactive molecules in nano carriers. Nano drug delivery vehicles can be deployed for the targeted and controlled delivery of the metabolites intended for efficient therapeutic potential (Lu et al., 2024). Development of synthetic analogues to these sulphur rich compounds can also retain the chemical potential of these metabolites without showing off-target effects.

Finally with advances in the field of bioinformatics and sandwiching it with drug formulation research can also pave a way to develop elite drugs having the inherent bioactivity of the parent molecules. Docking technologies coupled with *in silico* approaches can be developed to increase the selectivity and to pinpoint the off-target effects of the compounds. Moreover, it can also assist in the development of synthetic analogues as par with the redox and thiol reactivity of the parent compounds and in the development of modern synthetic molecules nomenclature as pharmacophores as an alternative to the traditional parent compounds (Mozafari et al., 2025). Lastly but not the least approach directed towards its intended use in pharmaceutical industry/sciences is the development of highly robust standardization and derivation protocols to meet the need of the hour demand. Extensive research and clinical trials need to be addressed to suffice the limitations and future of these novel compounds following stringent regulatory guidelines globally (Azam et al., 2025).

5. Concluding remarks

Though in the embryonic stage of development, maturation in the field of garlic and onion-based drug discovery is in the brink of realism as supported by extensive literature reviews globally. Various improvised strategies directed towards potent drug formulations are already in the pipe-line and can be harnessed to reap the benefits of these novel compounds. A bright future of these sulphur rich compounds holds in drug developments if the bottlenecks are channelized and bypassed. Extensive research in this field with better formulation technologies and strategies are the need of the hour to harness these biomolecules as potent drugs for therapeutic purposes aligning with the regulatory frameworks. This article in a nutshell can pave a way and raise the adrenaline of researchers in the field of pharmaceutical research to transform the compounds responsible for the kitchen tears to elite therapeutically active elite drugs.

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AMLA (*EMBLICA OFFICINALIS*) SUPERFRUIT: NUTRITIONAL, HEALTH POTENTIAL, PROCESSING APPROACHES AND VALUE ADDED PRODUCTS

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P. Lavanya^{a*}, Ananya Badiya^b, Sandeep Mann^c, Rahul Yadav^c, and Md. Anwar Ali^d.

^a-Scientist, ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata

^b-Scientist, ICAR- Central Soil Salinity Research Institute, Karnal, India

^c-Scientist, ICAR-Central Institute of Post Harvest Engineering and Technology, Ludhiana

^d-Assistant Professor, Crop Physiology, VIAT, SAFT, Vignan University, Guntur, India

*Corresponding Author: P. Lavanyaa

Introduction

Amla, scientifically called as *Embllica officinalis* is commonly known as “Indian gooseberry”. It is one of the most valuable fruits in India and has been utilized for thousands of years in ancient medical systems including Ayurveda, Siddha, and Unani. Amla is native to tropical and subtropical regions of India and is cultivated due to its remarkable nutritional and medicinal properties. The fruit is spherical, small to medium-sized, pale green to yellowish in color, and tastes sour, astringent, and slightly bitter in taste. It is a very rich source of functional and nutraceutical components with high commercial value. It is a good source of minerals, antioxidants, flavonoids and polyphenols and is particularly rich in vitamin C (Goraya *et al.*, 2015). Vitamin C content of amla is 20 times higher than that of oranges and 160 times higher than that of apples (Lalita pal *et al.*, 2024).

Additionally, it contains high amount of antioxidants and minerals. Amla as a natural source of bioactive compounds holds significant potential for improving human nutrition and health. Amla extract has a number of biological benefits, including antibacterial, anticancer, antioxidant, neuroprotective, gastroprotective, hepatoprotective, cardioprotective, anti-inflammatory, antidiabetic, and immunomodulatory effects (Gul *et al.*, 2022). Even though amla has many nutritional benefits, its astringent flavor and high acidity make it unsuitable for fresh consumption.

Therefore, the amla fruits are processed into value-added goods such dried slices, aonla powders, candy, sweets, jam, murabba, and juice.

Nutritional composition of Amla per 100 g (Priya & Islam 2019)

Chemical components	Percentage
Moisture	81.2 %
Mineral matter	0.7 %
Fat	0.1 %
Fiber	3.4 %
Carbohydrate	14.1%
Protein	0.5%
Calcium	0.05%
Phosphorous	0.02%
Iron	1.2 mg/100g
Vitamin C	600 mg
Nicotinic acid	0.2 mg/100g

Processing of Amla

Various traditional and modern processing methods are employed depending on the intended use, nutritional retention, and market demand

1. Amla Drying

Drying is one of the most commonly used methods to preserve amla. It is an important unit operation in processing of various agricultural products. It improves post harvest handling and packaging, increases the ease of product transportation by reducing its weight, increases shelf life, and preserves its quality attributes. Amla fruit is washed, blanched, sliced, and dried using with any type of drying methods like sun drying, solar drying, hot air drying, tray drying, vacuum drying, microwave drying or freeze drying. It minimizes moisture content of the product inhibits microbial growth, and also enhances shelf stability. Advanced methods like freeze drying retain maximum amount of vitamin C, color, and bioactive compounds. It is making dried amla suitable for different end products like powders, capsules, and herbal formulations. For example, Amla candy is a sweet–tangy healthful snack made from Indian gooseberry, known for

its high vitamin C and antioxidant content. It is prepared by osmotic dehydration of amla slices in sugar syrup followed by drying. In addition to being delicious, it promotes digestion, immunity, and general health.

2. Amla Juice Extraction and Beverage

Amla juice is prepared by crushing or pulping fresh amla and followed by filtration and pasteurization at required temperature and time combination. Enzymatic treatment is sometimes used to improve juice yield and its clarity. The juice may be processed into ready-to-drink beverages, nectar, squash, or blended functional drinks. Different thermal and non-thermal preservation methods such as pasteurization, ultrasonication, high-pressure processing and hybrid methods are used to maintain the quality of amla.

3. Amla Pickling and Salting

Traditional processing methods includes pickling of amla using salt, oil, and spices. This method extends shelf life through osmotic dehydration and acidification. This pickle is widely consumed due to its good taste and retains considerable medicinal properties.



Different Value added products of Amla

4. Amla powder

Dried amla is ground into powder and used in different applications like functional food ingredients, nutraceuticals, pharmaceutical and cosmetic products. Different extraction techniques like ultrasonic-assisted extraction, microwave assisted extraction, hybrid methods is used to produce concentrated amla extracts which is rich in antioxidants. These treatments are used prior to drying to maintain the stability of bioactive compounds.

