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Crop Diversification for Sustainable Hill Agriculture

Article ID: 72500

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Introduction

The northeastern region of India account for about 8 per cent of the country's total geographical area. However, most parts of the region are hilly being and confined to the valleys and hill slopes. Agricultural productivity is low as the topography does not permit the intensive use of irrigation and modern inputs. Thus, shifting or jhum cultivation become the only option in some parts with subsistence nature of farming. In such a situation, crop diversification towards high value crops, and bringing shifting cultivation into permanent through horticultural crops intervention could enhance farm income and livelihood of people in the region. Hence, crop diversification is essential for higher income, risk management, soil health improvement and increase resilience in hill agriculture.

Approaches of Crop Diversification

1. Horizontal diversification:

a. Crop substitution: Less remunerative crops are substituted with more suitable alternate crops depending on the agro climatic conditions of the area. This includes shifting of monoculture cereals based staple food to high value crops like vegetable, spices etc.

b. Crop intensification: It is the approach of adding new valued crops to existing cropping system to increase the farm's overall productivity. This includes intercropping, mixed cropping, sequential cropping, multi-tier cropping etc. This will enable to increase the grain equivalent yield of crops, system production efficiency, relative production efficiency and land use efficiency as compare to mono cropping in traditional cropping system (Fig.1).

Fig. 1: Intercropping of maize with black gram and soybean

2. Vertical diversification: It is the value addition to products through packaging, processing, regional branding, merchandizing to improve the marketable value of crops. Encouraging entrepreneurship on post-harvest technology can facilitate the market linkage and higher profitability. In most of the case, the tribal farmers intended to cultivate low yielding traditional landraces due to taste preference only.

3. Land based approach: This involved the selection of crops based on problems e.g. On sloppy lands of jhum farming which are prone to soil erosion, adoption of alternate cropping of erosion promoting and erosion resisting crops like legumes across the slope is essential (Fig. 2).

Fig. 2: Strip cropping of *jhum* rice and soybean against the slope to control soil erosion

4. Water based approach: Diversion of high water requiring crops to less water intensive crops. In case of rain fed farming (assured rainfall) on moisture retentive soils some minor crop requiring less moisture like pulses or cereals may be grown after the harvest of *kharif* crop,. E.g. Millet (Kharif) – Lentil and Buckwheat (Rabi).

5. Varietal diversification: Substitution of low yielding varieties can be one of the important strategies. However, in regions like north east region of India, taste and palatability has to be kept in mind for varietal introduction for wide acceptance among the tribal farmers.

6. Crop diversification for nutrient management: For proper and uniform utilization of available nutrients in the soil, and avoid crop for competition of nutrients uptake from soil, crops with taproot should be followed by those which have a fibrous root system. Such combination helps in reducing cost of cultivation.

7. Crop diversification for pest management:

a. Intercropping of cotton with legumes can deter whiteflies, and bollworms, while planting groundnuts with pearl millet may reduce thrips.

b. Trap crops to lure the pests away from the main crop. Example- Planting marigolds with tomatoes and eggplants to draw pests away notably root-knot nematodes and whiteflies.

c. Banker plant systems: Intentionally growing a non-crop plant that supports a non-pest herbivore can provide a continuous alternative host for the natural enemies of the target crop pest. Example- winter wheat to support the *Aphidius colemani* parasitoid for controlling aphids, and Purple Flash.

8. Crop diversification for risk reduction: Selection of crops based on local climatic conditions and market demand is essential to get a higher net return. Building up an ideal crop rotation around a hub crop for which the greatest comparative advantages exist will enable to enhance the profit.

Conclusion

Although there are challenges which cannot be ignored, crop diversification provides an opportunity to double farmers' income and create food security for the nation. Thus, crop diversification is one of the most effective ways to boost farm revenue, augment the income of small farm holdings, overcoming the risk of climatic variability, balancing food demand, beneficial for conserving natural resources with minimizing environmental pollution, overcoming dependence on off farm inputs, food and nutritional security.

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Technological Empowerment of Rural Women through Marigold-Based Trap Cropping: A Sustainable Approach to Solanaceous Vegetable Pest Management

Article ID: 72501

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Introduction

Women empowerment in agriculture refers to enhancing women's access to resources, knowledge, decision-making, and income opportunities within the farming sector. Empowered women farmers contribute significantly to household food security, nutrition, and rural economic growth. In many regions, women's participation in agriculture remains undervalued despite their crucial roles in production, processing, and marketing. They need technological back stopping such as knowledge, skills and exposure which help them in contributing more production agri-food system.

Horticulture is one of the largest and fastest-growing sectors of Indian agriculture, with production expanding steadily over the years. It encompasses a diverse range of crops, including fruits, vegetables, tubers, flowers, aromatic and medicinal plants, spices, and plantation crops. Farm women play a crucial role across the entire horticultural value chain, contributing an average of 7–8 hours per day to activities that span from pre-production to post-harvest handling, value addition, and marketing in vegetable production systems. Vegetable and flower cultivation has emerged as a sustainable and profitable avenue for empowering rural women. These activities require comparatively low land area and investment while offering high returns and year-round employment. Through training in improved cultivation techniques, nursery management, organic farming, and marketing, women gain both technical and entrepreneurial skills. Such initiatives not only enhance income and livelihood security but also strengthen women's confidence, social status, and leadership roles within the community. Promoting women-led vegetable and flower enterprises thus contributes to gender equity, food diversification, and sustainable rural development.

Vegetables are succulent, herbaceous crops that are highly susceptible to damage from insects, pests, and diseases. These biotic stresses significantly reduce crop yield and productivity, ultimately diminishing the economic returns associated with vegetable cultivation. Tomato, brinjal, cabbage, cauliflower, okra, beans, and cucurbits are among the major vegetables grown across India. However, the cultivation of hybrid and improved varieties, especially during off-seasons, combined with intensive farming practices and the unregulated use of insecticides, has disturbed the ecological balance between insect pests and their natural predators. The Solanaceous crop group comprises several economically important vegetables, including tomato (*Solanum lycopersicum*), brinjal/eggplant (*Solanum melongena*), chilli (*Capsicum annuum*), and potato (*Solanum tuberosum*). These crops are widely cultivated across India but are highly vulnerable to a range of insect pests, making integrated pest management strategies essential for sustaining productivity. This imbalance has led to the emergence of insecticide resistance in several key pests, such as the tomato fruit borer (*Helicoverpa armigera*), brinjal fruit borer (*Leucinodes orbonalis*), serpentine leaf miner (*Liriomyza trifolii*), and diamondback moth (*Plutella xylostella*) affecting cabbage (Moorthy *et al.*, 2004). Globally, it has been reported that insect pest infestations alone account for an estimated 15-20% loss of vegetables in the field and an additional 18-20% loss during storage (Ofuya e*t al*., 2023).

To mitigate yield losses caused by pest infestations, growers commonly adopt chemical control methods that effectively reduce insect populations in a short timeframe. However, the overuse of synthetic pesticides results in the accumulation of toxic residues in the soil and plant tissues, which ultimately enter the human food chain. Prolonged consumption of these chemical residues poses serious health risks and negatively impacts non-target organisms, including essential pollinators. Consequently, there is an increasing shift toward sustainable pest management strategies. Among these, trap cropping and intercropping have emerged as effective alternatives for maintaining pest populations below the economic threshold level while minimizing ecological and health risks (Ofuya *et al*., 2023).

To address these resistant pest issues, Integrated Pest Management (IPM) strategies are being developed. A trap crop is a plant species grown alongside the main crop to attract and divert insect pests, thereby reducing pest pressure and protecting the primary crop from damage (Shelton *et al*., 2006). In addition to serving as a pest management strategy, trap crops may also be harvested, providing supplementary economic benefits to growers. For instance, marigold is effectively used as a trap crop to manage the tomato fruit borer (*H. armigera*), while mustard serves as a trap crop in cabbage and cauliflower fields (Moorthy *et al*., 2004).

Marigold as Trap Crop

Marigold (*Tagetes* spp.) is widely used as a companion/trap crop due to its ability to naturally repel a variety of insect pests through the release of allelopathic compounds. These bioactive substances, particularly thiophenes, act as deterrents to nematodes, aphids, and other phytophagous insects, thereby reducing pest populations in adjacent crops. Additionally, marigold flowers attract beneficial insects such as pollinators and parasitic wasps, contributing to enhanced biological control within the cropping system. The incorporation of marigold in intercropping or trap cropping systems not only supports integrated pest management but also adds aesthetic and economic value to the field.

The roots of marigold have been reported to contain various phytochemical compounds, including flavonoids, di-hydroflavonoids, flavones, and flavonones that lack free hydroxyl groups. In addition, marigold roots possess other bioactive constituents such as amines, amides, phenols, and ketones. In a more recent study, El-Gengaihi *et al*. (2001) isolated three nematicidal compounds from *Tagetes erecta*, *Tagetes patula*, and *Tagetes minuta* using chloroform extraction. The compounds identified were 5(- ent-1-ol)-2,2-bithienyl, sigma-4, 22-dien-3-beta-ol, and 5-(4- acetoxy-1-butenyl)-2,2-bithienyl. Additionally, α-terthienyl, a sulfur-containing heterocyclic compound, has been recognized as a major constituent abundant in *Tagetes* tissues, contributing to its nematicidal activity.

Marigold as a Trap Crop for Solanaceous Vegetables

Solanaceous vegetables-primarily tomato (*Solanum lycopersicum*), brinjal or eggplant (*Solanum melongena*), chilli (*Capsicum annuum*), and potato (*Solanum tuberosum*)-constitute an important crop group cultivated extensively across India. These crops are grown throughout the year, with major production seasons spanning rabi, kharif, and summer, depending on regional climatic suitability. While they hold significant nutritional and economic value, Solanaceous crops are highly susceptible to a wide range of insect pests such as fruit borers, whiteflies, aphids, thrips and leaf miners. Integrating marigold (*Tagetes spp.*) as a trap crop within Solanaceous vegetable systems has proven effective in reducing pest infestation by attracting and diverting key pests away from the main crops. Thus, marigold-based trap cropping not only supports sustainable pest management but also enhances productivity and income for growers cultivating Solanaceous vegetables.

In tomato cultivation, the fruit borer (*Helicoverpa armigera*) is considered a major pest, capable of causing up to 55% crop loss. The larvae infest tomato plants throughout the growing season, damaging the fruits and rendering them unsuitable for human consumption. Cultivating marigold along the bunds surrounding the main crop (such as tomato) can also provide an additional source of income for rural households (Singh & Tripathi, 2017). In tomato crops, the fruit borer population remained below the Economic Threshold Level (ETL) due to the use of marigold as a trap crop. Monitoring should focus on the top three leaves, as the highest egg deposition by the fruit borer is generally observed on marigold flowers (Singh & Tripathi, 2017).

According to Jambhulkar *et al*. (2012) intercrop of tomato with marigold give additional income as well as fruit borer management. The use of marigold as a trap crop not only lowered the incidence of fruit borer but also enhanced the population of natural predators, such as coccinellid beetles. Tomato intercropped with marigold recorded the maximum reduction in fruit borer infestation, reaching up to 93.5% (Srinivasan *et al*. 1994). However, studies have shown that intercropping tomato with marigold as a trap crop significantly reduces pest infestation, thereby protecting the main crop from severe damage (Parihar *et al*., 2025).It has been observed that intercropping marigold with tomato in a 15:1 row ratio (15 rows of tomato to 1 row of marigold) significantly reduces the larval population of the fruit borer. The findings indicated that, although *Helicoverpa armigera* larvae infest tomato crops throughout the growing season, the incorporation of marigold as a trap crop effectively lowers larval incidence compared to tomato grown as a monoculture (Kumar *et al.,* 2017).

In brinjal, several pests attack the crop at different stages of its growth period. One of the most damaging pests in brinjal is the Hadda beetle (*Henosepilachna vigintiopunciata*). Marigold can effectively be cultivated as a companion crop alongside brinjal. Studies have shown that the presence of marigold surrounding the brinjal crop significantly reduces the pest load on the primary crop. Sucking pests such as jassids and whiteflies, as well as coleopteran pests like *Epilachna vigintioctopunctata*, are attracted to the marigold plants, thereby diverting them away from the brinjal. This diversion provides substantial protection to the brinjal crop.

Additionally, the brinjal shoot and fruit borer (*Leucinodes orbonalis*), which is a monophagous pest specific to brinjal, is also suppressed due to the odor emitted by marigold plants. The average percentage of shoot infestation during the vegetative growth stage of brinjal is considerably lower when marigold is grown as a companion crop. Similarly, fruit damage caused by the borer pest during the fruiting stage of brinjal is also significantly reduced, demonstrating the effectiveness of marigold as a companion plant in integrated pest management (Bhattacharyya, 2020).

Chilli crop that is highly susceptible to insect pest infestations. The major pests affecting chilli include aphids, whiteflies, thrips and yellow mites. These sap-sucking insects act as vectors for viral pathogens, leading to serious diseases such as chilli leaf curl. Yield losses attributed to aphid and whitefly infestations can reach up to 50%, while thrips can cause severe damage ranging from 50% to 90%. Fruit borers also pose a significant threat to chilli crops, causing yield losses of up to 90%. One such trap crop used successfully in chilli to control the population of the sucking pests is the marigold. However, among the various trap cropping systems evaluated, the combination of chilli and marigold was found to be the most effective in managing populations of both sucking pests and fruit borers (Parihar *et al*., 2025). Additionally, marigold has proven nematicidal and allelopathic properties, which further contribute to soil health and pest suppression.

Conclusion

The integration of marigold as a trap crop in vegetable cultivation presents a sustainable and ecologically sound approach to pest management, significantly reducing dependence on chemical pesticides. This practice not only helps maintain pest populations below economic thresholds but also enhances biodiversity and improves soil health through its allelopathic and nematicidal properties. For women farmers, especially in rural regions, vegetable cultivation combined with marigold offers multiple benefits: increased crop productivity, reduced production costs, and supplemental income from both primary and trap crops. Marigold cultivation, being low-input and marketable, serves as an additional revenue stream, fostering financial independence and elevating the socio-economic status of women. This dual advantage of pest control and income diversification aligns with sustainable agricultural principles and promotes gender equity in rural agrarian economies. Consequently, adopting marigold-based trap cropping systems empowers women not only as cultivators but also as active contributors to sustainable development and food security.

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The Price We Pay for Food: A Look at India's Markets Through a Farmer's Lens

Article ID: 72502

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Introduction

Every grain of rice, every onion, and every drop of milk travels through a long, complex chain before it reaches our kitchen. Consumers often feel the pinch of rising food prices, while farmers frequently receive prices too low to cover their basic production costs. This mismatch is not new, global and Indian studies show that farmers often receive only a fraction of what consumers pay (FAO, 2023; CACP, 2022).

Seeing the price, we pay for food through a farmer's lens reveals a story of risks, uncertainties, and market gaps in India's agricultural system.

Farmers Receive Much Less than What Consumers Pay

Agricultural markets in India are marked by a significant spread between the farm-gate price and the retail price. According to the Commission for Agricultural Costs and Prices, farmers commonly receive 20–60% of the consumer rupee, depending on the crop and the number of intermediaries involved (CACP, 2022).

A well-known example is tomato:

a. Farmer price in peak season: ₹8–₹12/kg
b. Retail price in cities: ₹40–₹60/kg.

The National Horticulture Board observes that perishables like tomato, onion, and leafy vegetables face some of the highest margins due to high wastage, handling, and transport costs (NHB, 2023). This is why consumers see high prices even when farmers get very little.

Why Prices Change as Food Moves Through the Chain?

India's supply chains are long and fragmented. Crops typically pass through:

1. Local traders
2. Commission agents
3. Wholesale markets (APMCs)
4. Urban wholesalers
5. Retail shops.

Each stage adds cost and margin. Acharya and Agarwal (2019) highlight that India's marketing structure naturally inflates consumer prices due to multiple market charges, commission fees, and inadequate infrastructure.

Price Volatility Adds Further Distortion

Weather shocks, unseasonal rains, and disease outbreaks can rapidly alter supply and push prices up. The Ministry of Agriculture reports that vegetables like onion can swing from ₹2–₹5/kg at the farm to ₹80–₹100/kg in retail within months due to seasonal supply gaps (MoAFW, 2022).

Global markets also influence domestic prices. India depends heavily on imported edible oils, making local prices sensitive to international fluctuations (SEA, 2022; OECD-FAO, 2023).

The Paradox: When Good Harvests Bring Low Prices

In agriculture, large harvests often depress prices. When thousands of farmers harvest the same crop at the same time, markets become flooded, and prices crash, a classic "glut problem." World Bank analysis shows that developing countries face this regularly, especially in vegetables (World Bank, 2020). In India, post-harvest losses in fruits and vegetables are 15–35%, driven by poor storage and cold-chain gaps (ICAR-CIPHET, 2019). These losses push down harvest-time farm prices while later causing shortages and high retail prices.

Thus, farmers lose during surplus, and consumers lose during shortage.

MSP Helps, but its Reach is Limited

Minimum Support Price (MSP) is intended to protect farmers from distress sales. However, NITI Aayog (2021) estimates that only 25–30% of farmers directly benefit from procurement, primarily in rice, wheat, and to some extent cotton.

Millions of farmers producing fruits, vegetables, pulses, and oilseeds still rely on open markets where prices fluctuate sharply.

Rising Costs, Shrinking Margins

Even as market prices rise for consumers, the cost of cultivation rises faster for farmers. Fertilizer prices, labour wages, and fuel costs have steadily increased. CACP (2023) reports that production costs for major crops like paddy, wheat, cotton, and pulses have risen 15–25% in the last few years.

Small and marginal farmers, who constitute 86% of India's farming households (Agricultural Census, 2019), face thin margins and higher vulnerability.

The Urban–Rural Price Divide

Price disparities between rural markets and urban centres are often extreme. NHB (2023) reports that the price gap for perishables can reach 300–500%, especially for papaya, tomato, and leafy vegetables.

Example:

a. Farmer price (rural): ₹5–₹8/kg
b. Retail price (urban): ₹30–₹40/kg.

This widening gap reflects inefficiencies and the need for shorter, better-managed supply chains.

The Promise of New Supply Chains

Digital platforms like e-NAM, Farmer Producer Organizations (FPOs), and private procurement systems offer hope. Small Farmers Agribusiness Consortium (SFAC, 2022) finds that these systems:

1. Improve price discovery
2. Lower marketing costs
3. Provide quicker payments
4. Reduce dependency on intermediaries.

But adoption remains low due to limited digital literacy, poor aggregation, and infrastructure constraints. Additional evidence from field studies supports this gap. A constraint analysis of the Kodangal Farmer Service Producer Company in Telangana found that FPOs commonly struggle with inadequate storage facilities, limited working capital, low member participation, and marketing challenges, factors that directly reduce their ability to secure better prices for farmers (Rajini Devi *et al.*, 2021).

Creating a Fairer Price System: What India Needs

To ensure both farmer welfare and consumer affordability, India needs systemic improvements:

1. Invest in storage and cold-chain: Reducing losses stabilizes prices across seasons (ICAR-CIPHET, 2019).

2. Diversify MSP and procurement: Including pulses and oilseeds reduces import dependence and protects farmers (NITI Aayog, 2021).

3. Strengthen FPOs: Collective marketing improves bargaining power and reduces price spread (SFAC, 2022). Studies show that many FPOs continue to face operational constraints such as poor infrastructure, low financial capacity, and limited marketing experience, as seen in the Kodangal FPO case study (Rajini Devi *et al*., 2021).

4. Real-time digital price information: Helps farmers identify better markets and avoid distress sales.

5. Build shorter value chains: Local processing, direct marketing, and aggregation models reduce price inflation and improve farmer returns.

Conclusion

India's food prices reflect the combined pressures of climate variability, rising input costs, fragmented supply chains, and global market influences. Yet the farmers who bear these risks often receive the smallest share of the consumer's food expenditure, revealing a structural imbalance in agricultural markets. Ensuring stable, remunerative prices for farmers while maintaining affordable food for consumers is essential for both national food security and sustainable agricultural growth.

To bridge the gap between farmgate and retail prices, India must strengthen storage and cold chains, expand procurement and MSP coverage, empower Farmer Producer Organisations (FPOs), and scale digital marketing platforms such as e-NAM. Investments in climate-resilient technologies, transparent value chains, and scientific price forecasting can further stabilize markets. A food system that rewards both efficiency and fairness ultimately honours the farmer's vital role in feeding the nation.

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Golden Genes: Unlocking Nature's Treasure for Better Crops

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Summary

Golden Genes: Unlocking Nature's Treasure for Better Crops talks about how important genetic resources are for making crops more resilient and sustainable in the face of global agricultural problems including climate change, population growth, and less farmland. The article talks about "golden genes," which are important features found in plants that can improve their output, make them more resistant to pests and diseases, and make them more nutritious. Breeders apply a mix of traditional approaches, cross-breeding, marker-assisted breeding, genome editing, and AI-powered procedures to harness these qualities. The chapter also stresses successful uses, such drought-resistant rice and disease-resistant pulses, which demonstrate the promise of these genetic resources in tackling food security challenges. The future of agriculture hinges on these developments to generate crops that are more adaptive to environmental challenges, ultimately providing a sustainable food supply for future generations.

Introduction

Every seed has a fascinating story that shows how evolution works in a subtle way, as well as how to be persistent and adaptable. Plants have been able to survive harsh climates, keep pests away, and fight off diseases for thousands of years. But because of changing weather patterns, growing populations, and less farmland, natural evolution needs help to move faster. "Golden Genes" refers to the priceless genetic resources found in plants that could change farming and make sure that our food supply lasts for future generations.

People used to think that plant breeding was a calm and orderly process that took time and careful selection. Now, it's a very important field that works hard to make sure everyone has enough food. The search for useful genes is changing farming systems. For example, new crops like drought-resistant rice, disease-resistant legumes, and nutrient-rich millets are being grown.

The Hidden Gold in Plants

There are thousands of genes in each plant species, but only a small handful of them can be called "golden." These amazing genes have amazing properties that are important for increasing resilience, production, and nutritional value. The traits associated with these powerful genes often remain concealed within the plant's genetic framework, awaiting identification and application. By uncovering these hidden traits, scientists and farmers can greatly improve the performance and sustainability of crops, which will help make sure that people all around the world have enough food and stay healthy. Many such traits are hidden inside:

1. **Traditional landraces** grown by farmers for centuries
2. **Wild relatives** that survive in extreme ecosystems
3. **Neglected or underutilized crops** with untapped potential

For example, a wild wheat species growing in arid mountains may carry a gene for drought tolerance. A tiny wild tomato may have immunity to a disease that destroys millions of tonnes of commercial tomatoes each year. These genetic gems often remain unnoticed until plant breeders discover them through careful study and testing.

How do Breeders Unlock Golden Genes?

Breeding plants is similar to figuring out a challenging treasure hunt. Breeders employ a variety of methods, some traditional and some innovative, to find, separate, and incorporate useful genes into modern crop types.

1. Traditional Breeding: The Foundation: For thousands of years, farmers have used natural breeding to pick better crops. This strict method has made crops more productive, tastier, and better able to handle different kinds of weather. The work of these early farmers still has an effect on breeding today, where choosing the right plants is important for creating new varieties. Modern breeders use thousands of years of experience to make crops that are better and better at meeting the needs of the market and the changing climate.

2. Cross Breeding: Mixing Strengths: By hybridizing two distinct varieties, breeders can effectively harness the advantageous traits of each parent. For example, crossing a high-yield rice variety with a traditional strain that is known for being able to survive droughts may result in offspring that do better in dry conditions. This strategic combination is meant to improve yield and make sure that the new line can survive in tough environmental conditions. These new ways of breeding are very important for dealing with the growing worries about climate change and food security. They make it possible to grow crops that can keep farming going even when the weather is bad.

3. Marker-Assisted Breeding: Fast and Accurate: DNA markers enable breeders to identify desirable traits in plants prior to their maturation. This advanced technology significantly reduces the time required for field testing and enhances the accuracy of breeding efforts.

4. Genome Editing: Precise Improvements: Biotechnology, particularly CRISPR/Cas9, has transformed plant breeding by allowing precise alterations to specific genomic sequences without foreign DNA. This new technology allows breeders to improve crop qualities including disease resistance, nutritional value, and tolerance to changing climates in a far shorter timescale than traditional breeding methods. By targeting and editing specific genes, CRISPR/Cas9 streamlines breeding and reduces genetic alteration risks, making it a potent tool for generating sustainable agricultural solutions to satisfy the needs of a growing global population.

5. Digital & AI-Powered Breeding: Artificial intelligence has the capability to analyze vast amounts of data, including weather patterns, soil characteristics, and plant attributes, to identify the optimal combinations for crop production. By minimizing the reliance on trial-and-error methods, AI enhances the efficiency of breeding processes, leading to more effective agricultural outcomes.

Nature's Treasures in Action

Around the world, golden genes have already given rise to remarkable innovations:

Drought-Defying Rice: Traditional rice varieties from India's semi-arid regions possess genes that confer drought tolerance. Breeders have harnessed these genetic traits to create new rice varieties capable of withstanding prolonged dry periods while minimizing yield loss.

Disease-Resistant Pulses: Wild relatives of pigeonpea and chickpea exhibit resistance to various threats such as wilt, pod borers, and rust diseases. These valuable genetic traits are now playing a crucial role in enhancing protein security in India.

Vegetables Rich in Nutrients: The orange-fleshed sweet potato, known for its high vitamin A content, is the result of extensive breeding efforts aimed at enhancing the nutritional traits found in traditional landraces.

Biofortified Crops: Zinc-enriched wheat and iron-rich pearl millet are improving nutrition in millions of households, especially in rural India.

Why are Golden Genes More Important Today?

The world's agriculture is facing unprecedented challenges:

1. Climate change brings unpredictable monsoons, droughts, and floods.

2. Soil health is declining due to intensive farming.

3. Pests and diseases are evolving faster than ever.

4. Global population is expected to reach 9.7 billion by 2050.

Relying solely on chemicals or improved management is no longer enough. Genetic solutions — durable, natural, and sustainable — hold the most promise. A single golden gene can save a crop from collapse or improve yields by 20–30% without harming the environment.

The Future: A New Era of Smart Breeding

The upcoming decade is poised to transform crop development dramatically. Innovations such as speed breeding, **pan-genomics**, **artificial intelligence** for trait prediction, and **robotic phenotyping** will enable breeders to uncover the intricacies of nature more efficiently than ever before. As a result, farmers will soon cultivate crop varieties that are better suited to meet the challenges of modern agriculture.

1. Require less water
2. Resist new diseases
3. Offer higher protein and mineral content
4. Thrive in degraded soils
5. Mature faster and reduce input cost

These innovations will not only improve farm income but also uplift rural communities and strengthen national food security.

Conclusion: Seeds of Hope

Golden genes provide a compelling reminder that nature has the remedies to many agricultural challenges. Just discover them, understand them, and use their power. This untapped genetic pool is linked to farmers' demands and consumers' desires through plant breeding. Harnessing these natural genetic treasures is crucial as climate change and increased food needs complicate our future. A worldwide need, not just a scientific question. Every new plant variety shows how great genetics is and how inventive plant breeders are in discovering the natural world's secrets. Overall, genetic material is valuable because it bears the potential of a healthier, more sustainable, and food-secure future. Plant breeding has advanced, making farms more productive and protecting our food systems from environmental issues. Focusing on these golden genes may allow us to create new products that meet the needs of our growing population and ensure the survival of our ecosystems. Since we want a future with enough food, scientists, farmers, and consumers must collaborate.