5. Thermal and Non-Thermal Processing of Amla

Different thermal techniques like blanching, pasteurization, sterilization and non thermal techniques like spray drying, ultrasonication, freeze drying, and encapsulation using different wall materials of polysaccharides and proteins are used to protect sensitive bioactive compounds (Mishra *et al.*, 2014). Thermal processing of amla involves the application of heat through methods such as blanching, pasteurization, sterilization, drying in order to increase shelf life and ensure microbial safety. However, this process frequently results in the loss of heat-sensitive components like vitamin C. These techniques are effectively utilized in both traditional and industrial processing of amla products because they are easy to use and cost effective. Non-thermal processing techniques namely high-pressure processing, ultrasonication, pulsed electric fields, and freeze drying. These methods help to retain bioactive compounds like phenols, antioxidants, natural color, and flavor. Large-scale use of non-thermal processing is hampered by its limited availability and higher expense, despite the fact that it provides superior nutritional quality.



Solar drying of amla



Hot air drying of amla

Table 2: Value Added Products of Amla with Market Price

S. No.	Value added products	Quantity	Price (Rs.)
1.	Amla juice	1 L	200 /-
2.	Amla Candy	500 g	170 /-
3.	Murraba	1 kg	200/-
4.	Amla powder	100 g	200/-
5.	Amla capsules	500 g	400/-

Conclusion

Amla is a remarkable superfruit because of its nutritional importance, health-promoting qualities and strong antioxidant profile. Its importance as a functional food is highlighted by its demonstrated advantages in enhancing immunity, promoting digestion, guarding against oxidative stress and promotes healthy skin and hair. Technological developments in processing have improved shelf life and consumer acceptability while preserving its bioactive contents more effectively. Its use in the food and nutraceutical industries is further expanded by the creation of various value-added products like candy, sweets, beverages, murraba and dried powders.

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PHYTOBIOTICS: ALTERNATIVE TO ANTIBIOTICS IN AUGMENTING BROILER PRODUCTION

Article ID: AG-VO6-I01-138**G. Prabakar*¹, S. Preethi², S. Prakash³ and P. Ravi⁴**

^{1,2,3} – Assistant Professor, Dept. of Livestock Production Management, Veterinary College and Research Institute, Udumalpet – 642 205, Tamil Nadu, India

⁴ - Associate Professor and Head, Veterinary College and Research Institute, Udumalpet – 642 205, Tamil Nadu, India

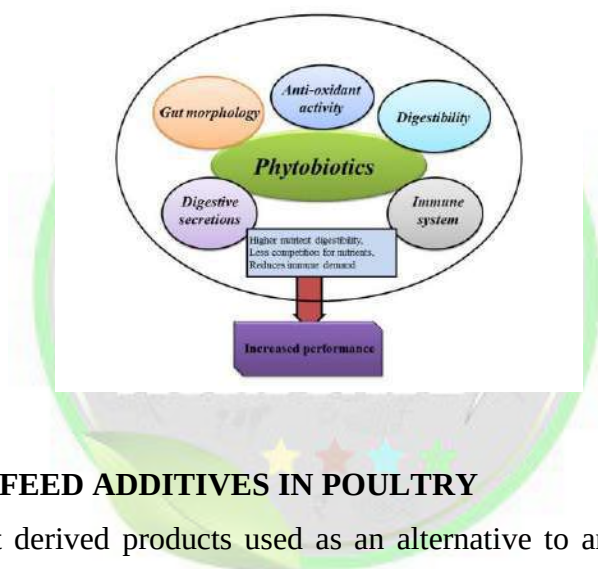
*Corresponding Author: G. Prabakar

Introduction

The ever-increasing consumer's awareness and their concern over the presence of antibiotic residues in poultry products necessitate looking for an alternative to antibiotic growth promoters. Among the numerous alternatives like probiotics, prebiotics, acidifiers, the plant origin compound attracts more interest than else. Phytogetic feed additives commonly defined as plant-derived compounds incorporated in to diets to improve the livestock productivity through amelioration of feed properties, improvement of nutrient digestibility, absorption and elimination of pathogens in the gut. Pthytogetic compounds included or incorporated in diet to improve the animals' production performance and improving the quality of food derived from those animals. According to their origin and treatment variety of plant derivatives used such as herbs (flowering, non woody and non-persistent plants), spices like cinnamom, coriandor, pepper, chilli, rosemary, oregano, anise, thyme and garlic. Essential oils (volatile lipophilic compounds derived by cold expression or by steam or alcohol distillation), or oleoresins (extracts derived by non-aqueous solvents). Some of the other compounds extracted from fruits such as flavonoids, are water soluble in nature, as this type of fruit extraction compound also used in poultry feed as additive. The technique for processing (e.g. cold expression, steam distillation, extraction with non-aqueous solvents etc.) modifies the active substances and associated compounds within the final product.

Properties of phytobiotics

Plant extracts have antimicrobial action, immune enhancement, antistress property anti-oxidant and gut microflora manipulation, nutrigenomics effects, digestibility enhancer, stress lowering effect, cholesterol-lowering effect. The plant herbs have these kinds of properties to increase the animal's health and performance. Phytogenic effects have been proven in poultry for feed palatability and quality (sensory aspects), growth promotion (improved weight gain and feed conversion ratio, reduced mortality), gut function and nutrient digestibility (improved growth), gut microflora (less diseases of the GIT, improved growth, reduced mortality), immune function (improved health) and carcass meat safety and quality (reduced microbial load, improved sensory).



PHYTOBIOTICS AS FEED ADDITIVES IN POULTRY

Nowadays plant derived products used as an alternative to antibiotic growth promoter. The extract from thyme, rosemary, sage and the carvacrol blend capsaicin, cinnamaldehyde using this bio active compounds can improve feed digestibility in broilers. Plant based bio active components have digestion stimulating properties, antimicrobial activity, increase enzyme secretion it leads to improve digestibility of nutrients, increase feed intake.

The mode of action of phytobiotics is described through their potential effect on gut microbial population, through their potential reduction in pathogenic microorganism. Improve the digestive capacity of intestine may be the indirect effect of stabilizing the intestinal microbes. Components from the phytobiotics reduce the animal's immune stress during dangerous situation and increase the availability and absorption of essential nutrients from intestine, thereby improve the intake of feed, feed conversion efficiency and increased the growth rate. Supplementation of

essential oils related to birds' growth performance is still controversial. Even though feeding of birds with essential oils among different age groups improved the growth performance. Effect of cinnamon and thyme in broilers diet have positive effect on birds feed intake, feed conversion efficiency, health status, live weight gain and performance traits.

Plant bioactive components like polysaccharide extracted from mushroom and herbs increased the growth of immune organs such as spleen thymus and bursal weight in both normal and immune-inhibition treated chickens.

GROWTH-PROMOTING EFFICACY

The growth promoting feed additives helps to reduce the stress in critical situation and helps to improve the immune status of host animal and increase the absorption of nutrients which can help to improve the better growth of birds. Phytobiotic feed additives stabilize the feed hygiene and beneficially affect the intestinal microbial ecosystem through controlling the harmful pathogens. A mixture of essential oils from anise, oregano and citrus peels along with an antibiotic growth promoter and noticed decreased microbial activity in terminal ileum, cecum and colon, reduced chyme content of volatile fatty acids, reduced bacterial colony count as well as biogenic amines. Relief from the microbial activity and its related product from small intestine because production of volatile fatty acids counteracts intestinal pH stabilization and required for digestive enzyme activity.

ANTIBACTERIAL AND ANTIVIRAL ACTIVITY

Phytobiotics especially spices and herbs are exerting well known antimicrobial activity in vitro including some major pathogens and fungi. A common growth enhancing and digestion modifiers present in hawthorn fruit, which is having more than seventy organic chemicals, bioactive, active components and some unidentified growth factors. Phytobiotics are having some complex active molecules that exhibits synergistic effect to increase the enhancement of growth as well as contain anti-microbial property. Tannic acid has the antimicrobial property to inhibit the intestinal bacteria such as *Clostridium perferingens*, *E. coli*, *Enterobactorcloaceae* and *Bacteriodesfragilis*. DNA synthesis was inhibited by phytochemical compound alkaloid which act as a intercalator or DNA inhibitor. Saponin is another phytochemical compound, have antimicrobial property through its ability to form complexes with sterols present in the microorganisms membrane, which cause membrane damage, followed by collapse of cells.

Essential oils have potential to act as alternative to antibiotics in broiler chicken due to its potent antimicrobial properties

ANTIOXIDATIVE ACTION

Herbes and spices have well known for its anti -oxidative property. Among variety of plant constituents possessing anti- oxidant activities, plants such as rosemary plant have phenolic compounds like rosmarinic acid and rosmarol, thymol and carvacrol derived from thyme and oregano. The mode of anti-oxidative properties of the plant additives through their effect (protection) of feed lipids from reactive oxygen species (ROS), this is main compound for formation of free radicals, it leads to lipid per oxidation for this reason the bioactive compounds reduce the ROS formation and prevent lipid peroxidation and prevent the feed/product damage.

IMMUNE STIMULATORY EFFECT

Certain plant derived polysaccharides have (adjuvant effect) immunostimulatory substances. Phytogetic compounds have prebiotic effect it helpful to improve or beneficial effect on gut health by improving the gut associated lymphoid tissue response (immunological effect) directly or short chain fatty acid mediation such as lactic acid producing bacteria. Polysaccharide compounds derived from mushroom (*Tremellafuciformis*, *Lentinusendodes*) and herbs (*Astragalusmembranaceus radix*) used in broiler chicken, these compounds act as immune modulator or enhancer to improve the innate or adaptive immunity or specific immunity (both cellular and humoral immunity).

SAFETY ISSUES OF PHYTOBIOTICS

Phytobiotics contain many pharmacologically active components which play a major role in the defence system of the plant. From this point of view safety concerns cannot be excluded, although, phytobiotics are generally assumed as GRAS (Generally Recognized as Safe. Phytobiotics also contain irritating ingredients which may be harmful to both animals and humans. Furthermore, undesired residues may not be excluded in a natural product.

Conclusion

The anti-microbial more specifically the anti-bacterial spectrum activity of phytochemicals is well documented worldwide; although their mechanism of action is not clearly described yet. Their anti-oxidant activity and hypo-lipidemic property of these plant derived compounds are being explored now in both animals as well as in human nutrition. These phytobiotics also impart readily acceptable flavour, alters the gut microbial population and also

aid indigestive process by improving the overall performance in broilers. The phytobiotics also reduces the environmental pollution. and. They also improve the shelf life of products mainly of preserved meat and eggs. With their wide range of activities these phytobiotics can be considered as a new group of feed additive for better growth in broilers rather than simply looking them as an alternate to antibiotics in broiler industry.

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ROLE OF E-LEARNING PLATFORMS IN DIGITAL NUTRITION EDUCATION

Article ID: AG-VO6-I01-139

¹Jyothi Isukala and ²Srinivas Tammiseti¹Subject Matter Specialist (Home Science), Acharya N.G. Ranga Agricultural University,² (M.tech), NIFTEM, Kundli, India

*Corresponding Author: Jyothi Isukala

Introduction

E-learning platforms are a key pillar in the digital transformation of nutrition education. They serve as comprehensive, accessible, and scalable tools to disseminate evidence-based nutrition knowledge to students, health professionals, and the general public. Their role is especially vital in contexts where face-to-face training is limited by geography, cost, or emergencies.

- **Enhancing Access to Evidence-Based Nutrition Knowledge**

E-learning platforms break down geographical and institutional barriers by allowing anyone with internet access to learn from global experts.

Example: The *FAO e-learning Academy*

- **Supporting Continuous Professional Development (CPD)**

Health professionals (e.g., dietitians, doctors, community health workers) can use these platforms to stay current with guidelines, complete certifications, and improve clinical practice.

- **Enabling Scalable Public Health Interventions**

Governments and NGOs can deliver national nutrition campaigns through e-learning platforms, ensuring consistent messaging across regions. Example: *India's POSHAN Abhiyaan*.

- **Supporting Multi-lingual and Culturally Adapted Content**

Many platforms offer materials in local languages, with culturally relevant examples, making learning more inclusive and effective. Example: The *WHO e-learning platform*.

- **Promoting Nutrition Literacy in the General Population**

E-learning modules tailored to the public can improve food label reading, portion control, balanced diet planning, and understanding of nutrition claims.

Example: *MyPlate (USDA)*'s digital platform includes interactive quizzes and videos that help families and students learn about healthy eating patterns.

Major e- learning platforms related to nutrition education

a. FAO eLearning Academy

Provides nutrition and food systems courses globally. According to a 2021 impact report, >80% of users reported behavior change in professional practice.

- Provider: Food and Agriculture Organization (FAO) of the UN
- Focus: Nutrition-sensitive agriculture, food systems, sustainable diets
- Features: Self-paced courses, multilingual options, certificates
- Best For: Professionals, students, public health workers
- Link: <https://elearning.fao.org>

b. WHO eLearning Hub (Open WHO)

Offers free nutrition modules (e.g., infant feeding, nutrition in emergencies). Evaluations show improved knowledge retention among healthcare workers

- Provider: World Health Organization ★★☆☆
- Focus: Nutrition in emergencies, breastfeeding, child malnutrition, anemia
- Features: Multilingual, mobile-friendly, certificates
- Best For: Health professionals, NGO workers, policymakers
- Link: <https://openwho.org>

c. Coursera (Free Courses)

University-based courses (e.g., Stanford's "Introduction to Food and Health") have reached millions, with high completion rates and self-reported dietary changes.