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Plant-Based Natural Food Dyes: Future Market with Focus on India

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Introduction

Plant-based natural food dyes are increasingly reshaping the global food and beverage industry as consumers, regulators, and manufacturers collectively move toward cleaner, safer, and more sustainable ingredients. These dyes, derived from botanical sources such as fruits, vegetables, flowers, seeds, roots, and spices, offer a natural alternative to synthetic food colours that have long dominated processed foods. As public concerns grow over the health risks and environmental impact associated with artificial dyes, plant-based colourants have begun to gain widespread acceptance. Their renewed importance is especially evident in markets with strong agricultural ecosystems and rich botanical heritage, such as India. With its abundance of natural pigment-rich crops and its rapidly expanding food processing industry, India stands poised to become one of the most significant players in the global natural food dye sector.

Why Demand for Natural Food Dyes?

Globally, the shift toward natural food dyes is driven by the “clean label” movement, which emphasizes transparency, fewer additives, and recognizable ingredients. Consumers increasingly scrutinize food labels, avoiding complex chemical names and opting for products coloured using familiar natural sources like beetroot, turmeric, spirulina, or hibiscus. This trend is strengthened by regulatory pressures in many countries where artificial dyes have been linked to allergies, hyperactivity in children, and potential carcinogenic risks. While synthetic colours offer cost advantages and stability, their perceived health risks have significantly impacted consumer trust, particularly in packaged foods, beverages, and confectionery items. As a result, plant-based food dyes, which are generally regarded as safer and more trustworthy, are becoming preferred ingredients in premium and even mainstream food products.

In India, the demand for natural food dyes has been rising in parallel with the growth of the food and beverage processing sector, one of the country’s fastest-growing industries. India’s food culture, which already embraces the medicinal and colouring properties of many natural ingredients, supports this shift. For instance, turmeric has been used for centuries not only as a spice but also as a natural dye imparting a deep golden hue to foods. Beetroot, carrot, annatto, marigold, and hibiscus have been used informally in household preparations, sweets, and traditional foods. The contemporary interest in health and wellness, reinforced by the influence of Ayurveda and the global preference for plant-based products, has revived the use of these natural colourants in industrial food production. As Indian consumers become more conscious of their food choices, they increasingly prefer products without artificial additives, especially in categories such as baby food, beverages, ice creams, dairy products, and baked goods.

India’s Botanical Advantage in Natural Food Dyes

One of India’s major strengths in the natural food dye sector lies in its agricultural and botanical diversity. The country is home to numerous pigment-rich crops such as turmeric (curcumin), beetroot (betanin), blue pea flower (anthocyanins), paprika and chilli (capsanthin), marigold petals (lutein and carotenoids), and hibiscus flowers (anthocyanins). These locally available raw materials provide a ready foundation for establishing a robust natural dye supply chain. India is already the world’s largest producer of turmeric, a major source of natural yellow pigment. Similarly, large-scale beetroot cultivation in states like Maharashtra, Gujarat, and Uttar Pradesh presents opportunities for producing natural red colour at competitive costs. Beyond food crops, India also generates immense quantities of floral waste from temples, markets, and urban households. Flowers such as marigolds, roses, and hibiscus often end up in landfills, but they can instead be used to extract vibrant natural pigments, creating a circular and sustainable resource loop that supports both environmental and economic goals.

Table 1. Commercial natural food dyes and their use:

Natural Colorant	Source	Hue	Applications
Annatto (bixin and norbixin)	*Bixa orellana* seeds	Yellow–Orange	Cheese, butter, margarine
Paprika extract (capsanthin, and capsorubin)	*Capsicum annuum* (paprika)	Orange–Red	Snacks, sauces, processed meat
β-Carotene	Carrots, palm oil	Yellow–Orange	Beverages, bakery, dairy
Lycopene	Tomatoes	Red	Beverages, soups, sauces
Anthocyanins	Grape skin, black currant, elderberry, red cabbage	Red- Purple- Blue	Soft drinks, confectionery, yogurt, jams
Beetroot extract (Betalains)	Beetroot	Red-Purple	Ice creams, candies, bakery, yogurt
Chlorophylls	Spinach, alfalfa, nettle	Green	Sauces, confectionery, beverages
Curcumin	Turmeric rhizomes	Yellow	Curry powders, dairy, bakery, beverages
Saffron	stigma and styles of *Crocus sativa*	Yellow	Dairy, beverages, bakery

Challenges

Despite these advantages, there are challenges that India must address to fully harness the potential of plant-based natural food dyes. The most significant among these is the issue of stability. Natural dyes tend to be sensitive to heat, light, pH variations, and oxidation. For instance, anthocyanin-based colours may fade in high temperatures or acidic environments, limiting their use in certain beverages or baked products. Manufacturers, therefore, must invest in stabilisation technologies such as microencapsulation, emulsification, and advanced extraction techniques to ensure consistency and long shelf life. Another challenge is the higher cost of production compared to synthetic dyes. The extraction of plant pigments often involves multiple processing steps, use of specialised equipment, and large quantities of raw material. These factors make natural dyes more expensive, posing cost-related barriers for mass-market adoption, particularly in price-sensitive segments of the Indian food industry.

Supply chain variability is another concern, as pigment yield in natural sources is influenced by seasonal fluctuations, soil quality, climate conditions, and variations in crop genetics. For example, the intensity of colour extracted from marigold petals or hibiscus flowers can differ from batch to batch, affecting the uniformity required in commercial food manufacturing. To overcome this, India requires organised, large-scale cultivation of dye-yielding crops, farmer training programs, and improved agricultural practices that focus on standardization and quality control. This challenge, however, also presents a major opportunity: the cultivation of natural dye crops can be integrated into rural development schemes, boosting incomes for farmers and tribal communities while supporting sustainability initiatives.

Demand of Natural Food Dye in India

The rising demand for natural food dyes in India is also closely linked to the growth of specific industry segments. The beverage sector which includes juices, mocktails, wellness drinks, and flavoured dairy beverages is one of the largest consumers of natural colourants. Vibrant hues from beetroot, turmeric, and blue pea flower are especially popular in this category. Bakery and confectionery products increasingly rely on natural dyes for icings, toppings, candies, and premium baked goods. In the ice cream and dairy sectors, natural colours such as curcumin yellow, beetroot pink, spirulina blue, and cocoa brown are in high demand, especially among artisanal and health-focused brands. The nutraceutical and Ayurveda markets which are rapidly expanding sectors in India represent an even more promising opportunity, as their products must adhere to strictly natural ingredient standards. Gummies, capsules, herbal drinks, and fortified foods are now routinely coloured using plant-based dyes to appeal to health-conscious consumers and ensure regulatory compliance.

Looking ahead, the future of plant-based natural food dyes in India appears bright and full of potential. With the Make in India initiative, growing export opportunities, and a global shift toward environmentally sustainable food systems, India is well-positioned to emerge as a major global hub for natural pigment production. Investment in research and development will play a critical role in this transformation. Indian research institutions and food laboratories are increasingly exploring methods such as fermentation-based pigment production, bioengineering, green solvent extraction, and encapsulation techniques that enhance the stability and performance of natural dyes. These advancements will help bridge the gap between natural and synthetic dyes in terms of reliability and usability.

Furthermore, the adoption of natural food dyes will create opportunities for rural development, organic farming, waste management, and women-led microenterprises, especially in regions where dye-yielding plants grow naturally. Encouraging farmers to cultivate marigold, hibiscus, turmeric, and annatto as dedicated dye crops can provide additional income streams, reduce dependence on synthetic agricultural inputs, and promote biodiversity. Likewise, converting temple flower waste into value-added commodity dyes offers a sustainable livelihood model that also reduces environmental pollution.

Conclusion

In conclusion, plant-based natural food dyes represent a significant shift toward healthier and more sustainable food systems, both globally and within India. Driven by rising consumer awareness, regulatory pressures, technological advancements, and India's inherent botanical advantages, the market for natural food colourants is poised for strong growth in the coming decade. While challenges related to cost, stability, and supply chain consistency remain, they are far outweighed by the opportunities for innovation, rural development, and global market expansion. As India continues to embrace natural ingredients rooted in its cultural heritage and agricultural richness, it has the potential not only to meet domestic demand but also to become a leading global supplier of high-quality plant-based food dyes. Through strategic investment, collaboration, and technological advancement, the country can play a transformative role in shaping the future of natural colouring in the global food industry.

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The Scientist and the Mystery of Bioluminescent Fungi

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The natural world is full of wonders, but few are as enchanting as the soft glow of bioluminescent fungi. These fungi, which emit light in the darkness, have intrigued scientists and nature enthusiasts for generations. While bioluminescence, a process where living organisms produce light through chemical reactions, is well-known in fireflies and deep-sea creatures, glowing fungi remain among the most enigmatic members of this luminous group.

The Glow: A Chemical Marvel

Bioluminescence in mushrooms results from a fascinating biochemical reaction. It involves luciferin, a light-emitting compound, and luciferase, the enzyme that catalyzes this reaction. When combined with oxygen, this process produces a greenish light that is highly efficient, generating little to no heat-often called "cold light."

Scientists have identified over 80 species of bioluminescent fungi, primarily within genera such as *Armillaria*, *Mycena*, and *Omphalotus*. One of the most famous species is *Mycena chlorophos*, known for its delicate green glow in the humid forests of Asia and the Pacific.

Why does Fungi Glow?

The purpose of fungal bioluminescence remains a subject of on-going research, with several hypotheses proposed:

1. Spore Dispersal Aid: Some researchers suggest that the glow attracts nocturnal insects, which help spread fungal basidiospores, much like how flowers draw pollinators.

2. Defense Mechanism: Another theory posits that light may act as a deterrent to predators or parasites, serving as a natural warning signal.

3. Metabolic By-product: Some scientists believe the glow might be a simple by-product of metabolic processes, though this explanation is less widely accepted.

Ecological and Cultural Importance

Bioluminescent mushrooms often thrive on decaying wood or bamboo in damp environments, where they play a crucial ecological role as decomposers. By breaking down cellulose and lignin, they recycle essential nutrients back into the forest ecosystem.

Culturally, these glowing fungi have inspired myths and legends across various societies. Often called "electric mushrooms" in Meghalaya or "fairy fire," they have been woven into folklore and even served as natural lanterns for nighttime army or travelers in dense forests.

Modern Applications and Scientific Research

Beyond their natural beauty, bioluminescent fungi are inspiring technological innovation. Scientists are exploring their potential to create sustainable, glowing plants for urban lighting. Additionally, the luciferin-luciferase system in fungi has become a valuable tool in molecular biology, particularly in bioluminescent imaging techniques.

In the field of synthetic biology, researchers are experimenting with transferring bioluminescent genes from fungi to other organisms. This could lead to practical applications ranging from bioindicators that detect environmental toxins to ornamental plants that glow in the dark.

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Ornamental Bioluminescent Mushrooms

As research advances, the potential for cultivating bioluminescent fungi as ornamental species is becoming a fascinating prospect. Imagine gardens and indoor spaces softly illuminated by naturally glowing mushrooms, offering an eco-friendly alternative to artificial lighting. These ornamental fungi could serve both aesthetic and functional purposes, creating enchanting landscapes while promoting sustainability.

With genetic engineering and innovative cultivation techniques, it may soon be possible to develop bioluminescent mushroom varieties tailored for ornamental use. Such developments could revolutionize the horticulture and landscaping industries, bringing a touch of nature's magic into everyday spaces.

Conclusion

The glow of bioluminescent fungi beautifully bridges the worlds of science and wonder. For researchers, they present a fascinating puzzle involving complex interactions between chemistry, ecology, and evolution. For the rest of us, they offer a glimpse into nature's hidden magic, softly illuminating forest floors and reminding us of the countless mysteries that still await discovery.

As scientific exploration continues, we may one day fully unravel the secrets behind these radiant fungi. Until then, they remain one of nature's most captivating and mysterious treasures, shining gently in the dark, with the exciting potential to brighten our homes and gardens in the future.

Self-Declaration

This article is original and has not been published elsewhere, prepared based on experience and photographs taken by the author.

Fig.1: *Bioluminescent Roridomyces* sp. emitting a natural glow in the dark, with visible illuminating basidiospores. This captivating display of bioluminance highlights the unique ability of certain fungi to produce light through biochemical reactions, often serving ecological roles like spore dispersal and attracting nocturnal insects.

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Black Soldier Fly Larval Frass: A Multifaceted Organic Source for Sustainable Agriculture

Article ID: 72506

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Abstract

Black Soldier Fly Larval (BSFL) frass as a sustainable and effective organic fertilizer amid rising concerns over declining soil fertility and limited organic nutrient sources. Derived from insect excreta, chitin and undigested matter, frass is nutrient-rich and boosts plant growth, soil health and microbial activity. Its nutrient content is influenced by the larvae's feed substrate, making it adaptable. Frass improves nitrogen use efficiency, suppresses diseases and enhances crop yield. Beyond its application as fertilizer, it can be used in growing media, soil amendments, animal feed, and biochar production. BSFL frass also contributes to waste recycling, turning organic waste into high-value inputs for agriculture. Its efficacy across various crops and soil types, advocating for its broader adoption in sustainable agriculture and agroecosystem management, particularly in addressing the nutrient deficiencies prevalent in Indian soils.

Keywords: Black soldier fly, decomposition, degradation, organic manure, yield.

Introduction

The use of organic manures to meet the nutrient requirement of crop would be an inevitable practice in the years to come for sustainable agriculture and generally improve the soil physical, chemical and biological properties and enhances crop productivity. A combined application of organic and inorganic fertilizers has been recommended to improve and sustain soil fertility, crop yields and agronomic nutrient use efficiency. A major challenge hindering the use of organic fertilizers is because of its limited source, therefore alternative sources of organic fertilizer for farm use such as insect compost are needed (Quilliam et al., 2020). Black soldier fly larval frass is one of the alternative resources in place of animal origin. Black soldier fly (BSF) (*Hermetia illucens* L.) belongs to the family Stratiomyidae and the larvae of BSF can be grown on a range of decomposable organic waste and have a high waste degradation efficiency (65% - 79%) (Rejeki et al., 2023). The frass, which is a byproduct contains substantial amounts of nutrients and use of this frass as an organic manure will improve growth and yield of crops.

Status of Soil Fertility in Indian Soils

The use efficiency (NUE) of nitrogen varies from 30–50%, 15–20% for phosphorus, 60 - 70% for potassium, 8–10% for sulphur and 1–2% for micronutrients. Nitrogen and phosphorus are main deficient elements in the world and also in India (Table 1).

Table 1: Nutrient deficiencies in world and India:

Nutrient	Percent deficiency in soils	
	World	India
Nitrogen	89	97
Phosphorus	80	83
Potassium	50	71
Sulphur	41	36
Zinc	49	39

Boron	33	47
Iron	15	37
Manganese	5	7
Copper	3	4

Source: IISS, Bhopal, (2018)

Why there is a Need of Novel Organic Manure?

1. To match the future food demands with increasing population growth while conserving the soil resources.
2. Soil health improvement.
3. Reduce soil and water contamination.
4. Enhance microbial diversity.

What is Frass and How Does it Affect Plant Growth?

1. Black soldier fly (*Hermetia illucens*), a member of the Stratiomyidae family, has garnered significant attention in recent years for its remarkable larvae. These larvae excel as bioconverters, transforming a diverse range of food and crop waste into valuable biomass.

2. Frass is defined as insect excrement, but in the context of the insect farming industry, it refers to a mix of predominantly insect faeces, remnants of shed exoskeletons, and undigested feed.

3. Frass is rich in readily extractable nutrients.

4. Frass seems to be a fast-acting fertilizer.

5. Frass deposition can result in a short-term pulse of plant-accessible nutrients due to stimulation of local activity of microbial decomposers, which can also accelerate the decomposition of recalcitrant organic matter.

6. Fragments of chitin-containing exuviae, which are present in frass as a minor component, may also provide additional benefits of frass application on plant growth and health.

7. In addition to improved plant productivity, frass application may also result in induced plant resistance to abiotic stresses.

8. These beneficial effects of frass are mainly ascribed to plant-accessible nutrients, although frass-associated microbes are also likely to play a role.

Recent studies have reported improved crop growth, yield, nutrient uptake, N use efficiency, and disease suppression in different plants grown using composted BSF.

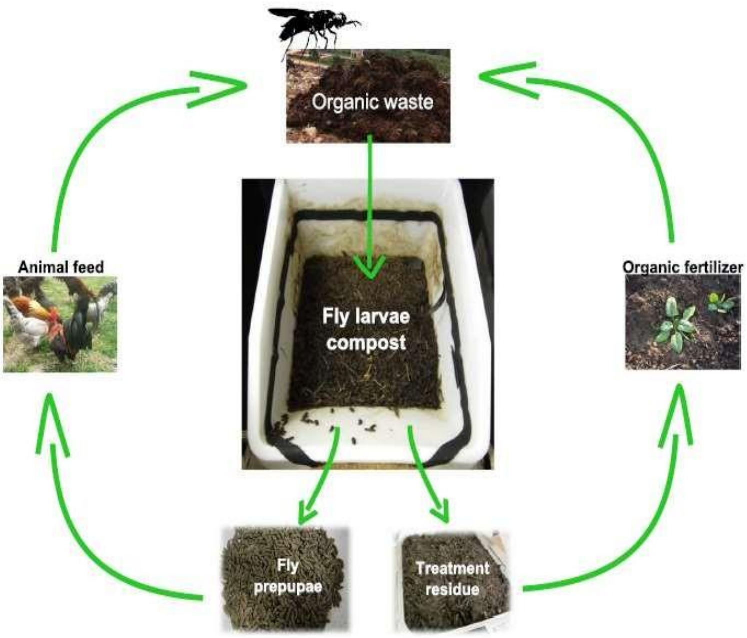

Fig 1: BSF as efficient organic waste decomposers

Table 2: Composition of different manures and composts to BSF frass:

Parameter (g kg^{-1} DM unless stated otherwise)	Pig slurry	Cow slurry	Poultry manure	Green compost	BSF frass
Dry matter (g kg^{-1} product)	107	92	562	599	660-780
Organic matter	738	772	740	299	844-866
Total N	65	43	51	8	34
Organic N	31	23	46	8	-
Phosphate (P_2O_5)	36	16	41	4	27-28
Potassium (K_2O)	44	59	34	7	35
C/N ratio	12	17	8	19	13-16

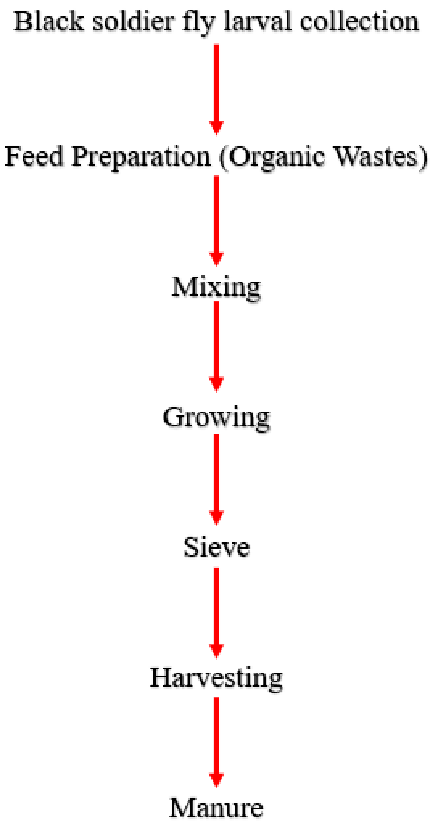

Figure 2: Flow Chart of BSF Rearing/Composting

BSF frass nutrition content depends on the feeding material less complex food will takes low time for conversion than the complex, hardy feed (Table 3).

Table 3: Physiochemical characteristics of BSFL frass from different food waste types:

Type of Food Waste	pH	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Household food waste	7.4	2.2	0.1	0.1
Food waste, chicken faeces and sawdust (3:2:1 ratio)	6.1-8.0	1.7	1.1	2.1
Fruits and vegetables	5.6	1.8		
Maize straw	8.0	0.6	2.5	2.1
Okra and wheat bran	7.5	4.8	1.0	0.9
Brewery spent grain	7.7	2.1	1.2	0.2

Benefits of BSFL Frass

1. BSFL frass contains chitin that improves the soil microbiome
2. Rich in nutrients (macronutrients, micronutrients, and organic matter)
3. High phosphorus concentrations in the BSFL frass promote nitrogen accumulation in plants

4. BSFL frass contains chitin that naturally produces antimicrobial peptides, which serve as a defence barrier for the plant
5. Beneficial microorganism population for plant uptake.

Applications for BSFL Frass

1. Organic Fertiliser:

a. BSFL frass is rapidly gaining global attention as an organic fertiliser.
b. BSFL frass has shown similar results in performing as organic fertiliser, even by feeding BSFL to different type of substrates: organic municipal solid waste food waste manure brewery spent grains mixture of poultry, brewery waste and green market waste mixture of pig manure, dog food and human faeces and fermented maize straw (Beesigamukama et al., 2020).
c. Studies on the quality of BSFL frass as organic fertiliser revealed a significant increase in NPK concentrations and a considerable reduction in heavy metals to the acceptable levels set by the regulatory authorities (Tanga et al., 2022).
d. BSF derived manure applied on soil provided remunerative growth of Pakchoi (*Brassica rapa* L.) (Agustiyani et al., 2021).

2. Soil Amendments:

a. Adding BSFL frass to the soil in agricultural settings is beneficial to the plant or insect ecosystem and has improved the organic matter quality of intensively cultivated soils.
b. BSFL frass can be a source of soil nutrients without affecting soil hygiene.
c. Klammsteiner et al. (2020) has suggested that regular addition of BSFL frass to the soil will prevent fungal disease pathogens, such as Rhizoctonia, Fusarium and Pythium.

3. Growing Media:

a. It was proved that BSFL frass is a suitable growing media to promote soil less agriculture because it can replace the commercial peat used in potted plants.
b. Using 80% commercial peat and 20% BSFL frass as growing media has a beneficial effect on crop growth without causing abiotic stress, especially in the increase in total dry weight, increased leaf area and the number of the production has increased up to 20% for potted plants, such as baby leaf lettuce, basil, and tomato when compared to potted plant production by using commercial peat (Anyega et al., 2021).

4. Biochar:

a. Researchers have investigated using insect frass pyrolysed to biochar as a bio-adsorbent for wastewater detoxification in industrial environments.
b. Even though frass from BSFL is not known to produce high-efficiency biochar, insect frass from mealworms feeding on wheat straw showed the best adsorption performance for bio-adsorbents and have the better capacity (1738.6 mg g^{-1}) of absorbing malachite green, (a cationic dye which is a highly toxic dye that may be found in wastewater) when compared to frass fed with wheat bran, raw wheat straw, and raw wheat bran.
c. Researchers are starting to turn their attention to producing biochar from insect frass because of the presence of chitosan, which might lower the cost of commercial adsorbents.
d. The chitosan derived from chitin is a naturally available bio-sorbent that could purify wastewater containing dyes in aqueous solutions.

5. Animal Feed:

a. Research into BSFL frass for animal feedstock has shown excellent results in improving the growth of hybrid tilapia and enhancing the resistance of innate immune components and resistance to bacterial infection.
b. This study fed five diets containing varying percentages of BSFL frass of 0, 5, 10, 20, and 30% to juvenile hybrid tilapia as a partial substitute for a mixture of soybean meal, wheat short, and corn meal on an equivalent protein basis (Boudabbous et al., 2023).
c. The improvement in hybrid tilapia growth could be due to the high protein content of BSFL frass.
d. The fish diet containing 5 to 30% BSFL frass has a slightly higher protein efficiency than the diet without BSFL frass fed to the control group.
e. BSFL frass could be used as a partial replacement for commercial animal feed.

6. Feedstock: If necessary, BSFL frass can be fed to a biogas plant for anaerobic digestion for further processing. This post-processing of BSFL frass could simultaneously resolve problem with the handling of wet, high moisture content BSFL frass and to reuse the potential energy sources from wet BSFL frass to run the plant.

Conclusions

Black soldier fly frass significantly enhanced the growth and yield of crops when applied directly or in combination with NPK fertilizers at a specified ratio. The use of insect frass as organic fertilizer in sustainable agriculture supposes the contribution of nutrients, beneficial microorganisms and biomolecules of interest to the soil could limit the use of agrochemicals. The composition of the BSF frass is strongly dependent on the feed substrate and as such there is no universal BSF frass composition.

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Green Terraces: Turning Rooftops into Gardens

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Introduction

Terrace gardening refers to cultivating fruits, vegetables, spices, medicinal, aromatic plants including flowers on rooftops or terrace spaces. Urban residents often experience higher temperatures than those in rural areas due to limited greenery around their homes. This issue can be resolved through terrace gardening, which helps in cooling the surroundings.

Fruit crops like acid lime, banana, guava, papaya and strawberries grow well on terraces. Among vegetables, potato, tomato, brinjal, capsicum and chilli as well as crops like okra, amaranthus and some cucurbitaceous vegetables such as bitter gourd, snake gourd, ridge gourd cucumber and bottle gourd are ideal choices for terraces. Spices such as turmeric, coriander and fenugreek also adapt well to terrace conditions. To support daily health needs, a variety of medicinal and aromatic plants can be successfully cultivated at home, ensuring easy access to natural remedies.

Terrace garden is an urban feature. Terrace gardening refers to the cultivation of fruits, vegetables, spices, medicinal, aromatic and flower crops on rooftops or terrace spaces. In urban areas, temperatures tend to be higher than in rural regions due to limited greenery around homes and buildings. Establishing terrace gardens helps reducing this heat buildup and simultaneously provides fresh produce. Suitable fruits plants includes guava, banana, papaya, pomegranate and acid lime for terrace gardening. Among vegetables, potato, brinjal, tomato, capsicum and chilli as well as okra, amaranthus and some of the cucurbitaceous vegetables like bottle gourd, bitter gourd, ridge gourd, cucumber and snake gourd can be grown well on terraces. Spice crops like turmeric, coriander and fenugreek are also ideal. Additionally, medicinal and aromatic plants, colourful flowers and potted plants can be raised successfully in terrace gardens to support everyday health and wellness needs. In recent years, many people have migrated to urban areas in search of employment and higher income. As a result, large portions of agricultural land near cities have been converted into residential zones, leading to a significant decrease in the area available for cultivating vegetables and fruits (Nitol *et al.*, 2021). Moreover, urban residents experience increased temperatures compared to those in rural regions due to limited greenery around their homes. Terrace gardening offers an effective solution to both the loss of cultivation space and the urban heat buildup.

Site Selection

Plants need sufficient sunlight for healthy growth and good yield. So, open rooftops, verandas or window sills are ideal locations for terrace gardening. Along with sunlight, a reliable water supply is essential for raising crops. Equally important is to ensure that the terrace surface is well-coated with waterproofing materials to prevent seepage into the roof floor.

Selection of Containers

Earthen pots, cement pots, grow bags, plastic containers and planter boxes, constructed troughs, benches on existing concrete floors can be used for planting. Additionally, crates, plastic barrels, boxes, wooden barrels, buckets, jars and drums of various sizes can be used for growing crops.

Tools and Other Inputs Required

Essential tools include spade/shovel, rose can, hand sprayer, hand hoe and a gardening hose with a sprinkler or drip laterals may be used. Use good-quality seeds and planting materials for growing crops. The soil mixture should be preferably consisting of red soil, sand and well-decomposed organic manure such as coir compost or leaf litter and it should be free from stones, clods and weed seeds. Apart from this, biopesticides, vermicompost and chemical fertilizers can be used for plant growth and bamboo stakes, jute threads are also required for providing physical support to the plants.

Plants Suitable for Growing in Terrace Gardens

Fruit crops ideal to grow in terraces include acid lime, banana, guava, pomegranate, papaya and strawberries can be successfully grown suitable pots.