- Provider: Universities (Stanford, Johns Hopkins, Wageningen, etc.)
- Focus: General nutrition, clinical nutrition, food & health, behavior change
- Features: Audit free courses (pay for certificate), university-level content
- Best For: Students, general learners

- Examples:
 - “Introduction to Food and Health” – Stanford University
 - “Nutrition and Lifestyle in Pregnancy” – LMU Munich
- Link: <https://www.coursera.org>

d. FutureLearn (Free Access)

- Provider: UK universities and public health agencies
- Focus: Child nutrition, food sustainability, health education
- Features: Free limited-time access, discussions, optional certificate
- Best For: Educators, dietitians, students
- Example: “Child Nutrition and Cooking” – Stanford
- Link: <https://www.futurelearn.com>

e. edX (Audit Free Courses)

- Provider: Harvard, TU Delft, Karolinska Institute, etc.
- Focus: Nutrition, biochemistry, health communication
- Features: Audit for free; professional-level content
- Best For: Graduate students, health professionals
- Link: <https://www.edx.org>

f. Alison

- Provider: Global platform offering free certified courses
- Focus: Human nutrition, food safety, diet and weight loss
- Features: 100% free courses; optional paid certificates
- Best For: Beginners, community educators
- Link: <https://alison.com>

g. Nutrition Module – UNICEF AGORA

- Provider: UNICEF
- Focus: Infant and young child feeding, community nutrition programs
- Features: Self-paced, for NGO/health program workers



- Best For: Community nutritionists, outreach workers
- Link: <https://agora.unicef.org>

h. NPTEL (India – IIT/AICTE)

- Provider: Indian Ministry of Education
- Focus: Biochemistry, public health nutrition, dietetics
- Features: Video lectures, assignments, free access
- Best For: Indian students, researchers
- Link: <https://nptel.ac.in>



CHILLI FRUIT ROT – MANAGEMENT

Article ID: AG-VO6-I01-140**Dharani . G**

Undergraduate Student of B.Sc., (Hons) Agriculture, S.Thangapazham Agriculture College,
(Affiliated to Tamil Nadu Agricultural University), Vasudevanallur, Tenkasi- 627760, India

Abstract

Chilli fruit rot is one of the most destructive fungal diseases affecting chilli cultivation, leading to significant yield and quality losses, particularly under warm and humid climatic conditions. The disease is mainly caused by *Colletotrichum capsici* and *Alternaria* species and is characterized by sunken, dark lesions on fruits that eventually result in rotting and premature fruit drop. Effective management of chilli fruit rot requires an integrated approach involving cultural practices, use of disease-free seeds, biological control agents, and judicious application of fungicides. Practices such as crop rotation, proper field sanitation, seed treatment, and timely fungicidal sprays play a crucial role in reducing disease incidence. Adoption of integrated disease management strategies not only minimizes crop loss but also ensures sustainable chilli production and improved fruit quality.

Introduction

Chilli (*Capsicum annum* L.) is one of the most important spice and vegetable crops grown widely for its culinary and commercial value. However, its production is severely affected by chilli fruit rot disease, especially during humid and rainy seasons. The disease primarily attacks developing and mature fruits, leading to rotting, premature fruit drop, and significant yield and quality losses. Chilli fruit rot is mainly caused by fungal pathogens such as *Colletotrichum capsici* and *Alternaria* species. Effective management of this disease is essential to ensure healthy crop growth, maintain marketable yield, and achieve sustainable chilli production. Chilli (*Capsicum annum* L.) is an important spice and vegetable crop grown extensively in tropical and subtropical regions. Chilli fruit rot is a major fungal disease that

causes severe economic losses by reducing both yield and market value of fruits. The disease is prevalent during flowering and fruiting stages, especially under high humidity and continuous rainfall.

Causal Organism

Chilli fruit rot is mainly caused by:

- *Colletotrichum capsici*
- *Colletotrichum gloeosporioides*
- *Alternaria alternata*

These fungi survive in infected plant debris, seeds, and soil, and spread through rain splash, wind, and farm implements.

Disease Symptoms

- Initial symptoms appear as small, circular, water-soaked spots on fruits
- Lesions enlarge and become dark brown to black with concentric rings
- Sunken necrotic lesions develop, giving a characteristic anthracnose appearance
- Pinkish or black fungal spore masses may appear on lesions under moist conditions
- Infected fruits rot completely, dry up, or drop prematurely
- Severe infection leads to poor fruit quality and reduced seed viability
- Small water-soaked spots appear on green or ripe fruits
- Spots enlarge and turn dark brown or black
- Sunken lesions develop with concentric rings
- In severe cases, fruits rot completely and fall off
- Fungal growth may be seen on infected fruits under humid conditions

Favourable Conditions:

- ❖ High humidity and rainfall
- ❖ Warm temperature (25–30°C)
- ❖ Poor field drainage
- ❖ Continuous chilli cultivation

Epidemiology

- Optimum temperature: 25–30°C
- Relative humidity above 80%
- Frequent rainfall and prolonged leaf wetness

- Dense crop canopy and poor drainage
- Continuous cultivation of chilli in the same field

Economic Importance:

Fruit rot can cause yield losses ranging from 20–50%, and in severe outbreaks, losses may exceed 70%. The disease also reduces export quality due to blemished fruits.

Integrated Disease Management

1. Cultural Practices

- Select well-drained fields and avoid low-lying areas
- Follow crop rotation for 2–3 years with cereals or legumes
- Maintain proper plant spacing to reduce humidity
- Collect and destroy infected fruits regularly
- Avoid excessive nitrogen fertilization
- Use drip irrigation instead of overhead irrigation



2. Host Resistance

- Use tolerant or resistant chilli varieties recommended by local agricultural universities
- Avoid using seeds collected from diseased fields

3. Seed Treatment

- Treat seeds with **Carbendazim or Thiram @ 2 g/kg of seed**
- For eco-friendly management, use **Trichoderma viride @ 4 g/kg of seed**

4. Biological Control

- Apply **Trichoderma viride** or **Trichoderma harzianum @ 2.5 kg/ha** mixed with FYM
- Soil application of **Pseudomonas fluorescens @ 2.5 kg/ha**
- Use neem cake @ 250–500 kg/ha to suppress soil-borne inoculum

5. Chemical Control

- Spray **Mancozeb 0.25%** or **Chlorothalonil 0.2%** at flowering stage
- Follow up with **Carbendazim 0.1%** or **Azoxystrobin 0.1%** at fruiting stage
- Spray at 10–15 day intervals depending on disease severity
- Rotate fungicides with different modes of action to prevent resistance

6. Post-Harvest Management

- Harvest fruits at proper maturity
- Avoid mechanical injury during harvesting and handling
- Dry harvested fruits properly to reduce post-harvest rot

Conclusion

Chilli fruit rot is a serious disease that can cause heavy yield and quality losses if not managed properly. Adoption of integrated management practices involving cultural, biological, and chemical methods is essential for effective control. Early detection, timely intervention, and good agricultural practices can significantly reduce disease incidence and ensure higher productivity and profitability for chilli growers. Chilli fruit rot is a complex disease influenced by environmental factors and crop management practices. Adoption of an integrated disease management approach combining cultural, biological, and chemical methods is essential for effective control. Early diagnosis, timely interventions, and farmer awareness can significantly reduce yield loss and improve chilli productivity.

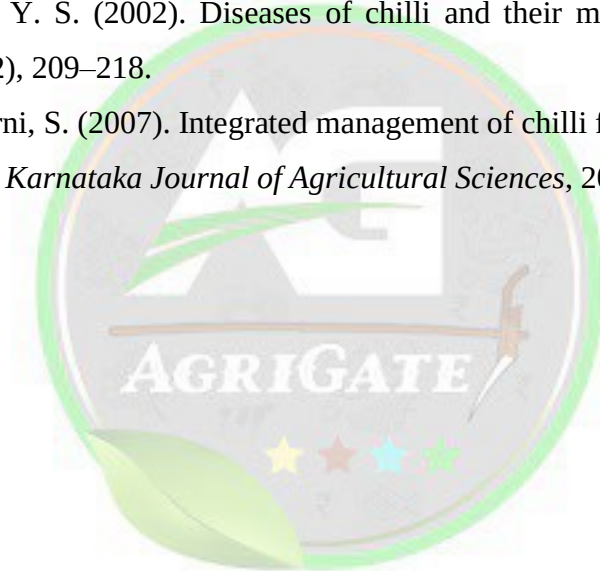
Acknowledgement

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preparation of this article. We thank the research institutions and published literature that served as references for compiling accurate and reliable information. Special thanks are extended to all those who directly or indirectly supported this work.

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MANAGEMENT FOR BANANA SOOTY MOULD *(Capnodium spp)*

Article ID: AG-VO6-I01-141**K.Shrinithi**

Undergraduate Student of B.Sc. (Hons.)Agriculture, S.Thangapazham Agricultural College
(Affiliated to TNAU), Vasudevanallur, Tenkasi-627760, Tamil Nadu, India

Abstract

Sooty mould is a common problem in banana cultivation, characterized by the development of a black fungal coating on leaves, pseudostem, and fruits. The disease is indirectly caused by fungi that grow on honeydew secretions excreted by sap-sucking insects such as aphids, mealybugs, scales, and whiteflies. Although sooty mould does not invade plant tissues, it reduces photosynthetic activity, weakens plant growth, and lowers fruit quality and market value. The incidence of sooty mould is favored by high humidity, dense planting, poor aeration, and excessive nitrogen fertilization. Effective management relies primarily on controlling the associated insect pests through an integrated approach involving cultural practices, mechanical removal, biological control, and judicious use of insecticides. Timely monitoring and adoption of integrated pest management practices help minimize the occurrence of sooty mould and ensure improved yield and quality in banana production."

Introduction

Sooty mould is a common problem in banana cultivation, characterized by the development of a black fungal coating on leaves, pseudostem, and fruits. The disease is indirectly caused by fungi that grow on honeydew secretions excreted by sap-sucking insects such as aphids, mealybugs, scales, and whiteflies. Although sooty mould does not invade plant tissues, it reduces photosynthetic activity, weakens plant growth, and lowers fruit quality and market value. The incidence of sooty mould is favored by high humidity, dense planting, poor aeration, and excessive nitrogen fertilization. Effective management relies primarily on controlling the associated insect pests through an integrated approach involving cultural practices, mechanical

removal, biological control, and judicious use of insecticides. Timely monitoring and adoption of integrated pest management practices help minimize the occurrence of sooty mould and ensure improved yield and quality in banana production."

SYMPTOMS

Appearance of a black, soot-like or powdery coating on the surface of leaves, especially on the upper leaf surface. Black fungal growth may also be seen on the pseudostem, petioles, and fruits. Affected leaves appear dirty and dull, losing their natural green color. Reduction in photosynthetic activity due to blockage of leaf surface. Leaves may show poor growth and reduced vigor in severe cases. Banana fruits covered with sooty mould become unattractive and unmarketable. The black coating can be easily rubbed off with fingers, indicating superficial fungal growth. Heavy infestation may lead to reduced yield and poor fruit quality.



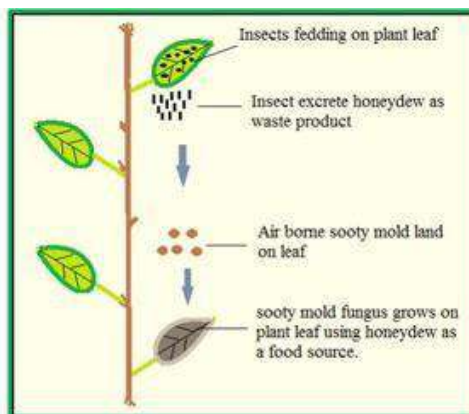
PATHOGEN CHARACTER:

Capnodium species are characterized by their sooty mold appearance, forming black encrustations on plant surfaces. They are saprobic on sugary exudates from insects and can cause significant damage to host plants. Key characteristics include: Superficial mycelium that spreads over leaves, stems, and fruits, often appearing as a network of dark brown hyphae. Ascomata that are superficial and can be globose to ellipsoidal, brown to dark brown or black. Bitunicate asci that are clavate, ovoid, or saccate, producing hyaline conidia. Host range includes major plants like mango, citrus, tea, and coffee, which are affected by their presence. These fungi alter the photosynthetic ability of plants, leading to reduced fruit set and growth issues.

MODE OF SPREAD:

Capnodium species spread through the sugary secretions of plant-feeding insects such as aphids, mealy bugs, which serve as a food source for the fungi. These insects, when they produce

honeydew, can carry the Capnodium fungi to various plant parts, including leaves, stems, and fruits. The fungi then establish themselves on these surfaces, leading to the black encrustation and other symptoms associated with Capnodium infections.