Vegetable crops such as potato, tomato, brinjal, capsicum, lettuce, onion, chinese radish and chilli, onion, radish as well as okra, amaranthus, other leafy vegetables and cucurbitaceous vegetables like bitter gourd, ridge gourd, snake gourd, cucumber and bottle gourd perform well on rooftops.

Spice crops suitable for terrace cultivation include turmeric, ginger, coriander, curry leaves and fenugreek.

Medicinal and aromatic plants such as aloe vera, rosemary, lemon grass, basil, mint, aswagandha, ajwain, giloy, brahmi also be successfully grown on rooftops to meet daily household health needs.

Flower crops like rose, chrysanthemum, table rose, dahlia, zinnia, lilium, marigold, jasmine, kaner, tabernamontana, orchids, aglaonema, diffenbachia, adenium, and some climbers like blue pea creeper, mandaevilla, allamanda, Nepal trumpet creeper, Rangoon creeper, bougainvillea and clematis can be trained on the shade-frame. Cacti and succulents can be planted in small sized pots with proper care at sunny sites. A beautiful collection of bonsai plants can also be maintained on terraces. Moreover, hanging baskets look charming and enhances the overall look of gardening.

Benefits of Terrace Gardening

1. It supplies year-round fresh fruits and vegetables.
2. Reduces household spending on buying produce.
3. Ensures efficient use of available rooftop space.
4. Offers a productive way to spend time through establishing and maintaining a terrace garden.
5. Supports the cultivation of chemical-free fruits and vegetables using organic methods.
6. Allows families to grow crops according to their preferences and dietary needs.
7. Enables the cultivation of medicinal plants for basic health care without relying heavily on medicines.
8. Beautifies the surroundings with colourful flowers and foliage potted plants.
9. Gardening activities help reduce stress and promote relaxation.
10. Helps keep buildings cooler in summer and can reduce energy consumption for air conditioning.
11. Enhances the overall livelihood and well-being of urban residents.
12. Creates opportunities for family members especially children to learn about the importance of agriculture.

Methods of Cultivation

1. Proper attention should be given to prepare the soil mixture.
2. Fill containers equipped with drainage holes using the prepared soil mixture.
3. For transplanted vegetables, pro-trays can be used to raise seedlings and seed pans are also suitable for nursery plant preparation.
4. Seeds of crops such as cluster beans, okra and cucurbitaceous vegetable crops can be sown directly at a depth of about two-and-a-half times their size.
5. Shallow containers are ideal for growing leafy vegetables, mint, coriander and fenugreek.
6. Crop selection should be based on the preferences of the family members.
7. Different spices and vegetables should be sown or planted at regular intervals to ensure a continuous household supply without relying on the market.

Conclusions

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Maintenance

1. Watering: Watering should be carried out according to the soil's moisture level. Plants generally require more frequent and careful watering during the summer than in the winter or rainy seasons. Overwatering can lead to root rot and increase the incidence of soil-borne diseases. Watering can be done using a rose can. To enhance plant growth and reduce water wastage, drip irrigation may also be used.

2. Support / Staking: Provide physical support to plants as needed to prevent them from bending or lodging especially during strong winds and heavy rains.

3. Nutrition: Regular application of vermicompost, farmyard manure and decomposed coir pith compost is adequate to support plant growth and yield. Inorganic fertilizers may be used only when necessary based on visible plant growth needs. A light top dressing of complex fertilizers at 5–10 g can help promote growth and improve vegetable yield. Avoid excessive fertilizer application, as it may cause phytotoxic effects on plants.

4. Hoeing: Hand hoeing and weeding should be done periodically to reduce competition between crops and weeds for water and nutrients. It reduces competition between crops and weeds for water, nutrients and other resources, while also improving soil aeration.

Pest and Disease Management

Organic cultivation practices are recommended for terrace gardening. Pests such as larvae or insects found on fruits and vegetables should be picked and destroyed manually. Neem oil at 3 ml per litre of water or a 3% Neem Seed Kernel Extract can be sprayed for effective pest management. The use of chemical plant protection products should be avoided.

Harvesting: Leafy vegetables should be harvested before they fully mature, preferably when they are still tender. Tomatoes can be picked at the three-fourths maturity stage or when fully ripe. brinjal and okra should be harvested once they reach full size but remain tender, while cucurbitaceous vegetables are best collected at full maturity.

Post-harvest operations: After harvesting, the soil from pots or containers should be removed and left aside for 10–15 days. It can then be reused by refilling the containers and mixing different biofertilizers, organic manures and other amendments as needed.

Conclusions

With the steady migration of people to urban areas, city residents increasingly need fresh fruits and vegetables, especially the leafy green vegetables as well as medicinal and aromatic plants for everyday health care. Terrace gardening enables urban households to access fresh, toxin-free produce year-round by reducing the expenses on market purchases and acts as stress relievers by spending quality time with plants. Therefore, adopting terrace gardening is essential for improving the quality of life and wellbeing of urban populations.

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The Silent Saboteur of India's Eucalyptus Groves: The Rise of the Invasive Eucalyptus Weevil

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Abstract
The Eucalyptus weevil (*Gonipterus platensis*) has recently emerged as a significant invasive defoliator of *Eucalyptus* species in India, posing a major threat to plantation productivity and pulpwood industries. The pest, earlier confined to Australia and parts of South America, has expanded its distribution across Asian countries, including Sri Lanka and now India. This article summarizes the invasion history, morphological characteristics, host preference, damage potential, and integrated management practices based on current field observations, published literature, and preliminary surveys in Indian *Eucalyptus* plantations. The rapid establishment of *G. platensis* highlights the need for systematic monitoring and region-specific management strategies to minimize economic losses.

Introduction
Eucalyptus plantations, with their tall silver trunks and cooling aroma, have become a defining feature of many Indian landscapes—from the misty folds of the Nilgiris to the plains of Andhra Pradesh and Karnataka. For decades, these plantations have supported the paper, pulp, plywood, and biomass industries, contributing significantly to rural livelihoods and industrial raw material supplies. But in recent years, this green success story has encountered an unexpected setback. A tiny beetle—the Eucalyptus Weevil, *Gonipterus platensis* (Coleoptera: Curculionidae) —has silently infiltrated India's eucalyptus belts, threatening the productivity and health of these vital plantations.

A Tiny Traveler with a Global Footprint
Native to Australia, Gonipterus weevils have gradually expanded their range across the world. Over the past century, they have invaded South Africa, Chile, Brazil, Portugal, Spain, New Zealand, China, Sri Lanka, and recently India. Hidden inside nursery stock, wooden crates, or timber shipments, the weevil can hitch a ride unnoticed across international borders.

How India First Detected the Invader — A Citizen Science Success Story
In 2019, an observer near Ooty photographed an unfamiliar beetle and uploaded it to iNaturalist. The platform's AI suggested it resembled a *Gonipterus* weevil. Entomologists later confirmed the species using DNA barcoding, matching Tasmanian populations. India officially had a new invasive pest (Arathi Menon, 2025).

Identification and Host Range
Adults measure only 6–8 mm, with a brownish-grey camouflaged body, curved snout, and mottled wing covers. Females lay eggs inside unique brown "egg cups," while larvae feed in groups, rapidly defoliating young eucalyptus foliage. The pest prefers *Eucalyptus globulus, E. grandis, E. camaldulensis,* and several commercial hybrids. Young plantations (6 months–3 years) are the most vulnerable. Pest has spread rapidly in India include monoculture plantations, susceptible clones, interstate movement of seedlings, favorable climate, and lack of natural enemies.

Fig 1: larva and adult (Yeshwanth *et al.*, 2025)

Life Cycle and Damage Symptoms

Eggs hatch in 7–10 days, larvae develop in 18–25 days, pupate in soil for 2–3 weeks, and adults survive up to 5 months. Multiple generations occur each year, especially in warm, humid climates like southern India. Symptoms include semicircular leaf notches, skeletonization, drying canopy, reduced photosynthesis, stunted growth, and weakened coppicing. Countries like Brazil and South Africa report 15–50% reductions in timber volume due to Gonipterus species.

Scientific Insights: Chemical Ecology & Attraction

Eucalyptus leaves rich in 1,8-cineole, oxalic acid, and sugars tend to experience higher feeding. Behavioral studies show adult weevils respond strongly to camphene, α-pinene, and 2-phenylethanol - chemicals that can be used in future lure-based traps.

Managing the Threat: India's Current and Future Strategies

1. Cultural Measures: Inspect nurseries, destroy egg cups, avoid seedling transfer, remove litter.

2. Mechanical Measures: Hand-pick egg capsules, use beat sheets.

3. Biological Control: The parasitoid *Anaphes nitens*, endoparasitic egg parasitoid used worldwide, may be evaluated for India.

4. Chemical Control: Imidacloprid, thiamethoxam, and lambda-cyhalothrin—used sparingly.

Why This Matters to India's Forestry Sector?

Eucalyptus supports more than a million hectares of plantations, crucial for the paper, pulp, and timber industry. An unchecked pest outbreak threatens supply chains, industries, and rural livelihoods.

Looking Ahead: A Call for Vigilance

The eucalyptus weevil's arrival reflects broader global challenges - biological invasions accelerated by trade and climate change. Yet its discovery through citizen science also shows the power of public–scientist collaboration. With early detection and integrated management, India can prevent this small beetle from becoming a national forestry crisis.

Conclusions

The Eucalyptus Weevil may be small, but its impact can be enormous. If left unmanaged, it threatens the productivity of India's eucalyptus-based paper, pulp, and timber industries. By blending scientific knowledge with field-level awareness, India can successfully contain this invasive pest and ensure the sustainability of its green plantations.

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Container Gardening for Sustainable Fruit Production

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Introduction

Container gardening is a new way to grow fruit crops in small spaces by selecting appropriate containers, using quality soil and providing adequate sunlight, water and fertilizer. The successful container gardening involves choosing the right container size, using well-drained potting mixture, regular watering and application of fertilizers in the container. The suitability of the containers mostly depend up on the crops to be grown, characteristics of crops like growth stage, duration of crop, vigour of plant, growth habit, root pattern, etc. Generally long duration, deep rooted and more vigorous plants require large containers compared to short duration, shallow rooted and less vigorous plants.

Fruit crops like guava, papaya, citrus, berries (strawberries, blueberries), figs and some apples, peaches and plums can also be grown successfully in containers, especially if they are dwarf.

Principle of Container Gardening

1. The principle of organic gardening is to improve the health of plants and people. But it also encourages using renewable resources that conserve soil, water and energy to improve the quality of the environment.

2. Container gardening is an environmentally safe way to grow fruits, vegetables and other plants in containers.

Choosing the Right Container

1. Ensure proper size: The container must be large enough for the plant to develop a healthy root system.

2. Proper drainage: Container must have adequate drainage holes to prevent waterlogging.

3. Consider container material: Fruit trees can be grown in many types and sizes of containers including wooden, ceramic, metal or plastic tubs, buckets, pots, or even grow bags. Most fruit plants require more water, so a sizeable container is necessary to prevent plants from drying out. A substantial amount of soil in a container will serve as a reservoir for water and thus be available during dry periods or when water loss from the plant is at its maximum. Be sure the container has holes in the bottom to allow good water drainage. An inch or two small stones or gravel in the bottom will aid water drainage. It should be kept in mind that if soil freezes, pottery containers tend to crack and break.

4. Containers suitable for gardening: Air pot, Terracotta, Grow bags, locally available materials and vessels, earthen pots, plastic pots etc.

Providing Proper Care

Location and Care: Full sun light is not necessary to grow containerized fruit crops; 5 - 6 hours of sun light will maintain good plant vigor. Containerized plants dry out quickly so, during periods of high temperature, it may be necessary to water a plant once, or even twice, a day. The location, soil mix, container size, and the weather will determine the frequency of watering required. Care should be taken not to overwater; plant roots need air as well as water. Before watering, soil has to be checked for moisture status.

Media / Soil: Use a high-quality, container-specific potting mixture that is enriched with compost or other organic matter. An ideal soil will have good water and nutrient holding capacity, have a sufficient amount of air to assure proper root growth and be heavy enough so that the container and plant do not fall over. Garden soil used alone is not recommended because it lacks sufficient aeration, may contain weed seeds, water drainage may be too slow and frequently it is deficient in organic matter. Garden soil or commercial top soil can be used if they are amended with peat and either vermiculite or perlite. An appropriate soil mixture contains 2 parts top soil, 1 part peat and 1 part vermiculite or perlite. Commercial potting mixes are available, but if used alone, are generally too light and dry out too rapidly to be acceptable.

Fertilize regularly: Application of balanced fertilizer, especially during the growing season is essential. A balanced liquid fertilizer or granular fertilizer with a lower nitrogen content is often best for fruit trees.

Manage winter hardiness: Roots in containers are more exposed to cold than those in the ground. So, container plants should be shifted to a protected area in winter or choose plants that are hardy to overcome extreme winter.

Repot when necessary: Some of the plants may outgrow their containers over time. If the roots become entangled and the plant shows signs of distress, consider repotting it into a larger container with fresh soil. Repotting is typically done during the spring when the plant is actively growing. Repotting is necessary when the plant roots are compact and nutrient level is low. Repot every 2–3 years to refresh the soil and provide space for new growth, trimming back about 10–20% of the roots.

Mulch: Adding a layer of mulch on top of the soil can help retain moisture.

Protect from pests: The smaller, more contained nature of container plants can make pest control easier. Regular monitoring, companion planting and organic pest control methods are preferable. Encourage biodiversity by planting flowers and herbs to attract beneficial insects and pollinators.

Handle with care: When moving a grafted fruit tree, care should be given to support the pot rather than the trunk to avoid breaking the graft union. Cut off any new stems growing from the rootstock below the graft.

Advantages of Container Gardening

1. Uniform and vigorous plant growth
2. Production of good quality produce.
3. Increases plant productivity as well as production time.
4. Easy to transport and to handle plants and moreover no transplanting shock will be observed.
5. Easy to maintain
6. Easy to harvest, grading and shifting of produce.
7. Good drainage and aeration facilities.

Benefits of Container Gardening

1. No yard required.
2. Anyone can try.
3. It is relatively inexpensive to start and maintain.
4. No digging or tilling is required.
5. Containers can be placed in any desired location.
6. It has better growing conditions.
7. Edible Herbs, vegetables and fruits can be grown for home need.
8. It saves space and is cheaper.
9. More varieties can be grown.

Importance of Container Gardening

1. Efficient utilization of space and resources
2. Year around production and increased yield
3. Food security and local resilience
4. Early harvesting
5. Pest and disease can be managed at ease.

Give it a Go, watch it Grow

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Enhancing Agricultural Resilience through the System of Crop Intensification

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High input-based agriculture provides short term profits, but it is detrimental to soil health, ecological balance, and the sustainability of agriculture in the long run. Therefore, it is necessary to strengthen and maintain soil health systematically. Productivity and resilience of land resources need to be increased. One of the practices aimed at increasing agricultural productivity, sustainability, food security and resilience to climatic change by adapting how we manage our crops, soil, traditional water sources and nutrients is cropping intensification. The principles of the SCI can be applied to a variety of crops such as rice, wheat, beans, sugarcane, and mustard. In order to improve production in a sustainable and environmentally friendly way, the system of intensive crop management allows crops to grow and expand. Given that the SCI, such as SRI, requires very small amounts of inputs to be bought off farm, this approach is particularly important for resource limited population with low nutritional status. However, as detailed in this paper, it is conceivable to measure up these processes for viable production with adequate mechanization. In both large and small farms, it is possible to encourage the establishment of larger, more efficient root systems and to increase and maintain more valuable soil life, which can mitigate the effects of drought storm damage, extreme temperatures, pests, and diseases. SCI is an agricultural production approach that aims to maximize and optimize the profits received by better utilizing available resources such as soil, seeds, water, nutrients, sun energy as well as air. It is a constant need to analyze farming alternatives in setting, captivating into justification of all aspects, exchanges of time plus space; so, as the field activities can be carried out in a judicious manner, with land area utilized adequately by crops rather than simply a solitary crop. It is also critical to include environmental services. Therefore, conventional farming practices need to be overhauled by adopting SCI to be more cost-effective and sustainable. One of the most important modern agricultural progresses, which spread to farmers' fields, is a rice intensification system that was set up in Madagascar in the 1980. SRI is a promising rural innovation that has emerged from the traditional research system. In order to increase the productivity of available land, labor, water and energy as well as improving food security in vulnerable farmer communities, it changes traditional paddy growing practices with more effective management of plants, water, soil and nutrients. A set of principles is included in the strategic roadmap which includes using young seeds, one seedling hill-1, square plantings, mechanical weed control, and intermittent wet and dried organic matter addition. The adoption of these concepts has been claimed to boost rice yield by 50% to 100%. SRI practices have recently been extrapolated to other crops such as wheat, Teff grass, maize, sorghum, finger millet, soybean, black gram, kidney bean, lentil, mustard, sugarcane, tomato, brinjal, chili, potato, carrot, and onion under the name SCI. SCI practices, like SRI, have been shown to enhance crop output levels by more than twofold. As for SCI, like SRI, counts on purchased supplies negligibly; it is especially useful for resource-limited and nutritionally challenged households. This piece brings along a whole lot of experiences in acclimatizing and bringing the ideas and approaches of SRI to use for sustainable development of diverse crops.

The Necessity for Sustainable Strengthening

The requirement for long-term agricultural intensification although different organizations use different terminologies, there is widespread arrangement that farming zones all over the world must follow customized plans for feasible escalation if worldwide food security demands be fulfilled during the era. It is these ideas which share a common denominator of being different from the type of growth that has taken place in agriculture over the past 50 years. Farmers are now able to benefit from enough land, machinery and purchased inputs that will enable the cultivation of increasingly large areas; an increase in their output by using better crop varieties with more water, increased capital investment, fossil fuel energy, as well as agrochemicals. Modern agricultural technologies, particularly those connected to the green revolution, have made this possible. More recent, more extensive production strategies, which were categorized by both fewer inputs and less results, have been improved by using more inputs to produce more output. However, it has also been connected to higher costs for farmers and ecosystems in terms of the economy and the environment. There are other types of intensification available than that, which is primarily dependent on enhanced utilization of external resources. Agroecology as a whole could be used to investigate additional intensification alternatives. This seeks to utilize as much of the natural resources as possible, comprising of the classes and hereditary varieties found in environment. Specifically, when land and aquatic resources become not so much in comparison to the human populace which relies on them, resource deficiency keeps a higher emphasis on betterment of the administration of all available environmental resources. In recent years, a phenomenon known as crop intensification (SCI) has evolved in many African and Asian nations, increasing the productivity of the land, seed, water, labor, and capital means that farmers engage in growing a diverse range of crops . As mentioned below, prominent organizations for example the Ethiopia's government Agricultural Transformation Agency and the World Bank are taking notice of this emergence. The experience of farmers and others with the rice intensification system has contributed to the ideas and practices that have made SCI possible (Table 1). The ideas related to the SCI and SRI are shared with other agroecological innovation areas, e.g. agricultural forestry, conservation agriculture, integrated pest control or integrated management of range and animals based upon proven agronomic theory and practice.

Table 1: Principles and practices of SCI:

Principles	Practices
To increase the production, use of renewable resources and on farm resources is emphasized	Principles of conservation tillage and crop rotation should be used to achieve sustainable intensification
Increasing resource use efficiency along with optimization of external input application to lower the negative impact of food production on environment and narrow the yield gap	Addition of leguminous crop for biological nitrogen fixation and cover crops in rotation
Use of improved crop varieties and livestock breeds	Integrated pest management
Food waste should be lowered with increasing productivity	Sustainability of soil and water conservation, soil health management
	Protection of plant genetic resources and improved varieties
	Insufficient irrigation, additional irrigation, water management, fertigation

1. Early and careful establishment of healthy plants with special attention paid to safeguarding and nurturing their potential for core system expansion along with the benefits that go along with it.

2. Significantly lowering crop density, transferring, or sowing seeds with more space between each plant.

3. Water use in a way that benefits plant roots and soil bacterial growth.

4. To support more root growth and to benefit the soil biota, it is essential that soils are enriched with organically material and maintained well.

Several other crops, including finger millet, mustard, and teff, have been found to benefit from careful transplantation of immature rice seedlings, an important technique used in the SRI methodology, but not in all crops. In combination with other methods, it may be possible to apply seeding directly.

With the growing population and demand for agricultural land, soil and water losses have emerged as a major issue worldwide, especially in developing countries. Results from a study have proved that applying organic mulch had various positive effects on soil and water conservation. Soil loss and water runoff rates a greatly reduced with the increased rates of mulching. To achieve the goal of zero-hunger and poverty alleviation, the population is dependent on agriculture to fulfil their demands. Furthermore, all agricultural plans depend on increasing the usage of chemicals to attain additional production which will eventually pose higher pressure on financial investments and on the environment as well. Hence optimizing the use of chemical fertilizers along with the organic sources in a balanced manner proves to be a better alternative. As reported by various researchers, using chemical and organic sources together is quite promising to achieve enhanced production and greater stability.

Status of SCI in Pulses in India

Pulses productivity has been considered by promoting the improved seeds that are properly selected and enhancing the early growth of plants in order to stimulate the root growth. Other efforts such as decreasing the spacings i.e., increasing plant density with enhanced organic matter. A case study showed that PSI situated at Dehradun has collaborated with smallholders in Himachal Pradesh, Uttarakhand, and Madhya Pradesh states to boost pulses output using modifications of SCI practice. In India, PSI initiated work using SCI ideas to boost pulse output in Uttarakhand state in 2007. PSI discovered that SCI yield upsurges about 45% across 7 types of pulses, with substantially lesser seed requirements and, probably more importantly, with less loss from either water scarcity or water excess. Due to a lack of resources and institutional backing for elevation of SCI for pulse crops in India, the spread has been primarily resourceful, often quick locally but gradual overall. Demonstrating the benefits of SCI practices with pulses has typically begun with a farmer or NGO project. According to the Bihar state poverty-reduction initiative, SCI methods increased pulse yields by 56% on average for 41,645 resource-limited households on 15,590 acres in 2012. Though, the use of crop intensification ideas and procedures for enhancing pulse cultivation is not as progressive as SRI for rice or SWI for wheat, these technologies are expanding regardless of whether they are labelled as 'SCI'.

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Strategies for the Development of Minor Horticultural Crops: Unlocking their Potential

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Horticulture plays a pivotal role in agricultural diversification by contributing to food security, farm income enhancement, nutritional security, and environmental sustainability. While major horticultural crops such as fruits and vegetables dominate commercial cultivation and research focus, minor horticultural crops remain largely underutilized despite their immense potential. These crops, which include lesser-known fruits, vegetables, spices, medicinal and aromatic plants, offer significant opportunities for niche markets, value addition, climate resilience, and livelihood diversification. Strategic and holistic interventions are therefore essential to unlock their full potential and integrate them into mainstream agricultural systems.

Market Research and Demand Assessment

Comprehensive market research is the foundation for the successful development of minor horticultural crops. Understanding consumer demand, preferences, emerging health trends, and market gaps helps identify high-potential crops with commercial viability. Analysis of price trends, supply chains, competition, and distribution networks enables farmers and entrepreneurs to make informed production and marketing decisions. Market intelligence also supports the identification of niche and export-oriented opportunities, especially for organically produced or specialty horticultural products.

Crop Selection and Diversification

Appropriate crop selection based on agro-climatic suitability, soil type, water availability, and local farming systems is crucial. Minor horticultural crops are often well adapted to marginal lands and adverse climatic conditions, making them suitable for diversification strategies. Crop diversification reduces production risk, improves farm resilience, and provides farmers with multiple income streams. Integrating minor crops within existing cropping systems also enhances biodiversity and improves resource use efficiency.

Research and Development Interventions

Investment in research and development (R&D) is vital to improve the productivity, quality, and adaptability of minor horticultural crops. Collaborative efforts among agricultural universities, research institutions, and private sectors can lead to the development of improved varieties with higher yield, enhanced nutritional value, disease resistance, and longer shelf life. R&D should also focus on refining cultivation practices, optimizing nutrient and water management, developing stress-tolerant varieties, and promoting eco-friendly production techniques. Strengthening post-harvest research is equally important to reduce losses and enhance marketability.

Farmer Training and Capacity Building

Empowering farmers through skill development and knowledge transfer is a critical component of crop development. Training programs, on-farm demonstrations, workshops, and extension services should focus on crop-specific agronomic practices, integrated pest and disease management, irrigation techniques, and sustainable farming methods. Capacity building enhances farmers' confidence in adopting minor crops and contributes to improved productivity and quality. Farmer-to-farmer learning and success stories can further accelerate adoption.

Access to Finance and Quality Inputs

Limited access to credit and quality inputs often constrains the adoption of minor horticultural crops. Facilitating affordable financial support through institutional credit, subsidies, and crop insurance schemes can encourage farmers to invest in these crops. Ensuring timely availability of quality seeds, planting material, fertilizers, and plant protection inputs through organized supply chains is equally important. Public and private sector participation can help strengthen input delivery systems.

Infrastructure Development

Adequate infrastructure is essential to support the growth of minor horticultural crops. Development of reliable irrigation facilities ensures consistent production, particularly under water-scarce conditions. Establishment of cold storage, pack houses, processing units, and value-addition facilities helps minimize post-harvest losses and improves income realization. Well-connected transportation and logistics networks facilitate timely movement of produce from farms to markets, enhancing competitiveness.

Value Addition and Marketing Strategies

Value addition plays a crucial role in maximizing the economic returns from minor horticultural crops. Processing into products such as dried fruits, juices, pickles, herbal formulations, and nutraceuticals extends shelf life and expands market opportunities. Branding, certification, and attractive packaging enhance consumer appeal and trust. Effective marketing strategies, including direct marketing, farmers' markets, cooperatives, and digital platforms, enable producers to access wider markets and achieve better price realization.

Policy Support and Institutional Framework

Supportive policy frameworks are essential for scaling up the development of minor horticultural crops. Policies should provide incentives for cultivation, processing, and export promotion while simplifying regulatory procedures for certification and quality assurance. Institutional support for cluster development, public–private partnerships, and extension services can accelerate adoption. Policies addressing sustainable land and water management further strengthen long-term viability.

Collaboration and Stakeholder Networking

Strong collaboration among farmers, researchers, extension agencies, entrepreneurs, and policymakers fosters innovation and knowledge sharing. Farmer producer organizations (FPOs), cooperatives, and industry associations provide collective strength, improve bargaining power, and facilitate access to markets and technology. Public–private partnerships play a vital role in bridging gaps in research, infrastructure, and commercialization.

Conclusion

The development of minor horticultural crops represents a promising pathway toward agricultural diversification, rural livelihood enhancement, and sustainable growth. Through strategic interventions such as market research, crop diversification, research and development, farmer capacity building, financial access, infrastructure development, value addition, policy support, and collaborative networking, the untapped potential of these crops can be effectively realized. A coordinated, multi-stakeholder approach will not only benefit farmers and consumers but also contribute to resilient and inclusive agricultural systems capable of addressing future challenges.

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Seaweed in Plant Disease Management

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Seaweeds are the essential plant growth bio-stimulants due to their high composition of phenols, flavonoids, polysaccharides and antioxidant compounds. Seaweed extracts stimulated the seed yield, seed germination, plant growth parameters, biometric attributes, thousand grain weight, plant height, protein and fat composition in agricultural and horticultural crops which were increased. Foliar application, soil application or seed treatment of seaweeds against various phytopathogens including biotic such as fungi, bacterial, nematode and mesobiotic pathogens like viral diseases as well as insects has been confirmed by many scientific reports. They are mostly used as a powder and sometimes available also as a liquid form. They are having the mode of action of inducing systemic resistance, bio protectant activity by induced or combined activity of microbial biota and enhancing crop yield.