MANAGEMENT:

- Physical removal is often the first step in treating sooty mold
- ☐ Washing off mold: Gently wash affected plant parts with a solution of water and mild soap. Use a soft cloth or sponge to avoid damaging the plant surfaces.
- ☐ Pruning: Cut away heavily infested leaves and branches to reduce the fungal load and improve air circulation. Dispose of pruned material properly to prevent further spread.
- ☐ Controlling sooty molds and insects simultaneously is essential. Use systemic
- pesticides like methyl demeton 25 EC to control insects. Add 1 kg of starch or maida to 5
- liters of water to form a solution. Dilute this mixture to 20 liters after boiling. Mold and dried starch flakes will be removed with this method.
- ☐ Spraying the plant with fish oil resin soap or crude oil emulsion and starch (250g: 250g:450 l water) will control the insect as well as remove the entire surface grown fungus mat, which will come off as flakes in due course.
- ☐ Dusting sulphur will also be helpful in the control of sooty mold
- ☐ Spraying insecticide followed by spraying with fungicide viz., Bordeaux mixture 1% is also recommended
- ☐ Spraying of wettable sulphur methyl parathion + gum acacia (0.2% + 0.1% + 3%) at 15 days interval reduces the sooty mold incidence.

Conclusion

Sooty mould in banana is a superficial fungal growth that develops on honeydew

excreted by sap-sucking insects such as aphids, scales, and mealybugs. Although the fungus does not directly infect plant tissues, it forms a black coating on leaves and fruits, reducing photosynthesis and market value. Effective management depends on controlling the insect vectors and maintaining proper orchard hygiene, which helps prevent honeydew accumulation and subsequent mould development.

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Volume: 06 Issue No: 01

TWO FARMERS, ONE VISION: INNOVATION AND TRADITIONAL DRIVING RURAL SUCCESS

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Padmavathi.K., Priyadharsan.D.S. and Ashika.D.C.

UG Scholar, B.Sc. (Hons.) Agriculture,
Agricultural College and Research Institute, TamilNadu Agricultural University,
Keezhvelur, Nagapattinam, TamilNadu, India.

*Corresponding Author: Padmavathi.K.

Introduction

Despite choosing different paths in agriculture, two progressive farmers- Karthekeyan and Rajasekar have demonstrated that innovation, traditional wisdom, and scientific thinking can transform farming into a sustainable and profitable enterprise. Their journeys highlight how challenges can become opportunities when farmers are willing to adapt and think beyond conventional practices.

FARMER 1 - KARTHIKEYAN

PROFILE:

- **NAME:** KARTHIKEYAN
- **LOCATION:** AYAKARANPULAM
VEDARANYAM, NAGAPATTINAM.
- **FARMING FOCUS:** PALMYRA TUBER CROPS
AND VALUE-ADDED FOOD PRODUCTS.



CHALLENGES:

Karthekeyan initially faced marketing difficulties despite obtaining a **high yield of tuber crops**. Market demand was poor, prices were unstable, traders were unwilling to purchase the produce, Leading to heavy losses and uncertainty.

CHANGE ADOPTED:

While searching for a solution, Karthekeyan recalled a **traditional practice followed by his**

grandmother, who used to boil tubers, add jaggery and prepare small sweet balls. Inspired by this memory, he experimented with similar products. however, the short shelf life became a limitation. This led to a break through idea-**drying and powdering the tubers to extend useability.**

PRACTICES:

He began producing odiyal powder, dry tuber, a **Value Added Product** and developed over 90 value added food items.



Including:

- BURFI, CAKE
- HALWA
- HEALTH MIX POWDER
- SWEETS
- ODIYAL
- BOILED TUBER
- DRIED TUBER
- MURUKKU (THUYAMALLI+TUBER)
- ATHIRASAM
- CHOCOLATE
- GHEE LADDU
- KANJI (POWDER+WATER=LEMON GRASS)
- PAYASAM
- KESARI



VISIT TO CIMKAS UNIT (KARTHEKEYAN SIR HOUSE)

RESULTS:

The odiyal-based products gained strong consumer acceptance due to their **traditional value, nutritional benefits, and long shelf life**. Today Karthekeyan runs a successful value-addition enterprise (CIMKAS UNIT) with consistent demand and improved income.

PUBLICATIONS:

IN YOUTUBE CHANNEL- THAMIZHACIRIYAR PANAKIZHANGU

DHINAMALAR -24/ 10/2022 & HE GOT AWARD AT JUNE 2022



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உணவுப் பதார்த்தங்களை சந்தை இளைசுகளும் தயாரிப்புகள் பட்டுள்ளன. கட்டுவதன் உற்பத்தி முனைவோர் பட்ட உத்தி கள் துறைகளின் மற்ற முனைவோரையும் பட்டொளிக்கப் படுகின்றன. சேகரிப்பு பதப்படுத்தல் பேக்கிங் மற்றும் சாண்டிப்படுத்தல் வரை உள்ள அனைத்து நடைமுறைகளையும் மாணவிகள் இறுதமாகக் கற்றுக் கொள்ளும். இதற்கு கவிதா பாரிவைவிட அரிதானது. ஆர்டிங் ஹரிப்பியா, ஹரிணி கம்பக்ஷ், கவிதாபாத்தமாவதித்த நினைக ஆகிய யோவான் கம்மூராவை மாணவிகள் கவந்து கொள்ளும். பனை அடிப்படையிலான மறிப்பை கட்டு தொழில் கம்மூராவை தொழில்முனைவாள் வாங்குதல் குறித்து பதமுள்ள அனுபவத்தை பெறும்.

FARMER 2 – RAJASEKAR**PROFILE:**

- **NAME:** RAJASEKAR
- **LOCATION:** MARUTHUR NORTH, VEDARANYAM TALUK, NAGAPATTINAM DISTRICT.
- **EDUCATION:** MECHANICAL ENGINEERING GRADUATE
- **FARMING SYSTEM:** LIVESTOCK FEED PRODUCTION AND TRADITIONAL PADDY CULTIVATION

**CHALLENGES:**

Rajasekar observed the difficulty farmers faced in accessing **quality and affordable cattle feed**, along with the gradual disappearance of **traditional paddy varieties** due to chemical- intensive farming. Initial cost is high, traditional paddy variety seed collection is a difficult one, Adaptation problem, rainfed condition so time period is very important.

CHANGE ADOPTED:

Using his engineering background, Rajasekar **designed and developed a cattle feed processing machine and cylindrical weeder for weed management and irrigation {FERTICATION} – WATER WITH FISH AMINO ACID AND WATER WITH POWDERED FYM to designed a suction pipe of his own model.** Feed formulas were scientifically developed with guidance from a veterinary doctor, ensuring balance nutrition. Organic food production. No cost farming, Market value is increased.

PRACTICES:

- ❖ Production of cattle, goat and poultry feed with premium quality.
- ❖ Chemical free cultivation of traditional paddy(PROMOTE ORGANIC FARMING) – seed production purpose over **30 varieties** and home consumption in 2 traditional varieties like **kudavazhai and thangasamba.**
- ❖ Online marketing across tamilnadu
- ❖ Operation of a retail outlet named “**NIGAMAM**” selling.

Including,

- RICE VALUE ADDED PRODUCTS SUCH AS

- Rice flour
- Rice bran oil
- Aval
- Aval health mix
- Kudavazhai laddu
- Karupukavuni laddu

Other products such as

- Hair oil
- Tooth powder
- Seeyakai
- Pure honey

RESULTS:

Rajasekar integrated approach reduced feed costs for farmers, conserved indigenous rice varieties and created a **direct farmer – to – consumer market**, ensuring sustainable income and biodiversity protection.



COMPARISON/ OR COMMON IMPACT:

While karthekeyan focused on **value addition of surplus produce to overcome market failures**, Rajasekar combined engineering innovation with traditional farming to support

livestock nutrition and seed conservation. Despite different approaches, both farmers achieved.

- Reduced dependency on middlemen.
- Improved income stability.
- Promotion of traditional knowledge.
- Sustainable and eco-friendly farming models.

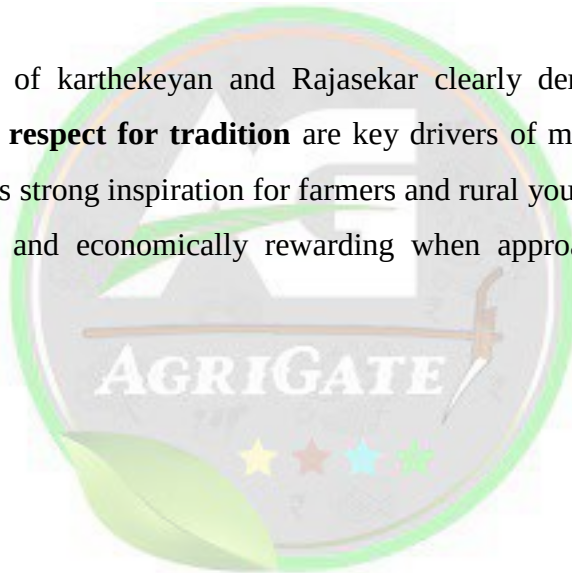
FARMER VOICES:

“What once felt like a loss became my biggest opportunity when I trusted traditional knowledge,” say **KARTHEHEYAN**.

“Engineering helped me strengthen farming, but traditional gave it purpose,” shares **RAJASEKAR**.

Conclusion

The success stories of karthekeyan and Rajasekar clearly demonstrate that innovation, **scientific guidance, and respect for tradition** are key drivers of modern agricultural success. Their experiences serve as strong inspiration for farmers and rural youth, proving that agriculture can be both sustainable and economically rewarding when approached with creativity and commitment.



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SOIL INFORMATION SYSTEM IN RELATION TO SUSTAINABLE AGRICULTURE BY IMPROVING BREEDING TECHNIQUES

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C. Sivaranjani¹, R. Vinoth^{2*} and J. Gokulakrishnan³

¹Senior Research Fellow (SS&AC), ²Teaching Assistant (PBG), ³Associate Professor (PBG),
Institute of Agriculture, TNAU, Kumulur, Trichy, Tamil Nadu, India

*Corresponding Author: R. Vinoth

Introduction

A Soil Information System (SIS) integrates soil data (testing, mapping, properties) with technology (GIS, AI, remote sensing) to guide sustainable farming, enabling precision management of nutrients, water, and amendments, which directly supports **plant breeding** by identifying ideal soil conditions for specific crop varieties, optimizing nutrient/water use, and developing stress-tolerant, high-yielding plants for diverse soil environments, fostering resilient food systems.

The Role of Plant Breeding and Genetics in Sustainable Agriculture



How SIS Supports Sustainable Agriculture:

- 1. Informed Decisions:** Provides data on nutrient levels, organic matter, water retention, and soil health, helping farmers optimize inputs (fertilizers, irrigation).
- 2. Precision Farming:** Uses GIS, drones, and sensors for targeted interventions, reducing waste and environmental impact (e.g., nutrient runoff).



3. Monitoring & Planning: Tracks land quality, assesses management impacts, and informs long-term land-use planning for improved soil productivity.

Soil Information System Link to Plant Breeding:

1. Matching Crops to Soil: SIS data helps breeders understand which soil traits (pH, nutrient profiles, water holding) suit specific crop varieties, guiding the development of locally adapted cultivars.

2. Developing Resilient Varieties: Breeders use genetic insights (marker-assisted selection, genome editing) to design crops that thrive in specific soil conditions or tolerate stressors (drought, poor soils) identified by SIS.

3. Optimizing Nutrient Use Efficiency (NUE): SIS data on nutrient cycling and availability informs breeding for plants that can better capture and utilize soil nutrients, reducing reliance on external inputs.

4. Improving Root Systems: Understanding soil physical properties via SIS helps breed crops with more efficient root systems for water and nutrient uptake.

5. Data-Driven Breeding: Integrated Cyber-Agricultural Systems (CAS) link soil data with breeding platforms, enabling faster development and deployment of superior, sustainable varieties.

Technologies in Soil Information system in relation with plant breeding

1. Geographic Information Systems (GIS): For spatial analysis of soil data.

2. Remote Sensing & Drones: For broad-scale soil and crop monitoring.

3. AI & Digital Twins: For complex modeling and decision support in breeding and production.

4. Soil Health Indicators: Soil Organic Carbon (SOC), bulk density, water holding capacity.

By bridging soil science and genetics, SIS creates a feedback loop, ensuring that breeding efforts

are precisely targeted to create resilient crops that perform optimally in diverse and changing soil environments, securing sustainable food production.

How Soil Information Systems (SIS) help plant breeding:

- **Identify Soil-Specific Needs:** SIS maps nutrient levels, water-holding capacity, and texture, highlighting areas needing specific soil amendments, crucial for breeders developing crops suited to particular soil types.
- **Targeted Trait Development:** Breeders use SIS data to select for traits like drought tolerance (e.g., drought-resistant corn) or nutrient efficiency, matching germplasm to challenging soil environments.
- **Optimize Growing Conditions:** By understanding field variability, breeders can test new varieties under precisely controlled, data-informed conditions to assess their performance accurately.
- **Improve Resource Efficiency:** SIS helps develop crops that use water and nutrients more efficiently, aligning breeding goals with sustainable agriculture practices and reducing nutrient runoff.
- **Data-Driven Breeding Platforms:** Integrates soil data with breeding databases (like Breed base), allowing for spatial analysis of genotype performance across diverse soil conditions, enabling faster genetic gains.