Types of Marine Algae

Marine seaweeds are classified into three families Chlorophycaeae (green), Rodophycaeae (red) and Phaeophycaeae (brown) (Raj et al., 2018). The coastal regions of India consist of 844 species of red seaweeds, 216 species of green seaweeds and 194 species of brown seaweeds. Similar to higher plants, green algae also possess chlorophyll, red algae contain phycoerythrin pigment and brown algae contain xanthophylls and fucoxanthin pigments (Abad et al.,2011). Due to their strong biostimulant activity (red algae), Jania rubens, Pterocladia pinata (green algae) Cladophora dalmatic, Corralina mediterranea Enteromorpha intestinalis, Ulva lactuca and (brown algae) *Ascophyllum nodosum*, *Ecklonia maxima, Sargassum* sp. are most frequently used in agriculture (Chatzissa vvidis and Therios, 2014). Different seaweed species are available in gulf mannar region in Tamil Nadu shown in Figure 1.

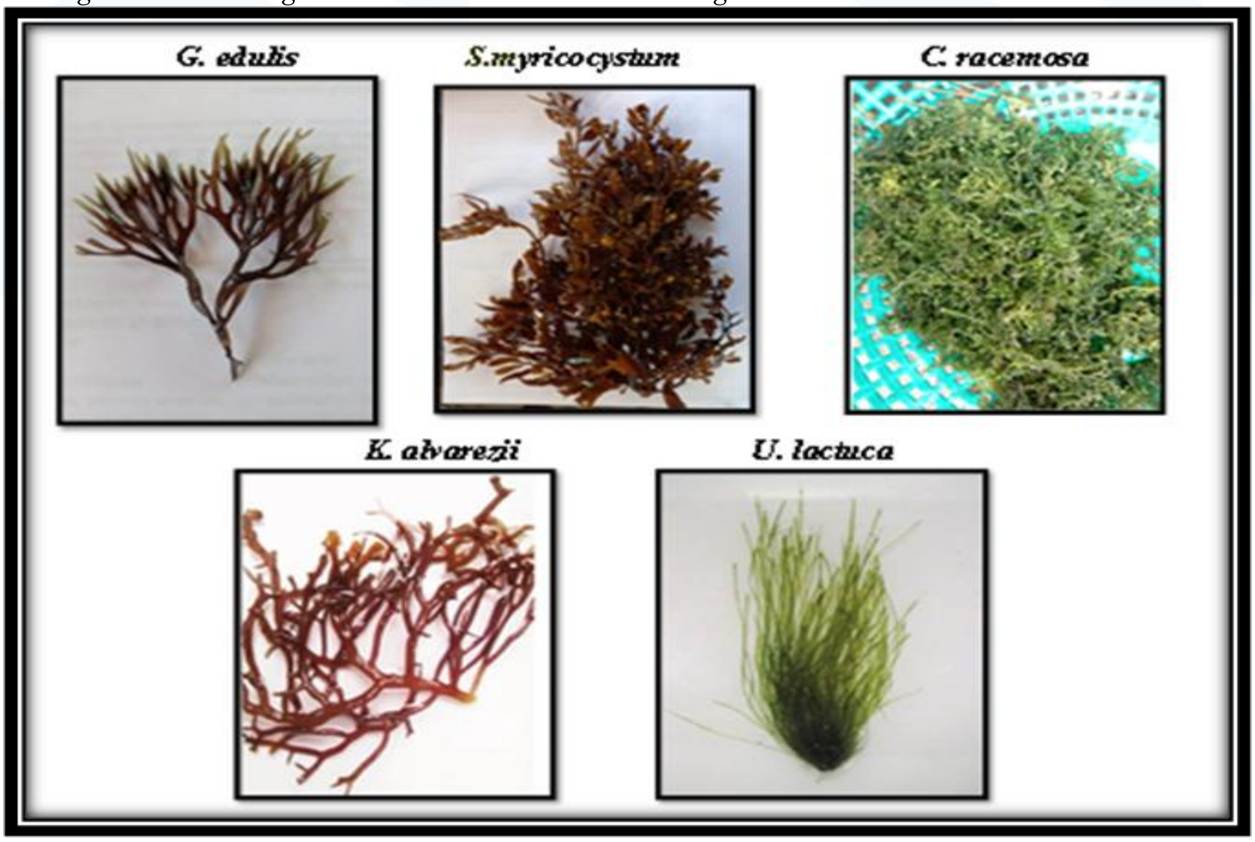

Figure 1. Different seaweeds in gulf mannar region in Tamil Nadu

Applications in Agriculture

Seaweeds are abundant and valuable marine resources that contain a diverse range of bioactive compounds, including lipids, minerals, phytohormones, amino acids, carbohydrates, osmo protectants, and antibacterial substances. Historically, seaweeds have been widely used in food, feed, and medicine, but their agricultural significance has gained increasing recognition in recent years. With the growing shift toward organic and sustainable farming, seaweed extracts (SEs) have been explored as bio fertilizers, soil conditioners, and natural bio control agents. They play a crucial role in enhancing soil health, improving plant growth, and increasing resistance against pests, diseases, and abiotic stressors such as drought, salinity, and extreme temperatures. Their ability to stimulate plant defense mechanisms and promote root development makes them an eco-friendly alternative to synthetic agrochemicals. Numerous studies have demonstrated the efficacy of seaweed extracts in boosting crop productivity while minimizing environmental impact. This review highlights recent advancements in seaweed-based agricultural applications, focusing on their benefits, mechanisms of action, and potential for integration into sustainable farming practices.

Seaweed in Plant Disease Control

In the last decades, there has been a higher concern over the toxicity of pesticides. Searches for reduced-risk pesticides, which have less negative impact on humans and the environment, are increasing. The concern over pathogens and insects' resistance to pesticides is evident as well. Consequently, some researches have been focusing on developing alternative strategies to control plant pathogens and insects without using pesticides or in alternation with the chemical control. In this context, the effects that seaweeds show against plant pathogens and insects have been reported in studies with seaweed collected on different countries. There are many species of seaweeds and their varied extracts that have been testing to control different plant diseases and insects that cause damage to the crops. In general, there are different modes of action by which the seaweeds control plant diseases and insects. Plant pathology studies have been showing positive results about the effect of induced resistance for plant defense against pathogens by seaweed extracts or their isolated compounds. Other researches have been showing the direct effect of seaweed extracts and/or their compounds against plant pathogens. They have activity against a broad range of bacteria or fungi that cause plant disease.

Seaweed Employ Several Strategies to Manage Plant Diseases

Plant Elicitation: Seaweed extracts stimulate plants to activate their internal defense pathways, leading to increased production of defense compounds like phytoalexins and defense enzymes.

Direct Antimicrobial Activity: Some seaweed compounds possess intrinsic antimicrobial properties, directly inhibiting or destroying plant pathogenic bacteria, fungi, and viruses.

Plant Growth Promotion: By providing essential nutrients, amino acids, and phytohormones, seaweed extracts improve overall plant health and vigor, making plants more resilient to disease.

Bio stimulant Effects: Seaweed extracts enhance nutrient uptake, increase stress tolerance, improve root development, and boost chlorophyll levels, contributing to stronger, more resistant plants.

Brown Seaweeds: Extracts from species like *Ascophyllum nodosum* have shown effectiveness in reducing fungal pathogens such as Alternaria radical and *Botrytis cinerea* in carrots and bacterial diseases in cotton.

Other Seaweed Extracts : Extracts from various red, brown, and green macro algae have demonstrated broad-spectrum antifungal and antibacterial effects against a wide range of pathogens.

Benefits of Using Seaweeds

Sustainability: Seaweeds are a renewable and abundant resource, providing a sustainable alternative to chemical pesticides.

Eco-Friendly: Seaweed extracts are biodegradable and considered safe for the environment, animals, and plants.

Integrated Pest Management (IPM): Seaweed applications can be integrated into conventional farming practices to reduce the need for synthetic chemicals, contributing to more sustainable and eco-friendly agriculture.

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Internet of Things (IoT) in Horticulture: Scientific Advances, Applications, and Future Prospects

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Abstract
The Internet of Things (IoT) has become a central component of digital agriculture, offering new capabilities for precision monitoring, automation, and data-driven decision support. Horticultural crops, due to their high value, sensitivity to microclimate, and intensive management demands, are particularly suited for IoT-based solutions. This paper synthesizes scientific advances in IoT applications for horticulture, including smart irrigation, protected cultivation, pest surveillance, orchard automation, and post-harvest management. The discussion draws upon peer-reviewed studies to highlight benefits, challenges, and future research prospects.

Introduction
Horticultural crops—fruits, vegetables, flowers, spices, and plantation crops—require precise environmental management to achieve quality and productivity. Climate variability, water scarcity, labour shortages, and increasing production costs have intensified the need for technology-driven solutions. The **Internet of Things (IoT)**, defined as a distributed network of sensors, communication technologies, and data analytics platforms, has emerged as a transformative tool in digital agriculture. IoT enables real-time monitoring of microclimate and soil properties, automated resource application, early detection of stresses, and improved traceability. These capabilities make IoT particularly relevant to horticulture, where environmental conditions directly affect produce quality, shelf life, and marketability.

IoT in Horticulture
A typical IoT system in horticulture includes four integrated layers:

1. **Sensing Layer** – Soil moisture, pH, EC, temperature, humidity, light intensity, CO_2 sensors
2. **Communication Layer** – LoRaWAN, ZigBee, Wi-Fi, NB-IoT, GSM, or satellite connectivity
3. **Data Processing Layer** – Cloud storage, edge computing, machine learning-based analytics
4. **Application Layer** – Mobile dashboards, automated control systems, early warning tools

Research shows that multi-sensor networks, combined with machine learning algorithms, significantly improve prediction accuracy for crop water needs, disease risk, and yield forecasting (Liakos *et al.,* 2018; Verdouw *et al.,* 2021).

Applications of IoT in Horticulture
1. Precision Irrigation and Fertigation: IoT-based irrigation systems integrate soil moisture sensors, weather data, and automated valves. Studies demonstrate:

- a. **Up to 40–60% water savings** using sensor-driven irrigation
- b. **Higher yield and quality** in horticultural crops such as tomatoes, strawberries, and pomegranates
- c. Reduced nutrient losses through precision fertigation.

Wireless sensor networks (WSNs) have significantly improved water productivity in both open-field vegetable production and greenhouse systems.

2 IoT-Based Greenhouse Automation: Smart greenhouses use IoT to regulate internal climate. Research shows:

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a. IoT-enabled greenhouses maintain more stable temperature and humidity regimes (Díaz *et al.,* 2020)
b. Automated control reduces disease incidence and improves uniformity (Ahmed *et al.,* 2021)
c. IoT integrated with AI enhances predictive climate modelling for protected horticulture (Kumar *et al.,* 2022).

3. Pest and Disease Surveillance: IoT enhances Integrated Pest Management (IPM) through:
a. Camera-based insect detection
b. Smart pheromone traps
c. Real-time disease models
d. Environmental data-driven outbreak forecasting.

Meng *et al.* (2015) demonstrated high accuracy in pest detection using IoT-camera systems, while Naresh *et al.* (2020) showed that predictive modelling can reduce pesticide use by 25–30% in vegetable crops.

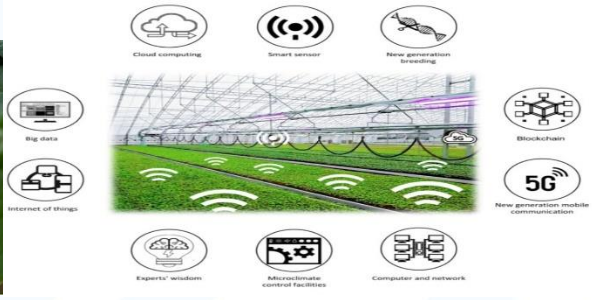

Fig. 1. Augumented Reality (AR) in Horticilture and Smart horticulture based on emerging technologies

4. Post-Harvest Monitoring and Cold Chain Management: Horticultural produce is highly perishable. IoT devices such as ethylene sensors, RFID tags, and temperature loggers enable:
a. Continuous monitoring of storage and transportation conditions
b. Reduction in post-harvest losses
c. Enhanced traceability and compliance with export standards

These technologies are crucial for fruits like mango, banana, citrus, grapes, and for cut flowers.

5. Automation in Orchards and Plantation Systems: IoT supports orchard management through:
a. UAV-based imaging (NDVI, thermal, multispectral)
b. Automated irrigation and fertigation
c. Precision spraying
d. Yield estimation and fruit counting

Shamshiri *et al.* (2018) highlighted how IoT integrated with robotics improves labour efficiency in orchards and facilitates digital phenotypin

Benefits of IoT for Horticultural Systems

1. **Improved input-use efficiency** (water, fertilizers, pesticides)
2. **Enhanced yield and produce quality**
3. **Reduced labour dependency** through automation
4. **Better risk management** via early warnings
5. **Environmental sustainability** through reduced resource wastage
6. **Increased profitability** for high-value crops

These findings are consistently reflected across multiple studies (Ayaz *et al.,* 2019; Misra *et al.,* 2020).

Challenges to Implementation

Despite significant progress, several constraints remain:
1. High initial investment and maintenance costs
2. Limited rural connectivity
3. Lack of technical skills among smallholder farmers

4. Interoperability issues between devices
5. Data privacy and cybersecurity concerns

Addressing these barriers requires integrated policy support, capacity building, and the development of low-cost, open-source IoT solutions.

Future Trends and Research Needs

The next phase of IoT in horticulture will integrate:
1. **Edge AI for on-device decision-making**
2. **Blockchain for transparent supply chains**
3. **Autonomous robots for pruning, harvesting, and scouting**
4. **Digital twins** for real-time simulation of horticultural systems
5. **Low-power IoT devices** optimized for remote orchards and protected cultivation

Research should focus on sensor calibration for diverse horticultural environments, crop-specific algorithms, and cost-effective solutions for small-scale farmers.

Conclusion

IoT is redefining horticultural crop production through real-time monitoring, precision management, and automation. Peer-reviewed literature consistently demonstrates significant improvements in water use efficiency, crop quality, pest management, and post-harvest handling. Although challenges remain, the integration of IoT with AI, robotics, and smart supply chains promises a technologically advanced, sustainable future for global horticulture.

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Calabash Wonder: The Healing and Cultural Legacy of *Crescentia cujete*

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Introduction

Crescentia cujete L., widely recognized as the Calabash tree, Gourd tree, or Higuerón, is a member of the Bignoniaceae family. This small to medium-sized evergreen tree is indigenous to Central and South America, yet it has found a place in tropical regions across Asia, Africa, and the Caribbean due to its adaptability and utility. The tree is particularly notable for its unique round or oval green fruits, which possess a hard, woody shell. These fruits have been traditionally utilized to create a variety of items, including bowls, utensils, and musical instruments, showcasing the tree's versatility and significance in various cultures.

In addition to its practical applications, *Crescentia cujete* is deeply embedded in traditional medicine and cultural practices. Different parts of the tree, such as the leaves, bark, pulp, and fruit, are employed in folk remedies to address a range of health issues, including coughs, asthma, colds, skin infections, and digestive problems. The tree's components are recognized for their anti-inflammatory, antimicrobial, and antioxidant properties, which have piqued the interest of contemporary scientific research. This blend of traditional knowledge and modern inquiry highlights the potential health benefits associated with the Calabash tree. Culturally, the Calabash tree plays a significant role in the daily lives and rituals of many communities in tropical regions. Its robust fruits are skillfully transformed into cups, containers, and musical instruments such as maracas and drums, reflecting a profound connection between nature, art, and healing practices. This multifaceted plant not only serves practical purposes but also embodies the cultural heritage and artistic expressions of the societies that cherish it. Thus, *Crescentia cujete* stands out as an extraordinary example of a plant that enriches human life through its ecological, medicinal, and cultural contributions across generations.

Cultural and Traditional Importance of *Crescentia cujete*

Crescentia cujete, is a species that carries profound cultural, spiritual, and traditional importance in various tropical regions around the globe. This remarkable tree is not only celebrated for its distinctive fruit, which resembles a gourd, but it also serves as a vital component in the everyday lives of numerous indigenous and rural communities. The Calabash tree has been intricately woven into the fabric of local art, where its fruit is often transformed into musical instruments, bowls, and decorative items, showcasing the creativity and craftsmanship of the people. Additionally, it plays a significant role in traditional healing practices, with various parts of the tree being utilized for medicinal purposes, reflecting a deep understanding of the natural world and its resources. The multifaceted uses of the Calabash tree underscore its importance as a symbol of cultural identity and sustainability, highlighting the interconnectedness of nature and human life in these communities.

Cultural Symbolism and Rituals

Across various cultures in Central and South America, Africa, and South Asia, the Calabash tree is revered as a sacred entity, embodying themes of fertility, protection, and the continuity of life. Its hard-shelled fruit serves a significant role in spiritual practices, often transformed into ritual vessels utilized during religious ceremonies, offerings, and traditional healing rituals. In both Caribbean and African traditions, the dried calabash is crafted into containers that hold sacred water or herbs, further emphasizing its importance in spiritual and medicinal contexts. Additionally, in Indian folklore, the tree is thought to possess protective qualities, believed to repel evil spirits and attract good fortune when planted in proximity to homes or temples, thus reinforcing its status as a symbol of well-being and prosperity within the community.

Use in Art, Music and Daily Life

The dried, hollow fruit of *Crescentia cujete* has been embraced as a versatile natural resource for artistic expression and daily utility. Artisans skillfully carve and embellish this unique fruit to create a variety of functional and decorative items, including bowls, ladles, containers, and ornaments that showcase their creativity. In addition to these crafts, the fruit is also transformed into musical instruments such as maracas, rattles, and drums, which play a vital role in traditional music and storytelling practices across various cultures. These artistic endeavors not only highlight the ingenuity and craftsmanship of local communities but also serve as a profound connection to their cultural heritage, allowing them to express their identity and traditions through the medium of this remarkable tree.

Traditional Medicinal Practices

In traditional folk and indigenous medicine, the Calabash tree is revered for its comprehensive healing properties, with every part of the tree—leaves, bark, pulp, and fruit—playing a vital role in various therapeutic applications. The pulp of the fruit is particularly valued as a natural remedy for ailments such as colds, coughs, asthma, and digestive issues, showcasing its versatility in addressing respiratory and gastrointestinal discomfort. Meanwhile, decoctions made from the leaves are commonly employed to treat skin infections, wounds, and inflammation, demonstrating their effectiveness in promoting skin health and healing. Additionally, the bark and seeds of the Calabash tree are recognized for their analgesic and antimicrobial qualities, further underscoring the tree's significance in traditional healthcare practices. This extensive utilization of the Calabash tree in medicinal contexts not only highlights its importance in local healing traditions but also reflects a deep understanding of the natural world and its resources among indigenous communities.

Phytochemistry and Pharmacological Activities

Crescentia cujete, is rich in a variety of bioactive compounds that contribute to its notable medicinal properties. Among these, alkaloids are recognized for their analgesic, antimicrobial, and anti-inflammatory effects, making them valuable in traditional medicine. Flavonoids, found in both the leaves and fruit, are particularly noteworthy for their strong antioxidant capabilities, which help mitigate cellular damage and reduce inflammation. Saponins also play a significant role, offering anti-inflammatory, anti-diabetic, and immune-modulating benefits. Additionally, tannins provide astringent and antimicrobial properties, which are beneficial for wound healing and infection prevention. Glycosides, including certain cardiac and phenolic types, further enhance the plant's profile by supporting antioxidant and anti-inflammatory activities. Terpenoids contribute to the plant's therapeutic potential with their anti-microbial, anti-parasitic, and anti-inflammatory actions, while coumarins, present in the fruit and leaves, are known for their antioxidant and anticoagulant effects. Lastly, pectins and polysaccharides found in the fruit pulp aid in digestive health and help soothe inflammation.

Numerous scientific studies have validated the traditional uses of *Crescentia cujete*, demonstrating a wide array of pharmacological activities. Extracts from this plant have shown significant antimicrobial properties, effectively combating various pathogens. Furthermore, its antioxidant and anti-inflammatory effects have been well-documented, supporting its use in reducing oxidative stress and inflammation in the body. The anti-diabetic and analgesic properties of *Crescentia cujete* have also been highlighted, indicating its potential in managing blood sugar levels and alleviating pain. Additionally, the plant exhibits anti-hypertensive effects, contributing to cardiovascular health, and hepatoprotective properties that safeguard the liver. Its anti-parasitic capabilities further underscore the versatility of *Crescentia cujete* as a valuable resource in both traditional and modern medicine.

Social and Environmental Role

The Calabash tree holds significant social and environmental importance, serving as a vital source of shade and ecological support. Commonly found in courtyards, villages, and temple gardens, it is cherished for its ability to provide cooling relief and protection from the sun's harsh rays. Beyond its role as a shade provider, the tree's fruit has historically been utilized as a storage vessel, making it an integral component of sustainable living practices long before the advent of modern containers. This dual functionality not only enhances the tree's value in local communities but also underscores its contribution to environmental sustainability, as it fosters biodiversity and supports various forms of wildlife.

Conclusion

The significance of *Crescentia cujete*, commonly known as the Calabash tree, extends far beyond its practical uses; it serves as a profound symbol of the interconnectedness of nature, art, and healing. For generations, various communities have held this tree in high esteem, recognizing it as a vital part of their cultural heritage. The Calabash tree is not merely a source of materials for crafting utensils and musical instruments; it embodies a deeper relationship between humanity and the environment. Its presence in rituals and artistic expressions highlights the reverence for nature that is integral to many traditions. As such, the Calabash tree stands as a living testament to the balance and harmony that can exist between people and the natural world, reinforcing the idea that our well-being is intricately linked to the health of our surroundings.

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Turkey Mushroom - *Trametes versicolor*

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Trametes versicolor, often called the "turkey tail," has the dubious distinction of being the only member of the forest fungal fowl community not named for the full bird, but a feathery fraction. However, the chicken of the woods and the hen of the woods look nothing at all like chickens or hens, while the turkey tail does look (vaguely) like a turkey's tail. *Trametes versicolor* is one of the most common mushrooms in North American woods, found virtually anywhere there are dead hardwood logs and stumps to decompose and occasionally on conifer wood too. Its cap colors are extremely variable, but tend to stay in the buff, brown, cinnamon, and reddish brown range. The mushrooms are strikingly "zonate" with sharply contrasting concentric zones of color, and the surface of the cap is finely fuzzy or velvety. Often the zones represent contrasts in texture as well as color, so that fuzzy zones alternate with smoother ones.

Occurrence Distribution

It is a cosmopolitan species found commonly in tropical, subtropical and temperate regions across all the continents. In India these mushrooms are seen naturally in western ghats sampaje forest near coorg, Karnataka. It thrives well in ecosystems like deciduous and mixed forests, woodlands, savannas and mountain regions since it is a lignicolous white rot macro fungus. It grows with a temperature range of 25°C - 30 °C, RH range of 80% - 85% and pH range of slightly acidic to neutral level. Preferred substrates are dead and live hardwoods of conifers such as pine, and oak trees.

		
Trametes hirsuta	***Trametes gibbosa***	***Trametes elegans***

Economic Importance

Trametes mushrooms, particularly *Trametes versicolor* (Turkey Tail), lies in their use in pharmaceuticals, food, and as a source for novel bio-materials. The mushroom and its extracts are recognized for their anti-cancer, immune-boosting, and other medicinal properties, driving demand in the nutraceutical and pharmaceutical industries. They also offer potential in bioremediation for breaking down industrial waste and can be used to create sustainable materials like packaging and construction elements.

Medicinal Benefits

Trametes versicolor contains potent bioactive compounds, especially polysaccharides, with demonstrated anti-cancer, immune-modulating, and antiviral properties. Its ability to stimulate the immune system and its potential role as an adjuvant in cancer therapy make it a high-value commodity for medication manufacturing. In Chinese, Korean and Japanese traditional medicine they're using turkey tail mushroom extracts as a part of their preparations, mostly prepared in forms of tea , decoctions , capsules ,powders and specific medicinal extracts.

Biomaterials and Sustainability

The mycelium of Trametes is being explored to create sustainable, biodegradable materials for diverse applications, such as packaging and building materials, offering an eco-friendly alternative to conventional products. As a white-rot fungus, Trametes can break down lignocellulosic waste, making it valuable for industrial applications like wastewater treatment and the production of biofuels.

Agriculture and Food

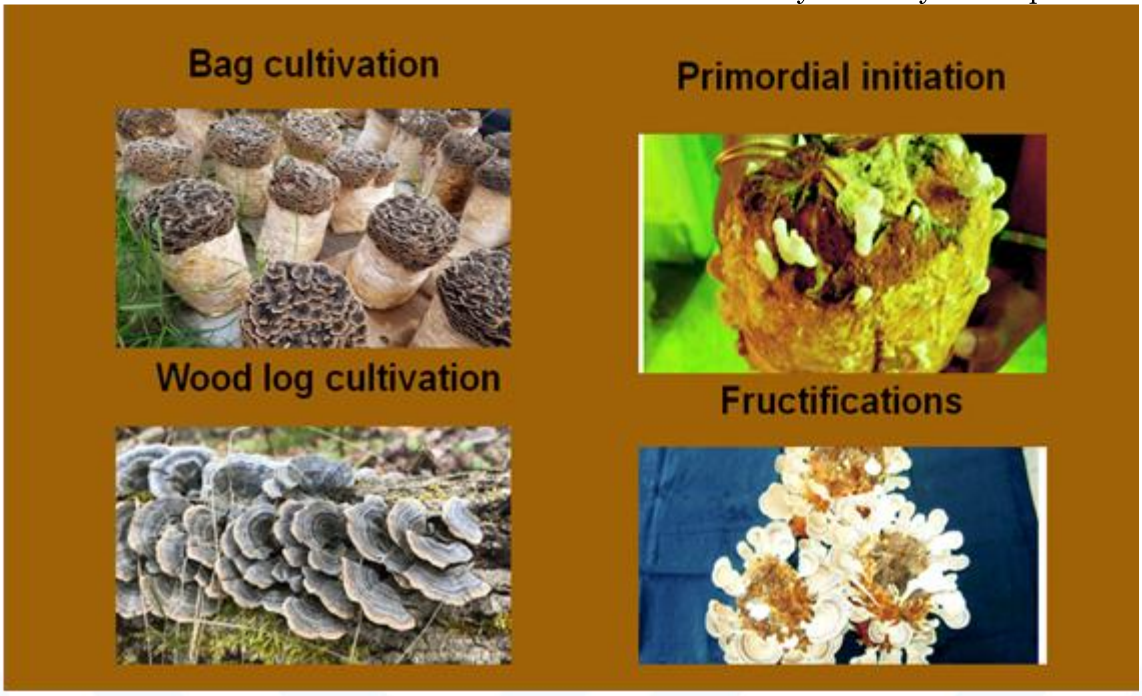
Trametes species have potential as a food source, contributing to food security and providing nutritional value. They can also be used in the agricultural sector to enhance crop quality and yield, although the specific mechanisms are still under research.

Cultivation

Trametes species are adaptable and can be cultivated on various substrates like sawdust, supporting a growing industry focused on bio-economy principles. Cultivating Tremetes, specifically the common species *Trametes versicolor* (Turkey Tail), involves creating a pure culture from a fresh mushroom, then cultivating the mycelium in a substrate like sawdust or agricultural waste. Optimal conditions for fruiting are a temperature around 20-25°C and 80-85% humidity, with fruiting bodies harvested for use in traditional medicine and supplements.

Steps for Mushroom Cultivation

Collect a fresh turkey tail mushroom and extract the inner mass to cultivate on a potato dextrose agar (PDA) medium in a sterile environment. Once a pure culture is established, create multiple subcultures to maintain and grow a larger, healthy mycelium. Grow the mycelium on a grain-based substrate like sorghum to create mushroom spawn. Choose a suitable substrate rich in lignocellulosic materials like sawdust and straw, which are high in hemi cellulose. A mix of 80% sawdust and 20% wheat straw has shown good results. Inoculate the substrate with the spawn and incubate it until the white mycelium fully colonizes the substrate. This process can take 18-20 days at 25°C. Transfer the colonized substrate to a cropping room maintained at 20 -25°C and 80 - 85% relative humidity. Provide light for 12 hours daily and ensure good ventilation. Harvest the mushroom fruit bodies when they are fully developed.



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Nano Urea & Nano DAP – Its Utility, Advantage, Disadvantage & Rumours Associated

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Abstract

Nano-fertilizers particularly Nano Urea and Nano DAP have gained major attention in India as next-generation nutrient formulations intended to enhance fertilizer-use efficiency, reduce input quantities, and minimize environmental losses. These products are marketed as highly concentrated liquid formulations containing nutrient particles in the nanometre range, designed for rapid foliar absorption and improved nutrient delivery. While manufacturers and supporters highlight potential benefits such as reduced dependence on conventional urea and DAP, lower logistics costs, and greater environmental sustainability, independent evaluations show mixed results across crops and regions. Concerns regarding inadequate long-term data, inconsistent agronomic performance, regulatory transparency, and widespread rumours among farmers have created a complex landscape. This review critically examines the utility, benefits, limitations, and misconceptions associated with Nano Urea and Nano DAP in the Indian context and offers guidelines for safe and evidence-based use.

Background: Understanding Nano Fertilizers

Nano fertilizers contain nutrients in extremely small particles or droplets, typically below 100 nanometres. The theoretical advantages of nano-scale formulations include higher surface-area-to-volume ratio, enhanced reactivity, improved nutrient absorption, controlled release, and reduced nutrient losses to volatilization and leaching. Mechanistically, nano-sized particles are believed to penetrate plant leaves through stomata or the cuticle more efficiently than conventional forms. When applied as foliar sprays, they may enter the phloem and move rapidly to growing tissues. However, these mechanisms are highly dependent on specific formulations, crop species, environmental conditions, and spray protocols.

Nano Urea and Nano DAP: Product Overview (India)

1. Nano Urea (Liquid): Nano Urea is marketed as a foliar spray containing nano-scale urea particles. It is positioned as an alternative or supplement to conventional pilled urea, with recommendations emphasizing foliar application at specific concentrations during critical crop growth stages.

2. Nano DAP (Liquid): Nano DAP is a recent addition that contains nano-formulations of nitrogen and phosphorus in liquid form. It is promoted for seed treatments, foliar sprays, and targeted nutrient delivery during vegetative and reproductive stages. The product is advertised as improving phosphorus availability, especially in soils where P fixation is high.

Claimed Utilities and Advantages

1. Higher Nutrient Use Efficiency (NUE): The nanometre-sized particles are believed to enhance plant uptake, thereby reducing the need for large quantities of conventional fertilizers.

2. Foliar Application Flexibility: Nano fertilizers can be quickly applied during mid-season when soil-applied fertilizers may no longer be effective. They are especially useful as rescue sprays in deficiency situations.

3. Reduced Environmental Losses: Manufacturers argue that because of improved nutrient uptake, less nitrogen or phosphorus is lost through volatilization, leaching, or runoff.

4. Lower Logistic Burden: Liquid nano-fertilizers come in small bottles, making them easier to store, transport, and distribute compared to bulky urea bags.

5. Potential Reduction in Subsidy Burden: If farmers reduce their usage of conventional fertilizers, national fertilizer subsidies may decline. This is a key policy driver behind nano-fertilizer promotion.

Empirical Field Evidence: What Studies Show

Field trials conducted by universities and independent researchers show highly variable results. In some cases, Nano Urea or Nano DAP used as supplements alongside reduced soil N or P have shown yield parity or modest benefits.

However, several multi-location trials indicate that using Nano Urea as a direct substitute for conventional soil-applied urea can lead to significant declines in yield, especially in nitrogen-intensive cereal crops such as rice and wheat. Declines in grain protein content and reduced biomass have also been recorded in some scenarios.

Overall, the accumulated evidence suggests:
1. Nano fertilizers may have value as supplements,
2. But not as complete replacements for conventional fertilizers, at least under current formulations and field conditions in India.

Disadvantages, Risks, and Limitations

1. Inconsistent and Limited Independent Data: Most available trials are short-term or limited in geographic scope. Long-term, multi-season, multi-location studies across India's diverse agroclimatic zones are still insufficient.

2. Risk of Yield Loss When Used as Substitutes: Replacing soil-applied nitrogen or phosphorus with foliar nano sprays has repeatedly resulted in lower yields in several major crops under field conditions.

3. Lack of Crop- and Region-specific Guidelines: Foliar uptake varies greatly based on humidity, leaf characteristics, crop stage, and spray quality. Current recommendations often overlook these complexities.

4. Higher Cost per Unit Nutrient: Although small bottles appear cost-efficient, nano fertilizers typically contain much lower total nutrient content compared to conventional granular fertilizers. Labour and equipment costs for foliar applications also add to expenses.

5. Regulatory Concerns and Transparency Issues: Critics argue that marketing claims have outpaced scientific validation. There is a need for clearer regulatory pathways and publicly available datasets from large-scale trials.

6. Environmental and Ecotoxicological Unknowns: The behaviour of nanoparticles in soil, water, and plant systems is not comprehensively understood. Their effects on soil microflora, insects, and long-term ecological health require further research.

Steps for Mushroom Cultivation

Collect a fresh turkey tail mushroom and extract the inner mass to cultivate on a potato dextrose agar (PDA) medium in a sterile environment. Once a pure culture is established, create multiple subcultures to maintain and grow a larger, healthy mycelium. Grow the mycelium on a grain-based substrate like sorghum to create mushroom spawn. Choose a suitable substrate rich in lignocellulosic materials like sawdust and straw, which are high in hemi cellulose. A mix of 80% sawdust and 20% wheat straw has shown good results. Inoculate the substrate with the spawn and incubate it until the white mycelium fully colonizes the substrate. This process can take 18-20 days at 25°C. Transfer the colonized substrate to a cropping room maintained at 20 -25°C and 80 - 85% relative humidity. Provide light for 12 hours daily and ensure good ventilation. Harvest the mushroom fruit bodies when they are fully developed.

Rumours, Misinformation, and Social Concerns in India

Nano fertilizers have become the subject of widespread rumours, fuelled by inconsistent performance, rapid commercial rollout, and communication gaps.

1. "Nano Urea causes crop failure.": Some farmers have experienced yield reductions when replacing all soil urea with nano sprays. While this is not inherent toxicity, inappropriate substitution has contributed to the perception.

2. "Government is forcing farmers to buy nano bottles.": In some regions, farmers reported pressure from cooperative societies to purchase nano fertilizers as part of bundled procurement. These operational issues have strengthened distrust.

3. "Nano fertilizers are just a marketing scheme.": The lack of transparent independent data and aggressive promotion strategies have led to a perception that the technology is industry-driven rather than science-driven.

4. "Nano fertilizers are harmful to health or environment.": There is no evidence of immediate toxicity, but long-term nanoparticle behaviour remains a research gap, contributing to speculation.

Policy and Regulatory Context in India

The policy and regulatory landscape governing Nano Urea and Nano DAP in India has evolved rapidly as the country seeks to modernize its fertilizer sector, reduce import dependence, and address the rising subsidy burden. The Government of India has permitted the commercial production, sale, and distribution of nano fertilizers under the Fertilizer Control Order (FCO) after initial evaluations by scientific committees. However, even after their introduction into the market, there has been a strong focus on expanding field-level validation through coordinated trials conducted by ICAR institutes, state agricultural universities, and public-sector agencies. Policymakers recognize the potential benefits of nano fertilizers, especially their lower logistical burden, reduced transportation emissions, and possible improvements in nutrient-use efficiency; yet they also acknowledge the lack of long-term evidence demonstrating their effectiveness across India's highly diverse agro-ecological zones. As a result, several official discussions have emphasized the need for caution in promoting nano fertilizers as full replacements for conventional urea and DAP. Parliamentary committees, expert groups, and agricultural institutions have repeatedly underlined the importance of transparent multi-location data, clear agronomic guidelines, and farmer-centric communication strategies before scaling up national-level adoption. The policy framework thus remains supportive but measured encouraging innovation while simultaneously calling for stronger regulatory oversight, greater scientific transparency, and robust monitoring of real-world performance to ensure that farmers are not exposed to economic or yield risks due to premature adoption.

Practical Agronomic Guidance for Farmers

From an agronomic standpoint, nano fertilizers should be used thoughtfully and strategically rather than as blanket replacements for conventional fertilizers. Farmers are advised to understand that Nano Urea and Nano DAP are foliar formulations designed primarily to supplement, not substitute, soil-applied fertilizers. The nutrients contained in nano sprays are insufficient to meet the full seasonal demand of major crops, especially cereals such as rice, wheat, and maize that require large amounts of nitrogen and phosphorus. When nano fertilizers are sprayed at recommended stages generally during active vegetative growth they may help correct mid-season nutrient deficiencies and provide rapid absorption under favorable humidity and temperature conditions. However, their effectiveness can vary widely depending on factors such as the timing of application, spray quality, leaf condition, variety, climatic conditions, and concurrent soil nutrient availability. Therefore, farmers should continue to apply basal doses of conventional fertilizers as recommended by soil tests or state agricultural universities, and only use nano products as supplementary inputs when required. Labour availability, cost of spraying, and compatibility with existing nutrient management practices should also be considered to assess overall economic viability. Moreover, farmers are encouraged to rely on guidance from unbiased scientific institutions rather than relying solely on promotional claims. An evidence-based, cautious approach guided by local extension services, field demonstrations, and university recommendations can help ensure that nano fertilizers are integrated safely and effectively into the broader nutrient management program.

Research Gaps and Future Priorities for India

Despite widespread interest, nano fertilizers remain a relatively new technological intervention, and several critical research gaps need to be addressed before they can be confidently recommended for large-scale use. India's diverse cropping systems require extensive multi-season field trials to evaluate the performance of Nano Urea and Nano DAP under different soil types, rainfall patterns, management practices, and crop varieties. These trials must be carried out independently across multiple agricultural universities and research bodies to generate robust and unbiased data. In parallel, mechanistic research is needed to unravel how nano particles behave within plant tissues, how efficiently they are absorbed through the leaf cuticle, how they move through phloem pathways, and whether they can fully replace the physiological functions of conventional fertilizers. Understanding the environmental fate of nano particles such as their persistence in soil, interactions with microbial communities, and potential movement into water bodies is equally important, given the long-term implications for ecosystem health. Another major research priority involves assessing the economic and behavioural dimensions of adoption. Farmers' perceptions, cost–benefit ratios, labour requirements for foliar spraying, and the influence of market or institutional pressures all shape how nano fertilizers are used in real conditions. Finally, there is a need for increased transparency through publicly accessible datasets, standardized testing protocols, and collaborative national networks that monitor performance across regions. These research efforts will help clarify where nano fertilizers can genuinely add value, where their use may pose risks, and how India can incorporate them responsibly into future nutrient management strategies.

Conclusion

Nano Urea and Nano DAP represent innovative approaches to nutrient management in India. While the technology promises improved nutrient-use efficiency, lower environmental losses, and reduced dependence on bulk fertilizers, current evidence does not support replacing conventional fertilizers with nano formulations. Instead, these products are best considered foliar supplements, not substitutes. Agronomic variability, lack of comprehensive data, and farmer-level inconsistencies underscore the need for long-term, transparent research. Until such evidence becomes available, cautious, evidence-based, and crop-specific use is essential to avoid yield penalties and misinformation-driven adoption or rejection. Nano fertilizers may become valuable tools within Integrated Nutrient Management systems, but only when supported by robust scientific proof and farmer-centric guidance.

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Emerging Smart Packaging Solutions for Fresh Produce Preservation

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Abstract
The global increase in fresh produce consumption is juxtaposed with significant postharvest losses, necessitating innovative preservation technologies. Smart packaging has emerged as a transformative solution, moving beyond conventional passive barriers to actively monitor, regulate and communicate the condition of packaged goods. This review explores the burgeoning field of smart packaging for fruits and vegetables, categorizing it into active and intelligent systems. Active packaging functions by interacting with the produce to extend shelf life, utilizing mechanisms such as moisture regulation, gas scavenging and antimicrobial activity. Intelligent packaging, conversely, monitors the internal and external environment through sensors, indicators and data carriers, providing real-time information on freshness, quality and safety. We detail the advanced materials enabling these functionalities, including biodegradable polymers, nanomaterials and stimuli-responsive compounds. The significant advantages of smart packaging such as extended shelf life, enhanced food safety and reduced waste are discussed alongside the challenges of cost, technological maturity and consumer acceptance. Finally, we outline future directions, emphasizing the integration of the Internet of Things (IoT), multifunctional material design and the development of sustainable, bio-based smart packaging systems that promise to revolutionize the fresh produce supply chain.

Keywords: Smart Packaging; Preservation; Active Packaging; Biosensors; Biodegradable Materials; Internet of Things (IoT); Food Safety.

Introduction
Fruits and vegetables are vital components of a healthy diet, rich in essential vitamins, minerals and dietary fiber. However, their high moisture content and active metabolic processes postharvest make them highly perishable. Factors such as transpiration, respiration, microbial growth and physiological decay lead to significant quality deterioration and economic losses, estimated to be up to 50% of the total production in some regions. Traditional preservation methods, including refrigeration and modified atmosphere packaging, have limitations and often fail to dynamically respond to the changing conditions of the produce or its environment.

In this context, smart packaging has arisen as a pivotal innovation in the food industry. It is an umbrella term for packaging systems that provide functions beyond mere containment and protection. These systems are designed to:

1. **Actively interact** with the produce to prolong its shelf life (Active Packaging).
2. **Intelligently monitor** and communicate information about the product's condition or the history of its environment (Intelligent Packaging).

Driven by advancements in material science, nanotechnology and sensor technology, smart packaging offers a dynamic approach to preservation. By providing real-time data and responsive control over the package's internal atmosphere, it ensures optimal conditions throughout the supply chain, from farm to fork. This review synthesizes the current state of smart packaging technologies, their mechanisms, applications in fresh produce and the path forward for their widespread adoption.

Classification and Principles of Smart Packaging
Smart packaging can be fundamentally divided into two complementary categories: active and intelligent packaging.

Active Packaging: Active packaging systems incorporate components that intentionally interact with the produce or its headspace to inhibit degradation processes. These systems work by emitting active compounds into the package or scavenging undesirable ones.

Table 1: Common Types of Active Packaging Systems for Fresh Produce:

Type of Active System	Mechanism of Action	Application Example
Oxygen Scavengers	Absorb residual oxygen to prevent oxidative reactions and inhibit aerobic microbial growth.	Sachets containing iron powder in packaged salads.
Ethylene Scavengers	Remove ethylene, a ripening hormone, to delay senescence and softening.	Potassium permanganate-based sachets or films for bananas and tomatoes.
Moisture Absorbers	Control excess humidity, reducing condensation and suppressing fungal growth.	Pads containing superabsorbent polymers under strawberries or berries.
CO_2 Emitters	Release carbon dioxide, which can suppress microbial growth and reduce respiration rates in some produce.	Often used in combination with O_2 scavengers in modified atmosphere packaging for meats and some fruits.
Antimicrobial Releasers	Slowly release natural or synthetic antimicrobial agents (e.g., essential oils, silver nanoparticles) to surface of the produce.	Chitosan films infused with clove essential oil for cherry tomatoes [2].

Intelligent Packaging: Intelligent packaging does not directly preserve the food but provides information about its quality, safety and history. It acts as a communication bridge between the product, the supply chain and the consumer.

Table 2: Categories of Intelligent Packaging Systems:

Category	Description	Technologies & Examples
Indicators	Provide a visual, qualitative change (usually color) in response to a specific trigger.	**Time-Temperature Indicators (TTIs):** Show cumulative temperature exposure. **Freshness Indicators:** Change color in response to microbial metabolites (e.g., CO_2, amines, pH changes). A red cabbage anthocyanin-based label turning from pink to blue indicates fish spoilage; similar principles apply for produce like mushrooms [3]. **Gas Indicators:** Detect specific gases like O_2 or CO_2.
Sensors	Detect and measure (quantitatively or semi-quantitatively) specific chemical or physical parameters and can transmit data.	**Gas Sensors:** Monitor O_2/CO_2 levels inside the package. **Biosensors:** Use biological elements (e.g., enzymes) to detect specific spoilage compounds. **Fluorescent Sensor Arrays:** Can classify freshness by reacting to a profile of volatile organic compounds released by different fruits and vegetables [4].
Data Carriers	Store and transmit static or dynamic data for traceability and information sharing.	**QR Codes & Barcodes:** Provide product origin, price and recipes. **Radio-Frequency Identification (RFID):** Enables wireless tracking of location, temperature and humidity history throughout the supply chain.

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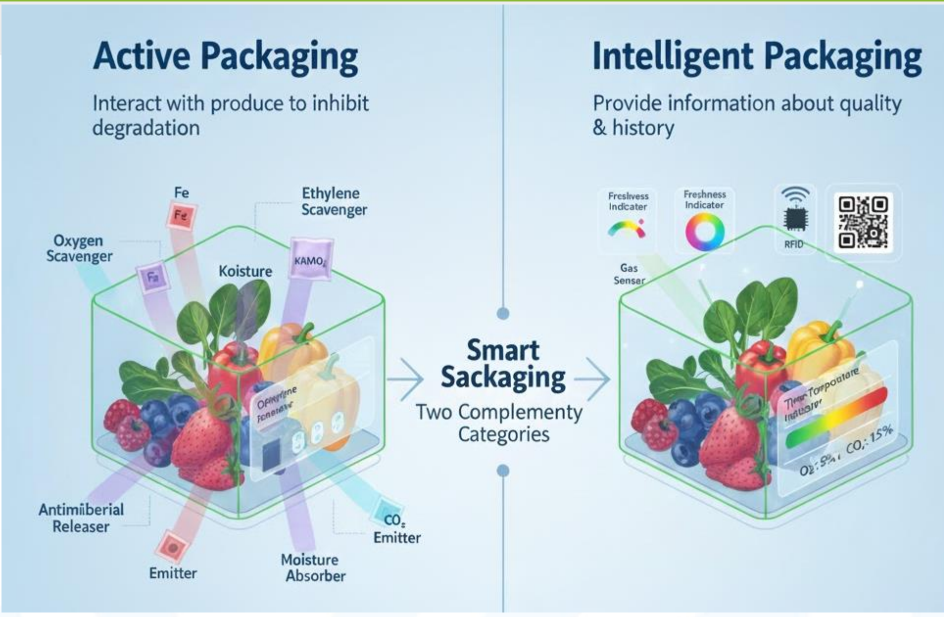

Fig. 1. Active vs. Intelligent packaging

Advanced Materials Enabling Smart Packaging

The functionality of smart packaging is underpinned by innovations in material science.

Biodegradable and Bio-based Polymers: The environmental impact of petroleum-based plastics has driven research into sustainable alternatives. Materials like polylactic acid (PLA), starch, chitosan, alginate and cellulose derivatives are being used to create both active and intelligent packaging. For instance, chitosan films inherently possess antimicrobial properties and can be further functionalized with active compounds.

Nanomaterials: Nanotechnology enhances packaging performance through materials with unique properties at the nanoscale.

a. **Nanocomposites:** Nanoparticles like nano-clay or cellulose nanofibers are incorporated into polymers to improve mechanical strength and gas barrier properties.
b. **Nano-Antimicrobials:** Silver nanoparticles (AgNPs) and zinc oxide nanoparticles (ZnO NPs) provide potent, sustained antimicrobial activity.
c. **Nano-sensors:** Nanostructures can increase the sensitivity and specificity of sensors for detecting spoilage gases or pathogens.

Stimuli-Responsive and Self-Healing Materials: These "smart" materials change their properties in response to environmental triggers like pH, moisture, or temperature. For example, a self-healing edible coating made from chitosan and sodium alginate can repair minor damages, maintain its barrier function and extend the shelf life of strawberries.

Applications and Advantages in Fresh Produce Preservation

The application of smart packaging offers multifaceted benefits across the fresh produce supply chain.

Extending Shelf Life and Maintaining Quality: By dynamically regulating factors like humidity and gas composition, smart packaging directly tackles the primary causes of spoilage. For example, a hydrophobic ethyl cellulose film with 1-MCP (an ethylene inhibitor) was shown to effectively delay the softening, browning and weight loss of mushrooms.

Enhancing Food Safety: Antimicrobial packaging actively reduces the microbial load on the surface of produce. A polycaprolactone film incorporated with a porphyrinic metal-organic framework (MOF-545) demonstrated high photodynamic antibacterial activity, killing 96% of microorganisms on fresh-cut apples and significantly delaying spoilage.

Improving Supply Chain Transparency and Efficiency: RFID tags and QR codes enable full traceability, allowing stakeholders to monitor the location and environmental history of a product. This data helps in optimizing logistics, identifying bottlenecks and verifying that cold chain integrity has been maintained.

Empowering Consumers: Intelligent labels provide consumers with direct, easy-to-understand information about the freshness of the product, moving beyond arbitrary "best before" dates and reducing unnecessary disposal of edible food.

Current Challenges and Limitations

Despite its promise, the widespread adoption of smart packaging faces several hurdles.

1. High Cost: The integration of sensors, active materials and electronics significantly increases production costs compared to conventional packaging, making it prohibitive for low-value commodities.

2. Technological and Regulatory Hurdles: The long-term stability, reliability and safety of some smart materials, especially nanomaterials, require further validation. There is a lack of global standardized regulations governing their use in food contact materials.

3. Consumer Acceptance: Public perception regarding the safety of "smart" components and the environmental footprint of complex packaging systems can influence market success. Clear communication and education are essential.

4. Environmental Impact: While biodegradable materials offer a solution, the end-of-life management of complex multi-material smart packages, which may contain electronic components, remains a challenge that needs to be addressed through design for recyclability or compostability.

Future Perspectives

The future of smart packaging for fresh produce is vibrant and points toward greater integration, intelligence and sustainability.

1. IoT and Big Data Integration: The combination of smart packaging with IoT platforms will enable real-time, cloud-based monitoring of entire shipments. Data analytics can predict shelf life, automate inventory management (e.g., first-expired-first-out) and provide unprecedented supply chain visibility.

2. Multifunctional and Synergistic Systems: Future packages will likely combine multiple active and intelligent functions. A single film could simultaneously regulate moisture, release antimicrobials and indicate spoilage, creating a holistic preservation environment.

3. Advanced Biodegradable Smart Materials: Research will focus on developing fully biodegradable systems where even the sensing and active components are derived from natural, non-toxic sources, such as plant extracts and biopolymeric nanoparticles.

4. Standardization and Circular Economy: The establishment of international standards will be crucial for safety and interoperability. Furthermore, designing smart packaging within a circular economy framework considering recyclability, reusability and compostability from the outset is imperative for sustainable growth.

Conclusion

Smart packaging represents a paradigm shift in the preservation of fresh produce. By actively controlling the package environment and providing real-time quality information, these advanced systems offer a powerful tool to reduce food waste, enhance safety and improve supply chain efficiency. While challenges related to cost, technology maturity and regulation persist, the ongoing convergence of material science, nanotechnology and digital technology is rapidly paving the way for innovative solutions. The future lies in developing cost-effective, sustainable and intelligently integrated packaging systems that will not only preserve the freshness of our food but also contribute to a more transparent and resilient global food system.

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Soil Organic Matter and its Impact on Fruit Quality

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Soil organic matter (SOM) plays a central role in determining soil fertility, sustainable productivity, and the overall performance of fruit crops. As a complex mixture of decomposed plant residues, microbial biomass, and organic compounds, SOM functions as the backbone of healthy soil. In fruit-growing ecosystems, where long-term soil health directly influences fruit yield, flavour, colour, shelf life, and nutritional value, maintaining optimum organic matter is essential. Improving SOM is considered one of the most effective strategies to enhance fruit quality while reducing the dependency on chemical fertilizers.

Soil organic matter significantly improves soil physical properties, including structure, porosity, aeration, and water-holding capacity. Fruit crops, especially perennial ones like mango, citrus, guava, and grapes, develop extensive root systems that perform best in well-structured soils. High SOM levels help create stable aggregates, which allow roots to penetrate deeper and more efficiently absorb nutrients and water. This directly influences fruit development, leading to better fruit size, uniformity, and overall quality. Additionally, SOM buffers the soil against extreme temperature fluctuations, creating a more favourable environment for root activity throughout the year.

The influence of SOM on nutrient availability is one of its most important contributions to fruit quality. Organic matter acts as a reservoir of essential nutrients such as nitrogen, phosphorus, sulphur, and micronutrients, releasing them slowly as it decomposes. This ensures a steady nutrient supply during critical stages like flowering, fruit set, and maturation. It also increases the cation exchange capacity (CEC) of soil, allowing it to retain nutrients that might otherwise be lost through leaching. As a result, fruit crops grown in soils rich in organic matter often show enhanced sweetness, improved colour development, higher vitamin content, and better aroma due to balanced nutrient uptake, especially of potassium, calcium, and micronutrients.

Moreover, SOM promotes microbial activity, which is vital for nutrient cycling and soil health. Beneficial microorganisms such as mycorrhizal fungi, nitrogen-fixing bacteria, and phosphate-solubilizing microbes thrive in soils rich in organic matter. These microbes enhance nutrient uptake, maintain soil structure, and protect roots from pathogens. Healthy root systems supported by active microbial populations contribute to higher fruit firmness, better skin texture, and reduced physiological disorders such as cracking, bitter pit, or blossom end rot. In crops like grapes and strawberries, microbial-rich soils are directly associated with improved flavour profiles and higher market value.

Water management is another key area influenced by soil organic matter. SOM increases the soil's ability to retain moisture, reducing the need for frequent irrigation and protecting plants during drought periods. Adequate moisture availability ensures uniform fruit growth and reduces the risk of small, misshapen, or sunburned fruits. In fruit crops grown under organic or sustainable farming systems, improved SOM often translates into greater resilience against moisture stress, resulting in consistent fruit size and better post-harvest life.

Soil Organic Matter and Its Impact on Fruit Quality

Soil is the foundation of all terrestrial agriculture, and its health is a critical determinant of crop productivity and quality. Among the various components that define soil health, **soil organic matter (SOM)** plays a pivotal role, particularly in fruit orchards where quality and nutritional content of fruits are essential. SOM is the fraction of soil that consists of decomposed plant and animal residues, microbial biomass, and humus. It acts as a reservoir of nutrients, improves soil structure, and influences water retention, all of which directly or indirectly affect fruit quality.

Components of Soil Organic Matter

Soil organic matter is composed of three main components:

1. Living Biomass: Microorganisms such as bacteria, fungi, and protozoa actively decompose organic residues and recycle nutrients.

2. Fresh Residues: Recently added plant materials like fallen leaves, pruned branches, and crop residues.

3. Stable Humus: Well-decomposed organic matter that persists in soil for years and contributes to soil fertility and structure.

Role of Soil Organic Matter in Nutrient Supply

SOM serves as a slow-release nutrient source. It contains essential macro- and micronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and trace elements. As microbes decompose SOM, nutrients are mineralized into plant-available forms. This continuous nutrient supply ensures optimal fruit development, enhancing fruit size, color, taste, and shelf life.

Influence on Soil Physical Properties

Organic matter improves soil structure by promoting aggregation, which increases **porosity** and reduces compaction. This enhances **root penetration**, ensuring better access to nutrients and water. Improved water-holding capacity due to SOM is particularly beneficial in fruit crops during critical growth stages such as flowering and fruit set, reducing the risk of fruit drop or poor development.