Soil Management in relation to sustainable agriculture

Requirements for research, practices and policies affecting soil management in relation to global food security are reviewed. Managing soil organic carbon (C) is central because soil organic matter influences numerous soil properties relevant to ecosystem functioning and crop growth. Even small changes in total C content can have disproportionately large impacts on key soil physical properties. Practices to encourage maintenance of soil C are important for ensuring sustainability of all soil functions. Soil is a major store of C within the biosphere – increases or decreases in this large stock can either mitigate or worsen climate change.

Deforestation, conversion of grasslands to arable cropping and drainage of wetlands all causes emission of C; policies and international action to minimize these changes are urgently required. Sequestration of C in soil can contribute to climate change mitigation but the real impact of different options is often misunderstood. Some changes in management that are beneficial for soil C, increase emissions of nitrous oxide (a powerful greenhouse gas) thus

cancelling the benefit. Research on soil physical processes and their interactions with roots can lead to improved and novel practices to improve crop access to water and nutrients. Increased understanding of root function has implications for selection and breeding of crops to maximize capture of water and nutrients. Roots are also a means of delivering natural plant-produced chemicals into soil with potentially beneficial impacts. These include biocontrol of soil-borne pests and diseases and inhibition of the nitrification process in soil (conversion of ammonium to nitrate) with possible benefits for improved nitrogen use efficiency and decreased nitrous oxide emission.

The application of molecular methods to studies of soil organisms, and their interactions with roots, is providing new understanding of soil ecology and the basis for novel practical applications. Policy makers and those concerned with development of management approaches need to keep a watching brief on emerging possibilities from this fast-moving area of science. Nutrient management is a key challenge for global food production: there is an urgent need to increase nutrient availability to crops grown by smallholder farmers in developing countries. Many changes in practices including inter-cropping, inclusion of nitrogen-fixing crops, agroforestry and improved recycling have been clearly demonstrated to be beneficial: facilitating policies and practical strategies are needed to make these widely available, taking account of local economic and social conditions.

In the longer term fertilizers will be essential for food security: policies and actions are needed to make these available and affordable to small farmers. In developed regions, and those developing rapidly such as China, strategies and policies to manage more precisely the necessarily large flows of nutrients in ways that minimise environmental damage are essential. A specific issue is to minimise emissions of nitrous oxide whilst ensuring sufficient nitrogen is available for adequate food production. Application of known strategies (through either regulation or education), technological developments, and continued research to improve understanding of basic processes will all play a part. Decreasing soil erosion is essential, both to maintain the soil resource and to minimise downstream damage such as sedimentation of rivers with adverse impacts on fisheries. Practical strategies are well known but often have financial implications for farmers. Examples of systems for paying one group of land users for ecosystem services affecting others exist in several parts of the world and serve as a model.

Climate-Smart Agriculture Starts with Smarter Seeds

Climate change has introduced a new level of uncertainty in farming. Crops now face heatwaves, floods, droughts, and unexpected weather events. Traditional seeds can't cope. To build resilience, we must start at the seed level. Plant geneticists are designing seeds that can adapt to extreme weather. New varieties of maize can survive dry spells. Chickpeas are being bred to flower earlier to avoid heat stress. Tomatoes that grow in high temperatures are now in trials.

The success behind these innovations lies in advanced tools. Gene mapping helps identify the exact location of useful traits in a plant's DNA. Marker-assisted selection allows breeders to speed up crop development by selecting only the best traits. Genome editing tools like CRISPR let scientists precisely change DNA without introducing foreign genes.

Components of an SIS for Breeding:

- **Data Acquisition:** Field sensors, soil sampling, and GIS mapping capture detailed soil and landscape data.
- **Data Integration:** Links soil data with existing databases, climate info, and management practices.
- **Analysis Toolbox:** Applies algorithms to convert raw data into actionable insights (e.g., soil fertility maps).
- **Decision Support:** Provides customized recommendations for management and guides breeding trials

Applications of soil information in breeding techniques:

- **Precision Fertilization:** Instead of blanket applications, SIS guides targeted nutrient delivery, ensuring crops get what they need where they need it.
- **Breeding for Resilience:** Develops varieties that thrive in water-limited or nutrient-poor soils, addressing climate change impacts.
- **Land Use Planning:** Helps assess a field's potential and challenges before planting, informing long-term crop selection

Conclusion

The first Green Revolution gave us a powerful tool that is food security. The second must give us something even greater, sustainability. We now know that feeding the world is not just about producing more. It's about growing crops that protect the planet, nourish people, and



secure the future. Plant breeding and genetics offer a clear path forward. Research on soil physical processes and their interactions with roots can lead to improved and novel practices to improve crop access to water and nutrients. With climate-resilient crops, nutrient-rich varieties, and advanced breeding tools, we can meet rising food demands without harming the environment.



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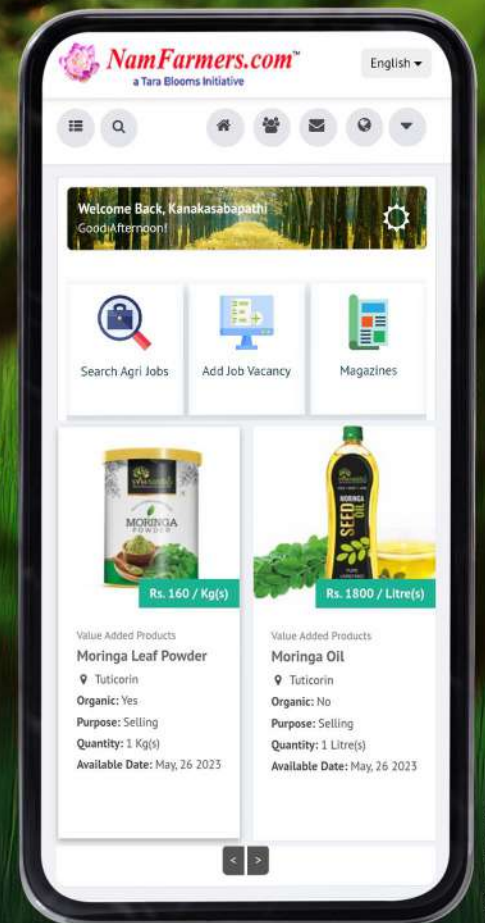
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