Impact on Soil Microbial Activity

High SOM content fosters a diverse and active microbial community. Beneficial microbes enhance nutrient cycling, suppress soil-borne pathogens, and promote plant growth through the production of growth-promoting substances. Healthy microbial activity directly correlates with fruit quality by reducing stress on the plants and improving nutrient uptake.

Relationship Between SOM and Fruit Quality

1. Fruit Size and Weight: Adequate SOM improves nutrient availability and water supply, leading to larger, well-developed fruits.

2. Color and Appearance: Balanced nutrient supply, particularly micronutrients such as magnesium and iron, contributes to vibrant fruit coloration.

3. Flavor and Sugar Content: Nutrient-rich soils enhance carbohydrate synthesis and accumulation in fruits, improving sweetness and flavor.

4. Shelf Life: Fruits grown in SOM-rich soils often have thicker skins and better structural integrity, reducing post-harvest losses.

5. Nutritional Value: Fruits from organically rich soils tend to have higher vitamin, antioxidant, and mineral content.

Practices to Enhance Soil Organic Matter

1. Addition of Organic Amendments: Use of compost, farmyard manure, green manures, and crop residues.

2. Cover Cropping: Planting legumes or other cover crops to return organic matter to the soil.

3. Reduced Tillage: Minimizing soil disturbance helps preserve SOM and microbial habitats.

4. Mulching: Applying organic mulches around trees reduces moisture loss and gradually adds organic matter as it decomposes.

5. Integrated Nutrient Management (INM): Combining organic and inorganic fertilizers for sustained soil fertility.

Conclusion

Soil organic matter is not just a measure of soil fertility; it is a critical driver of **fruit quality**. By enhancing nutrient availability, improving soil structure, and supporting microbial health, SOM ensures that fruit crops reach their full genetic potential in terms of size, taste, color, and nutritional value. Sustainable management practices that increase SOM should, therefore, be integral to modern fruit orchard management to produce high-quality, marketable fruits while maintaining long-term soil health.

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Integrated Nutrient Management (INM) in Fruit Crops: A Sustainable Approach for Improving Yield, Quality, and Soil Health

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Integrated Nutrient Management (INM) is a holistic strategy that combines organic, inorganic, and biological sources of plant nutrients to ensure balanced nutrition, maintain soil fertility, and enhance long-term productivity of fruit crops. With the increasing demand for high-quality fruits and the need to sustain soil resources, INM has emerged as a key component of modern horticultural management.

Introduction

Fruit crops are heavy nutrient feeders and require continuous nutrient replenishment to maintain high productivity, fruit quality, and plant vigour. Conventional reliance on chemical fertilizers alone has led to several problems, such as nutrient mining, decline in soil organic matter, micronutrient deficiencies, reduced microbial activity, and environmental pollution. INM addresses these issues by integrating different nutrient sources in a scientifically balanced manner. Integrated Nutrient Management (INM) in fruit crops is a sustainable approach that focuses on combining chemical fertilizers, organic manures, and biofertilizers to ensure balanced nutrition, long-term soil fertility, and high-quality fruit production. Fruit crops are heavy nutrient feeders, and relying solely on chemical fertilizers often leads to soil degradation, nutrient imbalance, reduced microbial activity, and declining productivity. INM helps overcome these issues by supplying nutrients from multiple sources in a balanced and scientific manner.

Organic manures such as farmyard manure, compost, vermicompost, green manure, and oil cakes not only supply essential nutrients but also improve soil structure, water-holding capacity, and organic carbon content. Biofertilizers like Azotobacter, Azospirillum, phosphate-solubilizing bacteria (PSB), potassium-solubilizing bacteria (KSB), and arbuscular mycorrhizal fungi (AMF) enhance nutrient uptake naturally by fixing nitrogen, solubilizing phosphorus and potassium, and improving micronutrient availability. Chemical fertilizers are still important, but INM promotes their judicious use based on soil test values and crop requirements to avoid over-application and nutrient losses. Practices such as mulching, crop residue recycling, and foliar application of micronutrients further strengthen the efficiency of nutrient use in fruit orchards.

INM plays an important role in major fruit crops like mango, banana, citrus, guava, and grapes by improving fruit size, colour, taste, and yield. For example, combining FYM, vermicompost, and biofertilizers with partial chemical fertilizers enhances flowering and fruiting in mango, while banana responds well to integrated sources of nitrogen and biofertilizer-enriched compost. Similarly, citrus orchards benefit from AMF, PSB, and balanced micronutrient sprays to prevent chlorosis and improve fruit quality.

The benefits of INM are extensive, including improved soil fertility, higher nutrient-use efficiency, better fruit quality, reduced fertilizer cost, and environmental protection. However, widespread adoption is limited due to lack of awareness, inconsistent quality of biofertilizers, and labour requirements for composting and organic input application. Despite these challenges, INM remains crucial for sustainable fruit production, ensuring high yields, long-term soil health, and ecological balance. By integrating multiple nutrient sources, farmers can achieve profitable and environmentally friendly orchard management that supports productivity for future generations.

Objectives of Integrated Nutrient Management

1. To supply balanced nutrition for better growth, yield, and quality.
2. To maintain long-term soil fertility and productivity.
3. To reduce dependence on chemical fertilizers.
4. To improve soil biological health and organic carbon levels.
5. To enhance nutrient-use efficiency and reduce losses.
6. To promote eco-friendly and cost-effective fruit production.

Components of INM in Fruit Crops

1. Chemical Fertilizers: Chemical fertilizers provide readily available primary nutrients (N, P, K) required for rapid plant growth. In INM, fertilizers are used judiciously based on soil test values, crop requirement, and growth stage.

2. Organic Manures: Organic sources include:

a. Farmyard manure (FYM)
b. Compost
c. Vermicompost
d. Green manure
e. Oil cakes (neem, groundnut, mahua).

These materials improve soil physical structure, microbial activity, water-holding capacity, and nutrient availability.

3. Biofertilizers: Microbial inoculants help fix or solubilize nutrients naturally:

a. Azotobacter, Azospirillum – Nitrogen fixation
b. PSB (Phosphate-Solubilizing Bacteria) – Release bound phosphates
c. AMF (Arbuscular Mycorrhizal Fungi) – Enhance uptake of P, Zn, and water
d. Potassium-Solubilizing Bacteria (KSB) – Improve K availability

4. Crop Residue Recycling: Pruned branches, fallen leaves, and crop waste are decomposed into compost, reducing nutrient loss and enriching soil.

5. Mulching: Organic mulches (dry leaves, straw, sugarcane trash) help conserve moisture, suppress weeds, regulate temperature, and add nutrients during decomposition.

6. Foliar Nutrition: Foliar sprays of micronutrients like Zn, B, Fe, and Mn correct deficiencies quickly and improve fruit set, size, colour, and overall quality.

INM Practices for Major Fruit Crops

Mango:

a. 50% recommended NPK + 20–30 kg FYM/plant
b. PSB + Azotobacter + AMF
c. $ZnSO_4$ and Borax foliar sprays for better flowering and fruit quality.

Banana:

a. 50% nitrogen through urea + 50% through FYM/compost
b. Vermicompost @ 10–15 kg/plant
c. Biofertilizers: Azospirillum + PSB dips for suckers
d. Regular foliar sprays of micronutrients.

Citrus:

a. Split nitrogen applications for better nutrient uptake
b. Organic manure 20–25 kg/plant/year
c. AMF + PSB inoculation
d. Foliar Zn and Fe help prevent chlorosis.

Guava:

a. 50% chemical fertilizer + 20–25 kg FYM + 5 kg vermicompost
b. Biofertilizers improve fruit size, TSS, and yield.

Grapes:

a. Organic mulches to maintain soil moisture
b. Humic acid, compost, and biofertilizers for soil health
c. Balanced NPK essential for berry size and quality.

Benefits of INM in Fruit Crops

1. Improved Soil Fertility: Organic and biological inputs enhance soil structure, organic carbon, and microbial activity.

2. Higher Nutrient Use Efficiency: Integrated sources ensure slow and steady nutrient release, reducing losses through leaching or volatilization.

3. Enhanced Fruit Yield and Quality: Balanced nutrient supply improves fruit size, colour, flavour, aroma, firmness, and storage life.

4. Sustainability and Environmental Protection: Reduced chemical dependency lowers pollution and promotes eco-friendly farming.

5. Cost-Effectiveness: Use of on-farm resources such as compost and residues reduces input costs.

Challenges in Adopting INM

1. Lack of awareness about correct nutrient doses
2. Limited availability of quality biofertilizers
3. Higher labour requirement for composting and organic manure application
4. Need for regular soil and leaf nutrient analysis.

Conclusion

Integrated Nutrient Management is essential for sustainable fruit production in the modern era. By combining chemical fertilizers with organic and biological sources, farmers can achieve higher yields, superior fruit quality, and improved soil health. INM not only enhances nutrient-use efficiency but also supports long-term environmental sustainability. Promoting INM practices in fruit orchards is vital for maintaining productivity while conserving natural resources for future generations.

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Cryogenic Grinding: A Revolutionizing Technology for Spice Industry

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Introduction

Spices have played a central role in global cuisine, medicine, and trade for centuries. From the pungency of black pepper to the vibrant colour of turmeric and the delicate aroma of cardamom, spices are valued for their sensory properties, aroma, flavour, colour, and medicinal compounds. However, conventional grinding techniques often compromise these qualities. The intense heat generated during grinding leads to the loss of volatile oils, degradation of flavour components, reduction in essential oil concentration, and colour fading. As global demand rises for cleaner, more potent, and high-quality spices, the need for an advanced grinding technology becomes evident. This is where cryogenic grinding emerges as a ground breaking innovation.

Cryogenic grinding, also known as cryo-grinding, is a process in which spices are cooled to extremely low temperatures using liquid nitrogen (−196°C) before and during the grinding stage. By reducing the temperature of the raw materials, this method effectively controls heat generation and preserves all the essential characteristics that consumers desire.

The principle behind cryogenic grinding is simple: colder materials become brittle and break easily with minimal pressure. Without heat build-up, degradation of the spice's bioactive compounds is minimized. As a result, the ground product retains its natural aroma, robust flavour profile, nutritional properties, and vibrant colour.

Today, cryogenic grinding is being adopted in spice-processing industries worldwide as a premium technique to meet the increasing demand for high-quality spices in food, pharmaceuticals, nutraceuticals, and herbal products.

How Cryogenic Grinding Works?

1. Pre-cooling of spices: The raw spices—such as turmeric, coriander, cumin, chilly, pepper, or cardamom, are first introduced into a pre-cooling chamber. Liquid nitrogen is sprayed into this chamber, rapidly lowering the temperature of the material. The spices become brittle, eliminating the elastic and fibrous behaviour that normally makes grinding difficult.

2. Grinding at ultra-low temperatures: Once adequately cooled, the spices enter a high-speed mill or grinder. Because they are already brittle, they require less energy to break down. Moreover, the absence of heat prevents melting, clumping, and oil release, common issues in conventional grinding.

3. Separation and collection: The finely ground material is separated using a cyclone separator or sieves. Since cryogenic grinding yields uniform particle sizes, the product consistency is superior. The powder is then collected in insulated containers to avoid condensation.

4. Recycling of nitrogen (optional): In advanced setups, evaporated nitrogen is recycled to reduce operational costs and environmental impact.

Key Equipment in Cryogenic Grinding Systems

1. Liquid Nitrogen Storage Tank: Stores and supplies liquid nitrogen to the grinding system.

2. Cryogenic Feeder: Pre-cools the spices uniformly before grinding.

3. Pin Mill / Hammer Mill / Attrition Mill: Modified for low-temperature operation.

4. Vibratory Screener: Ensures uniform and fine powder consistency.

5. Cyclone Separator: Separates ground material from nitrogen vapor.

6. Control Panel: Monitors temperature, flow rate, and grinding parameters.

Why Temperature Control Matters?

During conventional grinding, temperatures easily exceed 90–100°C. At such high temperatures:

a. Volatile oils evaporate.
b. Essential flavour compounds degrade.
c. Colour pigments oxidize.
d. Powders become sticky due to oil exudation.

Cryogenic grinding maintains temperatures as low as −100°C or below, preventing these problems entirely and ensuring superior product quality.

Advantages of Cryogenic Grinding

1. Retention of aroma and flavour: As volatile oils are preserved and do not vaporize, spices maintain their original fragrance and taste. This results in a more authentic and intense flavour profile.

2. Higher yield and quality: Cryo-ground spices exhibit improved brightness, stronger aroma, and richer colour. They also have uniform particle sizes and a smoother texture.

3. Increased shelf life: Lower temperatures and minimized oxidation help reduce microbial load and retard spoilage, extending the shelf life of the spice powder.

4. Improved grinding efficiency: Brittle materials require less energy to grind, resulting in lower power consumption and faster processing.

5. Reduced loss of active ingredients: Medicinal and bioactive compounds such as curcumin (in turmeric) or capsaicin (in chilly) remain intact, making cryogenic grinding ideal for nutraceutical products.

6. No heat generation: Eliminating heat prevents melting, clumping, and machine blockages leading to smoother operations and reduced machinery wear.

Applications of Cryogenic Grinding

Cryogenic grinding is widely used across industries:

1. Spice and Herbal Processing (chilly, pepper, turmeric, clove, nutmeg, cinnamon)
2. Food and Beverage Industry (seasonings, flavourings, bakery additives)
3. Nutraceuticals and Ayurvedic Medicines
4. Pharmaceuticals (temperature-sensitive materials)
5. Plastics, Rubber, and Polymers (to achieve fine powders)
6. Aromatherapy and Essential Oils Production.

Economic and Industrial Significance

As global markets shift toward premium-quality, additive-free spices, manufacturers must adopt advanced technologies to stay competitive. Cryogenic grinding offers:

1. Value addition to conventional spice products
2. Better export quality meeting international standards
3. Sustainable and efficient processing
4. Brand differentiation based on superior flavour and purity

Although the initial investment is higher than traditional grinding systems, the long-term benefits higher yield, better quality, and increased consumer satisfaction justify the adoption of this innovative technology.

Conclusion

Cryogenic grinding has truly transformed the way spices are processed. By leveraging ultra-low temperatures, this technology protects the delicate characteristics that make spices valuable aroma, flavour, colour, and medicinal compounds. With rising consumer expectations for purity and quality, cryogenic grinding stands out as an innovative, efficient, and future-ready solution for the global spice grinding industry.

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India's Rising NCD Burden and the Role of the 2024 Dietary Guidelines

Article ID: 72521

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Abstract
NCDs now cause over 63% of deaths in India, with rising rates of diabetes, hypertension, and obesity driven by poor diets and lifestyle factors. The 2024 ICMR–NIN Dietary Guidelines respond to this challenge by recommending balanced intakes of cereals or millets, vegetables, fruits, proteins, nuts, oils, and dairy to improve nutrition and reduce disease risk. Linking current NCD trends with these updated guidelines highlights how healthier dietary habits can help curb India's growing NCD crisis. The Government of India's holistic NCD strategy integrates medical care, digital health systems and lifestyle-oriented national programmes across multiple ministries. This coordinated approach strengthens prevention, early detection, and long-term management of chronic diseases at the population level.

Keywords: Non-communicable diseases (NCDs); ICMR–NIN Dietary Guidelines 2024; Lifestyle and nutrition; India's NCD prevention strategy.

Introduction

India's Growing Non-Communicable Diseases Burden: India is witnessing a rapid shift from infectious diseases to lifestyle-related non-communicable diseases (NCDs), driven by major changes in diet, physical activity and urban living. Recent data from the NFHS-5 (2019–21) show a steady rise in key risk factors: overweight and obesity have increased in both men and women, hypertension affects nearly one-fourth of adults, and elevated blood-sugar levels are becoming increasingly common. In India, non-communicable diseases (NCDs) cause 63% of all deaths, according to WHO's 2018 - NCD India profile (Figure 1). Complementing this, the ICMR-INDIAB study (2023–24) provides the most accurate national estimates, revealing that India now has over 101 million people with diabetes, 136 million with prediabetes and more than one-third of adults with hypertension reflecting a sharp rise in metabolic disorders across all regions (Anjana *et al*., 2024). Lifestyle patterns captured in the National NCD Monitoring Survey (NNMS) further explain this growing burden: tobacco use remains high, alcohol consumption is rising, nearly half of adults engage in insufficient physical activity, and unhealthy diets contribute significantly to the disease load. Together, these datasets highlight how India's health landscape is undergoing a critical transformation, with NCDs emerging as a dominant challenge that demands urgent public-health attention.

2024 Dietary Guidelines: A Timely Response: The ICMR–NIN Dietary Guidelines 2024 represent a major update to the older 2011 recommendations, shaped by India's changing nutritional landscape and the growing burden of lifestyle diseases. The 2011 guidelines mainly aimed to ensure basic nutrient adequacy through a balanced mix of cereals, pulses, vegetables, fruits, and dairy. In contrast, the 2024 guidelines broaden this approach by stressing greater dietary diversity, improved food quality and healthier daily habits. They advise people to include a minimum of eight food groups every day, increase intake of vegetables, fruits, nuts, seeds, millets and whole grains and limit cereal-based calories to under 45%, signalling a move away from the earlier carbohydrate-heavy meal pattern. A striking addition is the strong warning against ultra-processed foods, high-sugar and high-salt items and unnecessary protein supplements, along with guidance on reading food labels. The new guidelines also integrate lifestyle elements such as regular physical activity, safe cooking practices, adequate hydration, and better food hygiene, making them more holistic than the previous version. Overall, while the basic food quantities remain comparable, the 2024 guidelines shift the focus from simply meeting calorie needs to achieving diets that are more varied, nutrient-rich, and supportive of long-term health.

The 2024 ICMR-NIN dietary guidelines suggest that an average adult with a daily energy requirement of 2,000 KCal should consume a balanced diet including 250 g of cereals or millets, 400 g of vegetables, 100 g of fruits, 85 g of pulses, eggs, or other protein sources, 35 g of nuts and seeds and 27 g of fats or oils, along with milk or curd. This combination is designed to provide adequate macronutrients, essential micronutrients, and dietary fiber, promoting overall health and reducing the risk of non-communicable diseases. A large portion of India's NCD burden is driven by poor dietary habits, and the 2024 guidelines help address this by offering practical, culturally relevant recommendations that support healthier eating and reduce long-term disease risk (Table 1).

Government Initiatives for Controlling and Preventing Non-Communicable Disease Through Different Ministries

The Government of India adopts a comprehensive, multi-dimensional strategy to curb NCDs by combining prevention, early detection and lifestyle improvement. Through the National Programme for Prevention and Control of Non-Communicable Diseases (NP-NCD) under the Ministry of Health & Family Welfare (MoHFW), efforts focus on widespread screening, timely diagnosis and strengthening NCD clinics. These clinical measures are supported by lifestyle and nutrition initiatives such as Fit India led by the Ministry of Youth Affairs & Sports, Eat Right India implemented by the Food Safety and Standards Authority of India (FSSAI) under the Ministry of Health & Family Welfare and POSHAN Abhiyaan driven by the Ministry of Women and Child Development (MWCD) to promote better nutrition. In addition, tobacco and alcohol control measures are enforced by MoHFW through programmes like the National Tobacco Control Programme. Digital tracking and continuity of care are enhanced through the Ayushman Bharat Digital Mission (ABDM) overseen by the Ministry of Health & Family Welfare. Together, these initiatives address behavioural risks, strengthen primary healthcare, and foster healthier environments, forming a holistic approach to reducing India's NCD burden.

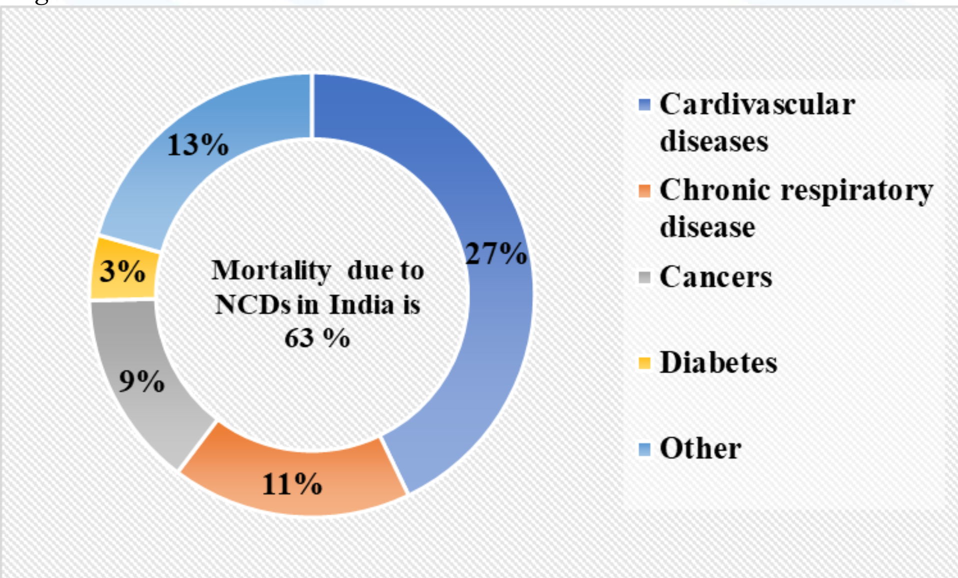

Fig 1. Mortality due to non-communicable disease in India (WHO 2018)

Table 1: Daily Food Group Requirements for a 2,000 kcal Diet as per ICMR–NIN (2024) Guidelines:

Food groups (2000 kcal)	Foods to be consumed raw weight (g/day)		% of energy from each food group/day		Total energy from each food group/day (Kcal)	
	Vegetarian	Non-Vegetarian	Vegetarian	Non-Vegetarian	Vegetarian	Non-Vegetarian
Cereals (including Millets)	250	260	42	45	843	876
Pulses	85	55	14	9	274	177
Chicken/meat	-	70	-	5	-	103

Milk/curd(ml)	300	300	11	11	216	216
Vegetables, Green leafy vegetables	400	400	9	8	174	184
Fruits	100	100	3	3	56	56
Nuts and seeds	35	30	9	11	181	155
Fats and oils	27	27	12	12	243	243
Total	1200	1242	-	-	2000	2000

Conclusion

India's rising NCD burden calls for strong preventive action, and the ICMR–NIN 2024 Dietary Guidelines offer a practical path toward healthier eating. By promoting balanced diets, portion control, and reduced intake of ultra-processed foods, these guidelines can significantly lower the risk of diabetes, hypertension, and obesity. Broader adoption through households, schools, and community programs can strengthen public health efforts, ease long-term healthcare costs, and help build a healthier, more resilient population. A multi-ministerial, preventive and system-strengthening model remains central to India's effort to curb rising NCDs. Sustained convergence, community participation, and digital health integration will be key to achieving long-term reductions in the national NCD burden.

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Evaluating the Effectiveness of Pre-examination Training for Limited Departmental Competitive Examination for the Post of UDCs in ICAR System

Article ID: 72522

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Abstract
The Limited Departmental Competitive Examination (LDCE) serves as an important avenue for Lower Division Clerks (LDCs) to advance to the post of Upper Division Clerk (UDC) within ICAR Headquarters and Institutes. Recognizing the need for professional growth and exam readiness, ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati, organized a structured pre-examination training program from 21st August to 6th September 2024. The course aimed to strengthen participants understanding of administrative and financial procedures, enhance their drafting and note-taking skills, and improve their conceptual clarity on ICAR rules and regulations. To evaluate the effectiveness of the training, pre- and post-assessment quizzes were given to 21 participants. The comparative analysis revealed a marked improvement in knowledge levels, validating the impact of the training intervention. Overall, the assessment demonstrated that a focused, interactive, and well-designed training module can significantly enhance the preparedness and confidence of LDCs aspiring to qualify for the UDC position.

Introduction
Lower Division Clerks (LDCs) are vital administrative personnel who ensure the smooth functioning of various sections across ICAR Headquarters and Institutes. Their responsibilities encompass maintaining section diaries, managing file movement registers, indexing, noting, typing, and drafting official communications. Recognizing their key role in supporting institutional administration, there is a growing emphasis on enhancing their efficiency, skill sets, and knowledge base. To facilitate career advancement and professional development, ICAR-NIASM, Baramati, initiated a Pre-examination Training for the Limited Departmental Competitive Examination (LDCE) for the post of Upper Division Clerk (UDC). This program was designed for LDCs who are eligible to appear for the LDCE and was conducted through an online mode to ensure wider participation. The 17-day training comprised around 10 interactive sessions, each of 75 minutes duration, covering both theoretical and practical aspects. Delivered by experienced master trainers and senior ICAR officers, the sessions blended lectures, case studies, and self-exploration exercises.

The training content was comprehensive, encompassing key topics such as General Awareness, English Comprehension and Writing Skills, Noting and Drafting, Office Procedures, Rules and Bye-laws of ICAR, Audit Manual, and Delegation of Powers. The overall goal was to equip participants with the competence and confidence necessary to excel in the departmental examination and strengthen their understanding of ICAR's administrative framework.

Assessment Approach
To measure the effectiveness of the pre-examination training, a quantitative assessment approach was adopted using before-and-after quiz tests. A total of 21 participants took part in both assessments, which were designed to evaluate their knowledge and conceptual understanding across the key subjects covered during the training. The pre-training test served as a baseline to gauge the existing level of understanding among participants. Following the training sessions, the post-training test was conducted to assess the extent of learning gains achieved. The difference between the pre- and post-test scores provided an objective measure of improvement. The analysis included statistical evaluations and visualizations such as histograms, bar plots, and box plots to compare score distributions and highlight the learning shift. A *paired t-test* was also applied to determine whether the observed improvement was statistically significant.

The results clearly indicated a considerable improvement in participants' scores, reflecting the training's effectiveness in bridging knowledge gaps and improving exam preparedness.

Results & Discussions

The analysis of pre- and post-training scores of 21 participants demonstrated a clear improvement in knowledge and skills relevant to administrative and financial management, essential for the LDCE for promotion from LDC to UDC. As shown in Figure 1, pre-training scores (green) were primarily concentrated between 5 and 15, whereas post-training scores (dark orange) shifted toward the 18-25 range. This rightward shift indicates enhanced performance, with more participants achieving higher scores after the training.

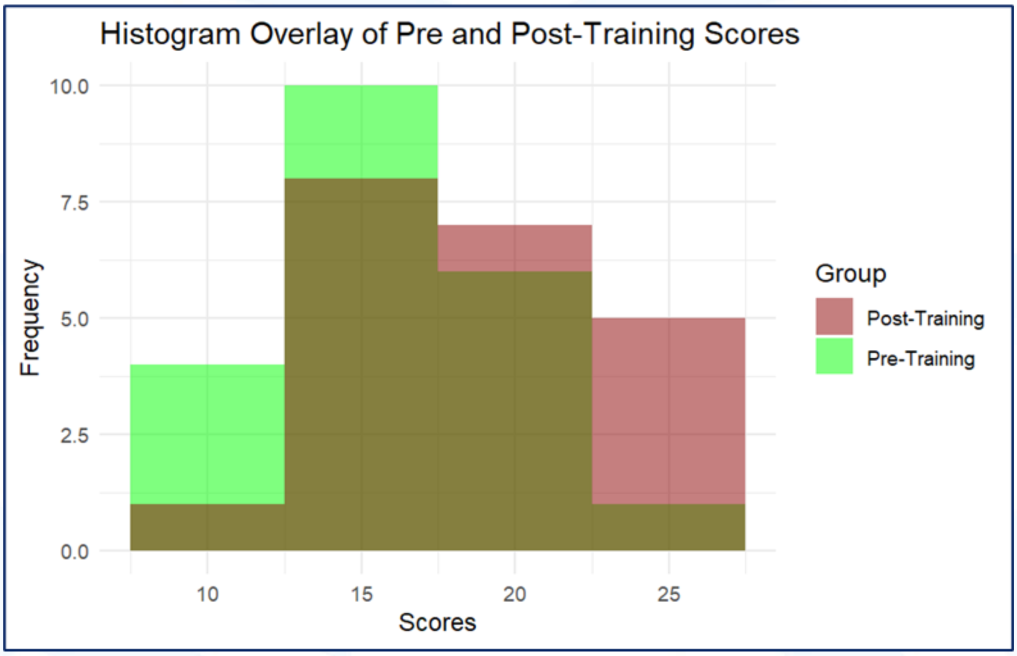

Figure 1: Histogram overlay plot

Figure 2 presents the gain percentages of individual participants. Most candidates exhibited positive gains, with several exceeding 20%, highlighting substantial learning progress. A few participants showed exceptionally high improvements, reflecting strong responsiveness, while some recorded modest gains, likely due to differences in prior knowledge or learning pace.

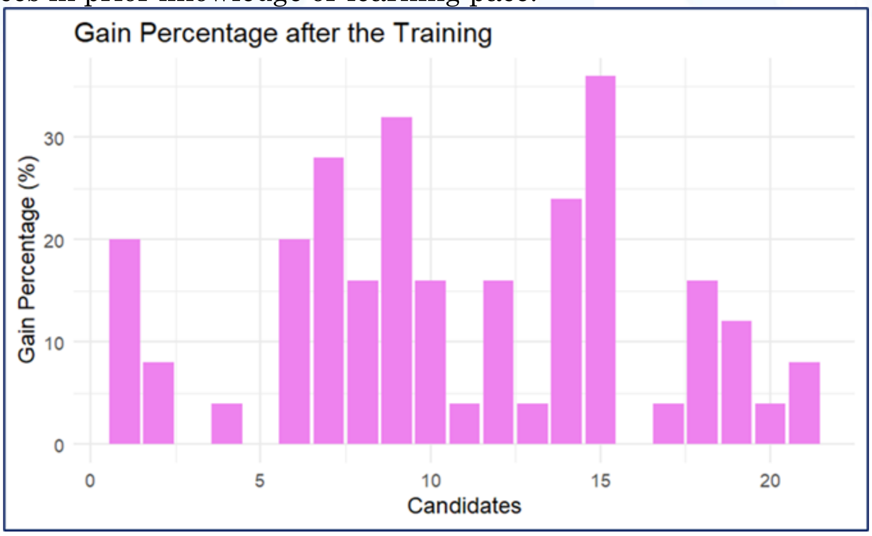

Figure 2: Gain percentage plot of candidates

The box plot and summary statistics (Figure 3) further illustrate the impact of the training. The mean score increased from 15.43 to 18.67, and the median from 14 to 18. The interquartile range (IQR) increased from 5 to 7 after the training, indicating a slight rise in score variation among participants. While most participants improved, the extent of their progress varied, showing that some gained more from the training than others.

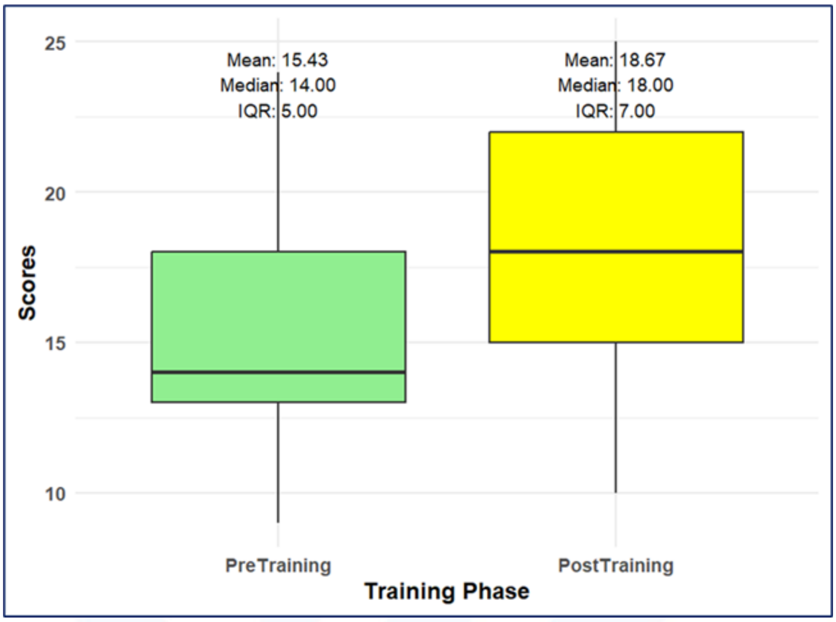

Figure 3: Box plot of distribution of scores before and after the training

A *paired t-test* confirmed a statistically significant improvement (t = -5.49, df = 20, $p < 0.05$), validating the training's effectiveness. Overall, the findings indicate that structured, interactive training programs can substantially enhance preparedness for the LDCE, supporting ICAR's objective of developing a competent and confident administrative workforce.

Conclusion

The pre-examination training program effectively enhanced the knowledge and confidence of LDCs aspiring for promotion to the UDC level. The pre- and post-assessment results demonstrated significant learning gains, validating the program's impact. This initiative underscores the importance of structured, data-driven training approaches in building a skilled and efficient administrative workforce aligned with ICAR's vision of continuous capacity development.

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Capacity Building Programme: Pre-examination Training for Limited Departmental Competitive Examination for the Post of UDCs in ICAR Headquarters & ICAR Institutes organized by ICAR-NIASM, Baramati, Pune, Maharashtra. (http://niam.res.in/training).

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Current Scenario of PADDY farming in Punjab

Article ID: 72523

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Introduction

Paddy (rice) is one of the most important crops cultivated in Punjab, playing a central role in the state's agriculture, economy, and food security. The favourable climate and widespread irrigation infrastructure have helped Punjab become one of the leading rice-producing states in India.

Why Punjab is Suitable for Paddy Cultivation?

Rice is a Kharif crop — sown during monsoon (June–July) and harvested around October–November.

Punjab's climate — warm temperatures and humidity along with good irrigation — supports paddy cultivation.

Historically, irrigated canal-command areas in Punjab made rice cultivation feasible, and over time many farmers adopted paddy cultivation in these regions.

Scale and Importance of Paddy in Punjab

In recent seasons, paddy (regular rice and basmati) was sown on about 32.44 lakh hectares in Punjab.

The state accounts for a significant share of India's rice output — in many years, Punjab contributes roughly 10–13% of the country's rice production.

Paddy (rice) remains among the top crops in Punjab, alongside wheat, and plays a major role in the country's food reserves and food security.

Varieties of Paddy Grown in Punjab

Punjab grows various improved and traditional rice varieties suited to local conditions.

Challenges and Concerns

While paddy cultivation has driven prosperity, there are mounting challenges:

1. Over-extension of Paddy Area: Although a large area (over 32 lakh hectares) is under rice cultivation, studies show only about 30% of Punjab's total geographical area is truly suitable for intensive crops like rice.

2. Water Stress & Groundwater Depletion: Rice is water-intensive. Continuous paddy cultivation — especially over large areas — has contributed to severe groundwater depletion in many parts of Punjab.

3. Declining Productivity Paradox: Despite more land under paddy, overall yield gains have been modest or stagnant in some years.

4. Vulnerability to Climate & Weather: Rice yields are sensitive to rainfall patterns, floods, and sudden weather changes. For example, excessive rains/floods can damage the crop at harvest time.

Recent Trends & Government Response

The state has been promoting crop diversification — encouraging farmers to grow alternatives to paddy/wheat to reduce pressure on water, soil and environment. Mongabay-India+1

Use of more water-efficient or shorter-duration paddy varieties like PR-

126 has been encouraged to reduce water and time requirements. ResearchGate+1

Emphasis on sustainable agriculture practices including proper water- management, soil health, crop rotation — to ensure long-term productivity.

Conclusion

Paddy cultivation remains deeply woven into the agricultural and socio- economic fabric of Punjab. It has helped make Punjab one of India's top rice producers, ensured food security, and supported farmers' livelihoods.

However, environmental concerns like groundwater depletion, soil degradation, and changing climate — along with the limitations of land suitability — pose serious challenges.

For long-term sustainability, it is important to strike a balance: adopt water- saving techniques, diversify crops, use suitable varieties, and follow sustainable farming practices.

Strategies for Freshwater Aquaculture that Enhance Climate-Resilient Pond Management

Article ID: 72524

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Abstact
Climate variability presents substantial risks to pond-based aquaculture due to extreme temperatures, erratic rainfall, water shortages, and heightened disease occurrences. Small-scale farmers utilizing low-control production systems are especially at risk. This paper integrates climate-resilient pond management strategies based on hydrological planning, water-quality stabilization, adaptive feeding, and risk-prediction methods, offering practical solutions that improve system stability and decrease mortality caused by climate change.

Introduction
Freshwater aquaculture ponds operate as open ecological systems considerably affected by external climatic elements. Increasing temperatures, unpredictable rainfall patterns, and extended dry periods affect pond water quality and fish well-being (De Silva & Soto, 2009). Creating strategies for climate-resilient management is crucial for maintaining productivity and safeguarding farmer livelihoods, particularly in tropical and subtropical areas.

Climate Stressors Affecting Aquaculture Ponds
Extreme temperatures decrease dissolved oxygen (DO), increase ammonia toxicity, and hinder immune response in cultured species (Boyd & Tucker, 2014). Uneven precipitation changes pH, alkalinity, and salinity, while runoff boosts pathogen and nutrient levels (FAO, 2022). During dry seasons, water scarcity intensifies metabolite concentration, leading to heightened physiological stress (Ahmed & Diana, 2020).

Climate-Resilient Pond Management Strategies
1. Hydrological and Water-Storage Interventions: Increasing Pond depth to 1.5–2.0 m enhances thermal buffering and reduces evaporation losses (Boyd & McNevin, 2015). Rainwater harvesting structures and farm reservoirs provide supplementary water during droughts, enabling stable water levels throughout culture cycles (Islam et al., 2019).

2. Water-Quality Stabilization Measures: Maintaining alkalinity between 80–120 mg/L $CaCO_3$ through liming minimizes pH fluctuations after heavy rainfall (Boyd & Tucker, 2014). Strategic aeration—especially pre-dawn—mitigates DO depletion during heatwaves (Rahman et al., 2021). Vegetative buffer strips and silt traps reduce nutrient-rich runoff and prevent harmful algal blooms.

3. Climate-Adaptive Stocking and Feeding: Dynamic feeding adjustments during thermal stress prevent ammonia accumulation and reduce metabolic strain (Ahmed & Diana, 2020). Lower stocking densities improve resilience when temperatures exceed tolerance thresholds. Use of tolerant species and locally adapted strains enhances survival under fluctuating environmental conditions (FAO, 2022).

4. Infrastructure Hardening and Emergency Preparedness: Reinforced embankments, functional drainage structures, and backup aeration systems reduce vulnerability to flood-induced pond breaches and power outages (Boyd & McNevin, 2015). Solar-powered aerators provide reliable oxygenation during grid failures.

5. Early Warning and Monitoring Systems: Low-cost DO and temperature sensors allow farmers to anticipate threshold-level changes and act before stress becomes lethal. Integration of weather forecasts with farm-level data supports proactive responses to heatwaves and heavy rainfall events (Rahman et al., 2021).

Conclusion

Climate-resilient pond management requires a combination of hydrological planning, water-quality stabilization, adaptive stocking strategies, and predictive monitoring tools. Implementing these interventions significantly reduces climate-driven mortality and enhances long-term sustainability in small-scale aquaculture systems.

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Smart Ponds: The Promise, Reality, and Why Most Farmers Aren't There Yet

Article ID: 72525

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Abstact

Many people believe that innovative pond technologies, which combine Internet of Things (IoT)-based sensors, automated aeration, and AI-driven decision-making tools, are future of aquaculture. However, there is still minimal adoption among small and medium-sized farmers. This article examines what a fully automated "smart pond" truly requires, why field-level deployment often fails, and the real-world obstacles that prevent most farmers from adopting it today. Unreliable low-cost sensors, high system costs compared to farmer profit margins, inadequate power and internet infrastructure, and AI algorithms that don't work well in unpredictable pond environments are some of the main obstacles. Instead of complete automation, the analysis emphasizes the need for robust, reasonably priced hardware, offline-capable systems, and incremental adoption strategies.

Introduction

Innovative pond systems are often marketed as the next significant step in aquaculture modernization due to their continuous IoT monitoring, automated responses, and AI-driven management. Theoretically, these systems optimize feeding, lower mortality, stabilize production under climate stress, and enhance dissolved oxygen (DO) management (Badiola et al., 2018). However, adoption is still low in reality, particularly among small and medium-sized farmers in developing nations.

What a Fully Automated Smart Pond Requires?

A real smart pond combines several elements:
1. IoT sensors for temperature, pH, turbidity, ammonia, and DO;
2. Automated aeration control based on current DO levels
3. AI-driven feeding optimization systems;
4. Real-time farm analytics dashboards; and
5. Disease and water quality prediction models

According to research, when hardware is reliable, these integrated systems can stabilize production and reduce losses (Avril et al., 2021). However, most field systems fall short in terms of reliability.

Why Smart Ponds Rarely Work in Real Farming Conditions?

1. Sensor Reliability Issues: Low-cost sensors used on rural farms suffer from drift, corrosion, and calibration loss, resulting in inaccurate readings (Pillay & Kutty, 2005). A single wrong DO number might cause aeration failures, killing an entire crop.

2. High cost compared to the farmer's profit: According to studies, the ordinary Indian freshwater pond farmer runs on razor-thin margins, making multi-sensor IoT systems economically unfeasible (Ramudu & Mallikarjuna, 2020).

3. Reliance on the Internet and Stable Power: IoT devices require consistent connectivity to transmit; however, rural aquaculture areas often experience inconsistent connectivity.

4. AI Models are Poorly Trained on Real Farm Data: Most artificial intelligence tools are trained on controlled research farms rather than unpredictable monsoon-driven ponds. As a result, when used in real-world scenarios, prediction accuracy suffers dramatically (Zhang et al., 2020).

5. Complexity Beyond Farmer Capacity: Small-scale aquaculture farmers often have limited digital literacy, which hinders their ability to utilize dashboards and effectively interpret model outputs.

What Must Change for Smart Ponds to Become Practical?

Farmers require strong, inexpensive, low-maintenance solutions rather than expensive lab-grade technologies to achieve widespread adoption. The key requirements include:

1. Rugged field-ready sensors that require minimal calibration
2. Offline-capable systems that can function without network connectivity.
3. Farm-specific AI models are trained on real pond variability.
4. Before proceeding to complete automation, consider incremental adoption pathways, such as a single DO sensor and an automatic aerator.
5. When deployed incrementally, these technologies can reduce mortality and increase yields without needing significant expenditure (Avril et al., 2021).

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Carbon Footprint in Fisheries and its Importance for a Sustainable Blue Future

Article ID: 72526

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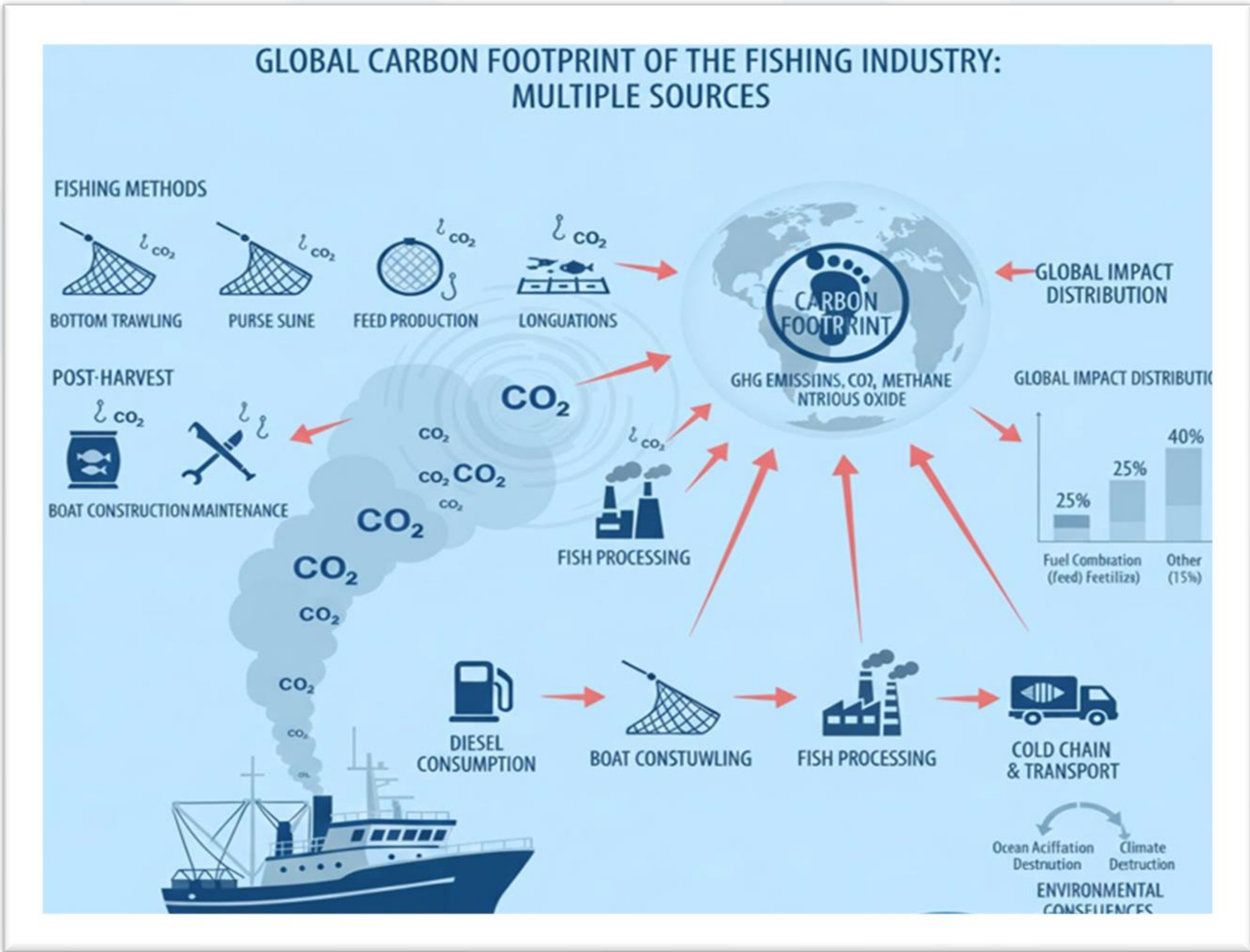
Abstact

Fisheries play a crucial role in providing food and supporting livelihoods, yet they contribute significantly to carbon emissions, primarily due to fuel consumption, energy-heavy processing, and long-distance transportation. Practices that result in high emissions, outdated fishing vessels, and dwindling fish stocks exacerbate the industry's carbon footprint, while climate change further affects fish availability and increases fishing expenses. This article examines the sources and effects of carbon emissions in the fishing industry and proposes solutions such as adopting fuel-efficient technologies, using low-impact fishing gear, harnessing renewable energy, improving post-harvest management, and conserving blue carbon ecosystems. Cutting emissions is essential for achieving sustainable and climate-resilient fisheries.



Carbon Footprint in Fisheries: Moving Toward Climate-Smart Harvesting

The fishing industry plays a vital role in supporting millions of jobs and is a key contributor to global food security. However, the seafood we enjoy, rich in protein, also raises a significant environmental issue: the carbon emissions from fisheries. As climate change becomes more severe, it is essential to understand and reduce the greenhouse gas emissions linked to fishing to ensure the long-term sustainability of marine resources and the well-being of coastal communities.

What is the Carbon Footprint in Fisheries?

The carbon footprint encompasses the total amount of greenhouse gases emitted into the atmosphere as a result of human activities. In the fisheries industry, this footprint is influenced by several stages, including fishing operations, the production of gear, cold-chain management, processing, packaging, and transportation. Among these, the fuel consumed by fishing vessels is the most significant factor, often representing over 70% of the total emissions. Modern fisheries have become more energy-demanding, with large engines, long-distance voyages, deeper fishing areas, and more powerful equipment leading many fleets to use substantial amounts of diesel. Even after the fish are caught, the energy required for ice production, freezing, and transportation further contributes to the overall carbon emissions.

Why Fisheries Produce High Emissions?

Fishing is often viewed as a more sustainable protein source than livestock farming, but emissions vary greatly across fishing methods. Trawlers, which drag heavy nets along the seabed, use substantial fuel due to the resistance created by the gear. As coastal stocks become depleted, vessels venture farther offshore and spend longer at sea, driving up fuel use. Many fishing communities also operate older engines and outdated gears, which are less fuel-efficient. The post-harvest sector further increases the footprint. Cold storage, processing units, and ice plants rely heavily on electricity, which in many regions is generated from fossil fuels. The trend of exporting seafood over long distances adds to transportation-related emissions. Small-scale artisanal fisheries tend to have the lowest carbon footprint because they operate close to shore, often use passive gears, and consume less fuel. Their low-emission nature shows that sustainability and livelihoods can coexist when practices are rooted in efficiency and ecological balance.

Impacts of Carbon Footprint on Fisheries

Fisheries contribute significantly to high carbon emissions, which exacerbate global climate change and, in turn, impact marine ecosystems. As ocean temperatures rise, fish species are often forced to migrate to cooler waters. Acidification poses a threat to shellfish and destabilizes entire food webs. Additionally, extreme weather events can disrupt fishing schedules and heighten safety risks at sea. Economically, fuel represents one of the largest expenses in fishing operations. When fuel consumption increases or prices rise, the profit margins for fishers, particularly those operating on a small scale, can decrease significantly. On the market front, there is an increasing demand for seafood that is low in carbon emissions and carries eco-labels. Fisheries that do not adopt sustainable practices may find themselves excluded from premium global markets. Therefore, reducing the carbon footprint is not only an environmental necessity but also a means to enhance livelihoods and ensure the long-term viability of the fisheries sector.

How Fisheries can Reduce their Carbon Footprint?

Although there are obstacles, fisheries have significant potential to transition to low-carbon practices.

1. Enhance fuel efficiency: Significantly reducing fuel consumption can be achieved by upgrading engines, maintaining hulls and propellers, and optimizing fishing routes. Additionally, lightweight boat designs and modern navigation tools can decrease the time spent searching for fish.

2. Embrace low-impact fishing gear: Switching from high-drag equipment like bottom trawls to more efficient techniques such as purse seining, hook-and-line, traps, and gillnets can lower energy requirements. Modifying gear, like using improved trawl doors or high-efficiency nets, also helps reduce fuel usage.

3. Encourage renewable energy: Cleaner options for vessels include solar-powered lights, hybrid engines, and battery-assisted systems. Onshore, solar-powered ice plants, cold storage, and processing units further decrease dependence on fossil fuels.

4. Enhance post-harvest systems: Using energy-efficient refrigeration, insulated storage boxes, and improved cold-chain management can minimize waste and reduce electricity consumption. Preventing spoilage also decreases indirect emissions from discarded fish.

5. Bolster fisheries management: Healthy fish stocks lead to more efficient fishing. Implementing measures such as seasonal closures, regulated fishing efforts, marine protected areas, and community-based monitoring helps maintain stock levels. When fish are plentiful and easy to find, vessels spend less time at sea and use less fuel.

6. Safeguard blue carbon ecosystems: Mangroves, seagrasses, and salt marshes are effective natural carbon sinks. These ecosystems not only capture atmospheric carbon but also provide nursery grounds for commercially important fish. Restoring and protecting them aids both climate mitigation and fisheries productivity.

Toward a Low-Carbon Blue Economy

Minimizing the carbon emissions of fisheries is crucial for fostering a climate-resilient blue economy. This approach promotes healthier marine environments, reduces expenses for fishermen, enhances access to markets for eco-friendly seafood, and sustains the livelihoods of countless individuals reliant on ocean resources. Achieving a climate-smart fisheries sector is not a far-off aspiration but a feasible goal. By implementing efficient fishing methods, embracing renewable energy, enacting robust policies, and encouraging community involvement, the fisheries industry can greatly diminish its carbon emissions while continuing to provide sustainable nourishment globally.

Conclusion

Minimizing the carbon footprint in the fishing industry is crucial for safeguarding marine environments, boosting economic stability, and ensuring the sustainability of seafood supplies. By implementing fuel-saving technologies, using fishing gear with minimal environmental impact, adopting renewable energy solutions, and enforcing effective fisheries management, the industry can greatly reduce emissions while increasing efficiency. Protecting blue carbon ecosystems further bolsters climate mitigation strategies. Transitioning to a low-carbon, climate-smart fishing sector is both feasible and essential for securing the future of coastal populations and global food security.

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Carbon Sequestration in Fisheries as Nature's Hidden Climate Solution

Article ID: 72527

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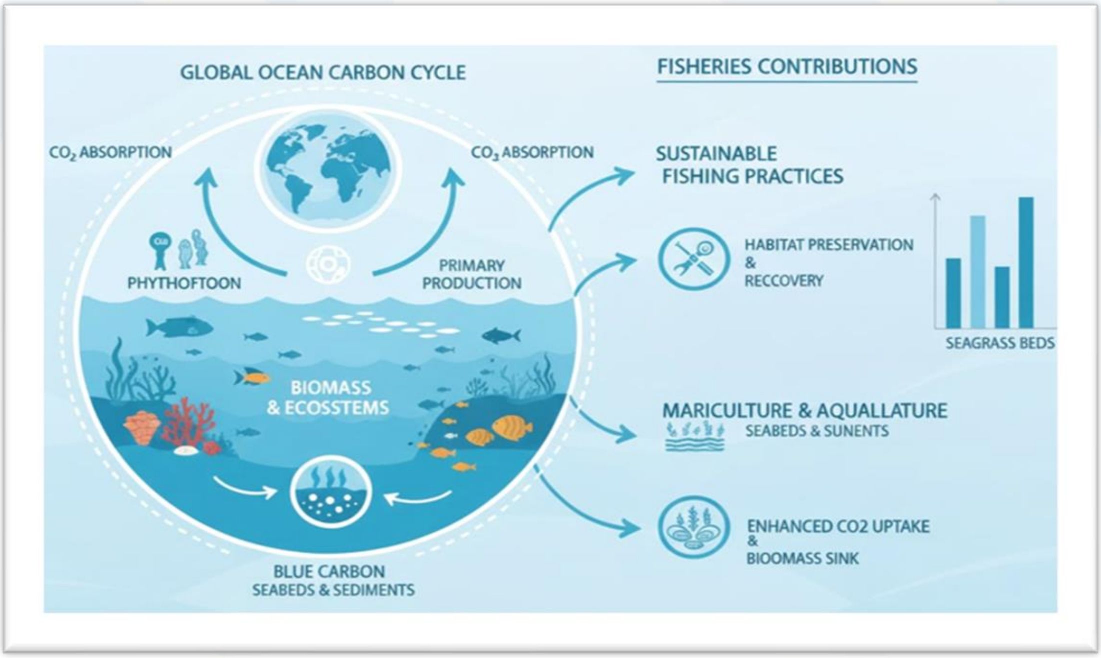
Abstact

Carbon sequestration in fisheries involves the natural mechanisms by which marine life and coastal habitats capture and store carbon, thereby aiding in the reduction of atmospheric greenhouse gases. This article delves into the role of fisheries in carbon storage through blue carbon ecosystems—such as mangroves, seagrasses, and salt marshes—as well as through marine biomass including fish, shellfish, and plankton. It also emphasizes how sustainable fisheries management, habitat restoration, and conservation efforts boost carbon sequestration while promoting biodiversity and supporting livelihoods. Enhancing carbon sequestration in fisheries offers a significant opportunity for climate mitigation and fostering a more resilient blue economy.



Introduction

The fisheries industry is well-known for its contribution to global food security, livelihoods, and nutritional requirements. Yet, aside from catching fish and supporting coastal populations, fisheries also have a crucial but less recognized role in carbon sequestration, which involves the long-term capture and storage of atmospheric carbon dioxide (CO_2). As climate change effects become more pronounced, it is increasingly important to understand how marine ecosystems and fisheries contribute to carbon sequestration. Oceans absorb about 30% of the world's CO_2 emissions, positioning them as one of the largest carbon sinks on

Earth. Through their ecosystems and biological activities, fisheries significantly boost this natural carbon storage capability. This presents a unique opportunity: fisheries can not only supply food but also aid in the fight against climate change.

What is Carbon Sequestration in Fisheries?

In fisheries, carbon sequestration refers to the biological and ecological mechanisms that capture carbon in marine vegetation, sediments, and living organisms. This process occurs through two primary pathways:

1. Blue Carbon Ecosystems: These coastal ecosystems rank among the most effective natural carbon sinks globally:

- **a. Mangroves**
- **b. Seagrass meadows**
- **c. Salt marshes**

They store carbon in both vegetation and deep sediment layers, where it can stay trapped for centuries.

2. Marine Organisms and the Biological Pump: During their growth, fish, shellfish, plankton, and other marine organisms take in carbon. Upon their death, a portion of this organic matter descends to the ocean floor, effectively sequestering carbon in the deep-sea sediments through a mechanism called the biological carbon pump. Fisheries influence these processes in various ways. Maintaining robust fish populations, safeguarding coastal ecosystems, and ensuring balanced marine food chains all play a role in enhancing carbon sequestration.

Blue Carbon Ecosystems: The Heart of Marine Carbon Storage

Blue carbon ecosystems serve as the most vital connection between fisheries and carbon storage. They offer essential nursery environments for fish, help stabilize shorelines, and hold vast quantities of carbon.

1. Mangroves: Per hectare, mangroves can sequester up to ten times more carbon than land-based forests. Their thick root networks capture carbon-rich sediments and organic material.

Benefits for fisheries:

- a. Serve as breeding and nursery habitats for shrimp, crabs, and finfish Help prevent coastal erosion,
- b. Enhancing fishing stability
- c. Provide defence against storms and rising sea levels.

2. Seagrass Meadows: Seagrasses absorb carbon dioxide through the process of photosynthesis and store it in the sediment. These underwater fields are vital habitats for economically significant species like seahorses, young fish, and shellfish.

3. Salt Marshes: Salt marshes capture carbon by means of plant roots and the organic material that gets buried. They also provide habitat for shellfish and small fish species that are vital to coastal fisheries. These ecosystems collectively serve as the backbone of coastal fisheries and play a significant role in carbon storage.

Marine Organisms as Carbon Carriers

Marine organisms themselves act as carbon reservoirs:

1. Fish Biomass: As fish mature, they accumulate carbon within their bodies. Upon their natural death, a significant portion of this carbon descends to the ocean's deeper layers.

2. Shellfish and Corals: Their shells and skeletons, composed of calcium carbonate, capture inorganic carbon. As these structures descend to the ocean floor, they play a role in the long-term sequestration of carbon.

3. Plankton: Plankton are the unsung heroes of carbon sequestration. Through the biological pump: During photosynthesis, phytoplankton take in CO_2. Zooplankton feed on phytoplankton, transferring carbon through the food chain. The remains of deceased organisms and fecal matter descend to the ocean's depths.

This process stores gigatons of carbon each year.

Human Activities that Influence Carbon Sequestration

The impact of fisheries on marine carbon sinks can be either positive or negative, depending on how they are managed.

1. Activities That Reduce Carbon Sequestration:

a. The destruction of mangroves for aquaculture or coastal development
b. The disruption of seabed carbon reserves due to bottom trawling
c. The imbalance in marine food chains caused by overfishing
d. The detrimental effects of pollution and eutrophication on the productivity of seagrass and plankton.

These activities not only reduce carbon storage but also weaken fisheries' resilience.

3. Activities That Enhance Carbon Sequestration:

a. Restoring mangroves, seagrasses, and salt marshes
b. Avoiding harmful fishing equipment Safeguarding breeding and juvenile habitats
c. Managing fisheries sustainably and rebuilding fish stocks
d. Establishing marine protected areas (MPAs).

How Fisheries can Boost Carbon Sequestration

1. Restore Blue Carbon Habitats: Restoring degraded mangroves and seagrass meadows improves:

a. Carbon storage
b. Fish nursery habitats
c. Water quality

2. Promote Low-Impact Fishing: Minimizing disruption to the seabed helps maintain carbon storage. Employing traps, longlines, and gillnets lessens the destruction of habitats.

3. Implement Climate-Smart Aquaculture: Practices in sustainable aquaculture, like seaweed cultivation and integrated multi-trophic aquaculture, boost carbon sequestration while also generating income.

4. Protect Marine Food Webs: Restoring fish populations enhances the biological pump. An increase in fish numbers results in greater carbon sequestration within their biomass.

5. Engage Communities in Carbon Projects: Coastal communities can participate in:

a. Carbon credit initiatives focused on blue carbon
b. Carbon financing through mangrove ecosystems
c. Sustainable fishing collectives

This creates incentives to protect natural carbon sinks.

Toward a Climate-Resilient Blue Economy

With global warming posing a threat to marine ecosystems, boosting the natural ability of fisheries to store carbon becomes an essential climate action. By safeguarding ecosystems and implementing sustainable methods, fisheries can both support economic livelihoods and help lower CO_2 levels in the atmosphere.

Carbon sequestration offers a powerful pathway to:

a. Enhance climate adaptability
b. Support ecological diversity
c. Boost fishery yields
d. Create additional revenue through carbon trading.

Conclusion

Fisheries play a crucial role in addressing climate change through carbon sequestration, a natural solution. By utilizing blue carbon ecosystems, marine life, and the biological pump, fisheries contribute to capturing and storing significant amounts of carbon. Safeguarding mangroves, seagrasses, salt marshes, and marine food webs not only boosts carbon storage but also promotes sustainable fisheries and thriving coastal communities. By combining conservation efforts, responsible fishing, and climate-smart strategies, the fisheries industry can progress towards a resilient, low-carbon future that benefits both humanity and the environment.

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Wealth out of Waste: Unlocking the Potential of Transglutaminases from Fish Waste for Food Applications

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Abstact

The fish industry produces not only valuable products like fresh fish, oils, meal, and skincare ingredients but also a large volume of waste. Instead of allowing these by-products to accumulate, they can be transformed into something useful. One promising approach is the extraction of transglutaminase, an enzyme naturally present in fish tissues. This enzyme plays a vital role in improving the quality, texture, and stability of various food products. By extracting transglutaminase from fish waste, we can reduce environmental impact, support sustainable processing, and create value-added products by utilizing it in the food industry and they can also be used as feed. This article explores the significance of transglutaminase, its extraction from fish waste, and its growing applications in the food industry, along with the challenges and opportunities involved.

Introduction

The fish industry is one of the fastest-growing sectors in the global food system. Every day, large quantities of fish are processed into food, health supplements, cosmetics and agricultural products. Alongside these valuable commodities comes an equally large amount of waste: heads, skin, bones, viscera and other leftover parts. If not managed properly, this waste can become an environmental burden. However, these discarded materials hold immense potential. Fish waste is rich in proteins, enzymes, oils, and minerals that can be converted into meaningful products. One such enzyme is transglutaminase, widely used in the food industry for its ability to improve texture, enhance stability, and increase the shelf life of many foods. Instead of being thrown away, fish waste can become a sustainable source of this enzyme. This creates a win–win situation: reducing environmental impact while adding economic value to the industry and we could build circular economy by implementing this solution.

Transglutaminase: A Valuable Enzyme Hidden in Fish Waste

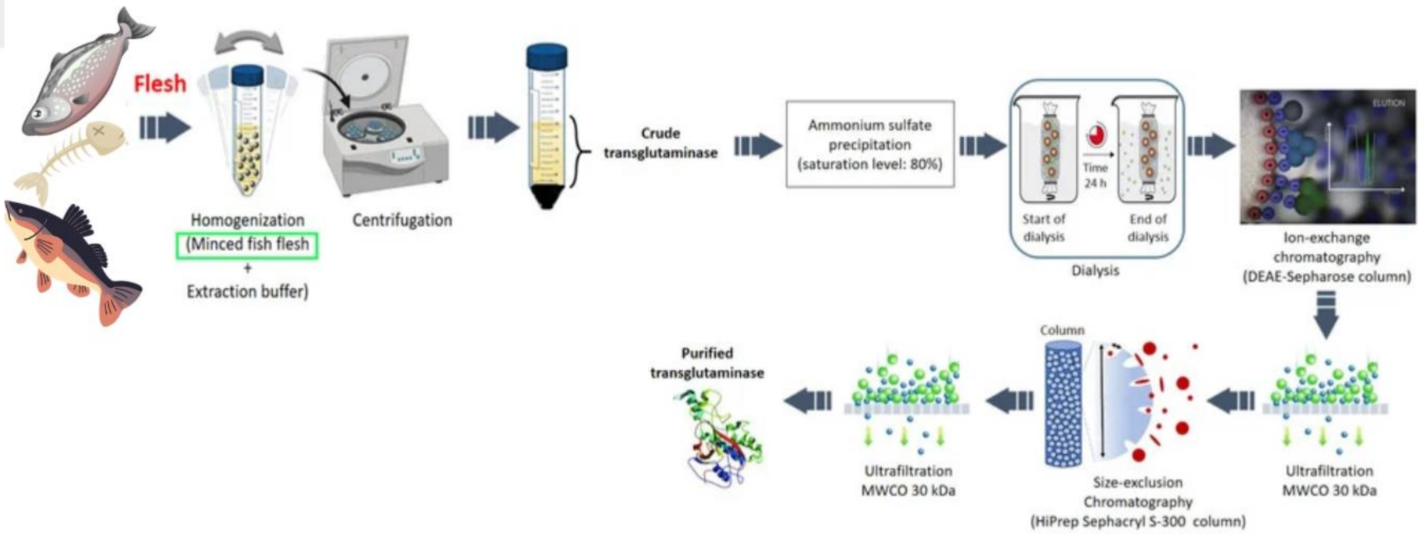
1. Abundant Raw Material: Fish processing generates a large amount of residue namely, heads, tails, frames and internal organs. These tissues naturally contain transglutaminase, making them a promising and low-cost source for enzyme extraction.

2. Sustainable Waste Utilization: Recovering enzymes from waste supports eco-friendly practices. It reduces the pressure on the environment, lowers disposal costs and moves the industry toward a circular economy. Instead of being thrown away, these materials become valuable resources.

3. Extraction and Purification: The Concept: Extracting transglutaminase from fish waste involves:

a. Breaking down the tissues to release enzymes
b. Separating solids from the liquid extract
c. Concentrating the enzyme
d. Purifying it through modern methods such as ultrafiltration or chromatography.

Although the procedure is technical, the principle is simple: recover the enzyme, clean it and prepare it for use in food applications.



Applications of Transglutaminase in the Food Industry

1. Improved Meat Texture: Transglutaminase helps bind proteins together. This gives meat products better firmness, elasticity and sliceability. It is especially useful in processed meat, sausages and seafood products.

2. Better Dough Quality: In bread and bakery items, the enzyme strengthens the gluten network, improving dough elasticity and final bread volume. It also helps overcome weaknesses in low-quality wheat flour.

3. Enhanced Dairy Products: In cheese and yogurt manufacturing, transglutaminase improves gel structure, increases yield, and enhances creaminess in both full-fat and low-fat varieties.

4. Nutritional and Shelf-Life Benefits: By modifying protein structures, the enzyme helps food retain moisture, maintain texture and resist spoilage for a longer time. This leads to fresher, more appealing products with enhanced nutritional value.

How the Enzyme Works?

Transglutaminase catalyzes the formation of strong bonds between protein molecules, particularly between glutamine and lysine. This natural "protein cross-linking" is what gives foods their improved structure and stability.

Why This Matters: The Marine Shelf-Life Challenge

Marine products are extremely perishable. They spoil due to:

1. Rapid microbial growth
2. Enzymatic breakdown of proteins and fats
3. Oxidation of unsaturated fatty acids
4. Drip loss and texture degradation
5. Poor temperature or packaging control.

Transglutaminase, integrated into processing, can help improve product firmness, retain moisture, and reduce waste caused by spoilage ultimately enhancing shelf life in a natural way.

Challenges in Using Fish Waste for Transglutaminase Extraction

1. Variation in Raw Material: Fish waste differs from species to species and even from batch to batch. This makes it difficult to maintain consistent enzyme yield and quality.

2. Sensitivity of the Enzyme: Transglutaminase is sensitive to pH, temperature, and handling conditions. Special care is required to maintain its activity.

3. Complexity of Purification: Fish waste contains many biological substances. Removing unwanted protein and contaminants requires careful purification to produce food-grade quality.

4. Cost of Scaling Up: Moving from laboratory extraction to industrial production involves investments in equipment, skilled labour and energy.

5. Consumer Perception: Some consumers may feel hesitant about enzymes derived from waste unless properly informed about safety and sustainability benefits.

6. Regulatory Requirements: Food-grade enzymes must meet strict quality and safety guidelines, which can add complexity to the process.

Conclusion

Extracting transglutaminase from fish waste offers a promising solution for sustainable resource use in the seafood industry. It transforms what is often discarded into a high-value product with major benefits for food texture, stability, nutrition and shelf life. While challenges exist such as consistency, processing cost and regulatory compliance ongoing research and technological improvements continue to strengthen the feasibility of this approach. By embracing this concept, the seafood industry can reduce environmental burden, increase profitability and contribute to a circular economy where nothing goes to waste. The future of fish processing may very well depend on such innovative, eco-conscious solutions.

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Value Addition in Cumin: Importance, Methods, and Emerging Prospects

Article ID: 72529

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Introduction

Cumin (*Cuminum cyminum*) is a highly significant spice in India, serving as a key ingredient in household cooking, food processing, herbal medicine, cosmetics, and international trade. India is the world's leading producer and exporter of cumin, with Rajasthan contributing the largest share of production. In recent years, value addition has emerged as a major pathway to improve profitability, enhance product quality, and secure better access to national and global markets. By processing cumin into different high-value products, farmers and entrepreneurs can greatly improve their income and reduce dependence on fluctuating raw seed prices.

Importance of Value Addition

1. Reduces Market Volatility: Raw cumin prices often vary widely due to seasonal and climatic factors. Value-added products retain more stable prices, offering economic security.

2. Enhances Profit Margins: Converting raw cumin into graded seeds, roasted cumin, powders, oils, and blended products significantly increases its market value.

3. Higher Global Demand: International buyers prefer standardized, hygienically processed, and branded products. Demand for cumin-based functional foods and organic spices is consistently rising.

4. Boosts Rural Employment: Small processing units, packaging centers, and marketing activities generate extensive livelihood opportunities, particularly for rural youth and women.

Major Value-Added Products of Cumin

1. Cumin Powder: Prepared through efficient cleaning, controlled roasting, and fine grinding. Widely used in culinary preparations, processed foods, and restaurant chains.

2. Cumin Essential Oil and Oleoresin: Extracted using steam distillation techniques. These concentrated products are employed in pharmaceuticals, aromatherapy, flavor industries, and natural cosmetics.

3. Branded and Packaged Whole Cumin: Clean, uniform seeds packed in attractive retail packs increase consumer trust and ensure premium pricing.

4. Herbal and Ayurvedic Preparations: Products like digestive mixtures, herbal teas, immunity blends, and cumin–ajwain powders have growing popularity in the wellness sector.

5. Roasted Cumin: Light roasting enhances aroma and stability. It is widely used in beverages, dairy products, snacks, and seasoning mixes.

6. Instant Cumin Mixes and Masala Combinations: Includes cumin-flavored drink mixes, spice blends, flavored water formulations, and ready-to-use masala kits.

Key Processes in Cumin Value Addition

1. Cleaning and Grading: Removal of dust, stones, immature seeds, and other contaminants. Upgraded quality helps in meeting export and industrial standards.

2. Roasting: Gentle roasting develops a stronger fragrance and improves the shelf life of both whole seeds and powder.

3. Grinding: Low-temperature grinding preserves natural essential oils, resulting in high-quality, aromatic cumin powder.

4. Packaging: Use of airtight, moisture-resistant and properly labeled packaging keeps the product fresh and visually appealing. Accurate labeling builds confidence among consumers.

Economic Gains from Value Addition

Product Type	Approx. Price (₹/kg)
Raw Whole Cumin	250–300
Cleaned & Graded Seeds	350–450
Cumin Powder	500–600
Roasted Seeds	450–550
Cumin Essential Oil	2500–3500
Herbal Mixtures	800–1200

1. Grading alone increases the value by 30–40%.
2. Essential oils provide high returns due to their premium usage in multiple industries.
3. Through proper value addition, farmers' and processors' earnings can increase 2–4 times.

Challenges in Value Addition

1. Lack of Standardized Processing Methods: Inconsistent cleaning, grinding, or packaging processes affect product quality.

2. Limited Awareness of Food Safety Regulations: Many small units lack knowledge about FSSAI, AGMARK, and export certification requirements.

3. Weak Branding and Market Linkages: Without strong branding and marketing skills, many entrepreneurs fail to reach high-value markets.

4. Climate Sensitivity of Cumin: Cumin is prone to frost, drought, and pest damage, affecting raw material availability.

Future Opportunities

1. Growth of Ready-to-Cook and Convenience Foods: Demand for instant mixes, spice blends, and ready-to-use masalas is growing rapidly.

2. E-commerce and Digital Marketing: Online platforms enable small processors to reach national and international customers directly.

3. Rising Demand for Organic Cumin: Premium prices in global markets create major opportunities for certified organic cumin products.

4. Expansion of Health and Wellness Industries: Growing preference for natural products boosts demand for cumin-based herbal supplements.

Conclusion

India's dominance in cumin production and Rajasthan's strong cultivation base present tremendous prospects for developing a wide variety of value-added cumin products. Through improved processing such as cleaning, roasting, grinding, packaging, and oil extraction, significant economic benefits can be achieved. With increasing export demand and rising interest in wellness-focused products, value addition in cumin offers a promising pathway to increase farmers' income two to four times while opening new markets at both national and global levels.

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The Rise of Resistant Pests: How Insects Outsmart Insecticides

Article ID: 72530

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Introduction

Insecticides have served as one of the most effective tools for crop protection, enabling farmers to manage destructive insect pests and safeguard food production. However, the persistent and often over-reliant use of these chemicals has led to an unintended consequence: the evolution of insecticide resistance. Resistant pests not only undermine pest control strategies but also increase production costs and threaten global food security (Sparks & Lorsbach, 2022).

Resistance arises through natural selection. When insecticides eliminate susceptible individuals, the few possessing genetic traits for survival reproduce and pass these traits to the next generation. Over time, resistant populations form, sometimes within just a few seasons. Sap-feeding pests like whiteflies, aphids, planthoppers, and thrips are especially prone to developing resistance due to their short life cycles, high fecundity, and continuous exposure to pesticides (Zhang *et al*., 2020).

Why Resistance Evolves So Rapidly?

Environmental and agricultural factors accelerate resistance evolution. Intensive monocropping, warm climatic conditions, and frequent applications of the same insecticide groups create persistent selection pressure. For example, the whitefly *Bemisia tabaci* (Gennadius) has demonstrated an exceptional ability to develop multi-class resistance in cotton, vegetables, and ornamental crops (Fang *et al*., 2021). Similarly, the brown planthopper (BPH), *Nilaparvata lugens* (Stal), a major rice pest in Asia, rapidly evolves resistance to neonicotinoids and other insecticides commonly used in rice ecosystems (Zhang *et al*., 2020).

Mechanisms of Insecticide Resistance

1. Target-Site Mutations: Resistance often results from mutations that alter the structure of target proteins, preventing insecticides from binding effectively. E.g.: The *kdr* (knockdown resistance) mutation in *Bemisia tabaci* for pyrethroids. Point mutations in nicotinic acetylcholine receptors (nAChRs) reduce neonicotinoid sensitivity in several sap-feeding pests (Bass & Field, 2022). Even a single amino acid change can compromise the activity of an entire insecticide class.

2. Metabolic Resistance: This is the most widespread and concerning mechanism. Insects overexpress detoxifying enzymes such as cytochrome P450 monooxygenases, glutathione S-transferases (GSTs) and Carboxylesterases. These enzymes rapidly break down insecticides before they can act. For instance, elevated P450 activity is strongly associated with imidacloprid resistance in *N. lugens* (Zhang *et al*., 2020).

3. Reduced Penetration: Changes in cuticle composition reduce insecticide absorption. A thicker or chemically altered cuticle allows pests to withstand higher doses.

4. Behavioural Resistance: The onion thrips, *Thrips tabaci* (Lindeman) may shift to flower tissues that are less exposed to sprays. Whiteflies reduce probing behaviour when exposed to treated surfaces, reducing dosage uptake (Fang *et al*., 2021). Behavioural resistance often appears early but is the hardest to detect.

Examples from Agriculture are *B. tabaci* resistance to organophosphates, pyrethroids, neonicotinoids, and some newer chemistries; *N. lugens* to imidacloprid and several other neonicotinoids linked to multiple P450 gene amplifications; *T. tabaci* resistance to spinosad, pyrethroids, and organophosphates.

Why Modern Agriculture Accelerates Resistance?

1. Repeated use of the same mode of **action** without rotation.
2. Tank mixes that unintentionally select for cross-resistance.

3. Climate change increasing insect reproduction and metabolism (Sparks & Lorsbach, 2022).
4. Protected cultivation creating year-round pest activity cycles.
5. Minimal monitoring in many production systems.

Sustainable Resistance Management Strategies

1. Rotate Modes of Action (MoA): Alternating insecticides with different IRAC MoA numbers prevents continuous selection pressure.In rice, alternating neonicotinoids (MoA 4A) with pymetrozine (MoA 9B) helps manage resistance in *N. lugens* (Zhang *et al*., 2020).

2. Integrate Biological Control: Natural enemies suppress pest populations, slowing resistance evolution. *Chrysoperla carnea* (Steph.) reduces aphid and whitefly pressure in vegetable crops. Parasitoids such as *Anagrus* spp. naturally regulate planthopper eggs in rice.

3. Deploy Host-Plant Resistance: Resistant crop varieties reduce dependence on insecticides.

4. Adopt RNAi and Novel Biopesticides: Next-generation tools provide targeted pest suppression. RNAi constructs silencing detoxification genes increase susceptibility in *B. tabaci* (Bass & Field, 2022). *Beauveria bassiana*-based formulations reduce whitefly numbers even when chemical resistance is high.

Bt biopesticides remain effective against diamondback moth in resistance-prone regions.

5. Precision Monitoring and Application: Using digital tools decreases unnecessary pesticide use. Pheromone traps for *Helicoverpa armigera* Fabricius guide threshold-based spraying. Smartphone apps record pest intensity and recommend MoA rotations. Drone-based spot spraying reduces blanket applications and resistance pressure (Mota-Sanchez & Wise, 2023).

Conclusion

The rise of insecticide-resistant pests reflects insects' remarkable adaptive capacity. As pests continue to develop sophisticated defense mechanisms, reliance on chemical control alone is no longer sustainable. A future-ready pest management system must integrate resistant varieties, biological control, precision monitoring, and innovative molecular tools. Proper stewardship of insecticides, combined with ecological strategies, will be essential to preserving the effectiveness of current chemistries and ensuring stable crop production.

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The Secret World of Insect-Borne Plant Viruses

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Introduction

Across agricultural landscapes, a silent alliance between insects and plant viruses determines the fate of millions of hectares of crops. Unlike insect pests that damage plants through feeding alone, virus-transmitting insects introduce an additional threat, one that hijacks plant physiology, disrupts growth, and drastically reduces yields. Over the last decade, insect-borne plant viruses have intensified as major constraints to crop production, driven by climate change, global trade, and monoculture practices (Zhao *et al*., 2023).

Among sucking pests mainly aphids, whiteflies, leafhoppers, and planthoppers are the primary vectors of plant viruses. Their piercing-sucking mouthparts, phloem-feeding behaviour, high fecundity, and rapid dispersal make them excellent carriers. Recent research shows that viruses do not merely rely on these insects but may manipulate their behaviour, feeding patterns, and movement to enhance transmission (Whitfield *et al*., 2022).

How Plant Viruses Move Through Insects?

Plant viruses cannot independently penetrate plant cell walls. Instead, they depend on vectors capable of bypassing these barriers. When insects feed, their stylets reach into the phloem or xylem. Depending on the virus, these particles may attach to mouthparts, bind to the foregut, or invade and circulate through the insect body (Ng & Zhou, 2021). Based on these factors, there are different modes of vector transmission. These transmission modes shape how quickly epidemics spread and how challenging they are to control.

Table 1. Modes of Transmission of Plant Viruses by Insect Vectors:

Transmission Type	Retention Site	Retention Time	Acquisition Time	Replication in Vector	Examples
Non-Persistent	Stylet (mouthparts)	Seconds-minutes	Seconds	No	Cucumber mosaic virus (aphids)
Semi-Persistent	Foregut	Hours-days	Minutes-hours	No	Criniviruses (whiteflies)
Persistent-non-Propagative	Internal tissues (haemolymph → salivary glands)	Days-weeks	Hours	No	Barley yellow dwarf virus (aphids)
Persistent-Propagative	Internal tissues; replicates inside body	Lifelong	Hours	Yes	Southern rice black-streaked dwarf virus RRSV, RGSV (Plant hoppers)

(Ng & Zhou, 2021; Whitfield *et al*., 2022; Wang *et al*., 2020)

These sophisticated interactions highlight a deep co-evolution between viruses and their insect vectors.

Major Virus-Vector Systems Impacting Agriculture

1. Tomato yellow leaf curl virus (TYLCV): Transmitted by *Bemisia tabaci* Gennadius, TYLCV causes severe stunting, leaf curling, and yield losses up to 100%. It is now widespread across Asia, Africa, and Europe. TYLCV-infected whiteflies show increased feeding frequency and improved survival on infected plants, enhancing virus spread (Moreno-Delafuente *et al.,* 2020).

Fig. 1: Tomato fields attacked by severe whitefly vectored TLCV in Kolar region of Karnataka

2. Rice virus complexes in Asia: Planthoppers such as the brown planthopper (BPH), *Nilaparvata lugens* Stal and white-backed planthopper (WBPH), *Sogatella furcifera* Horvath transmit several major rice viruses *viz.,* Rice grassy stunt virus (RGSV), Rice ragged stunt virus *(RRSV)* and Southern rice black-streaked dwarf virus (SRBSDV). Outbreaks of SRBSDV have expanded sharply across Southeast Asia (Wang *et al*., 2020).

3. Leafhopper-transmitted maize viruses: Maize streak virus, transmitted by leafhoppers, remains one of the most damaging viral diseases in sub-Saharan Africa.

Why are Virus Epidemics Increasing?

Several global and regional forces contribute to the escalating spread of insect-borne viruses:

1. Climate warming increases insect reproduction and expands vector distribution ranges (Zhao *et al*., 2023).

2. Monoculture cropping enables rapid amplification of both vectors and viruses.

3. Insecticide resistance allows vector populations to thrive despite heavy pesticide use (Moreno-Delafuente *et al*., 2020).

4. Global trade and seed movement introduce viruliferous vectors into new regions.

5. Protected cultivation environments provide ideal microclimates for whiteflies and aphids.

These factors create highly favourable conditions for persistent viral epidemics.

Managing Insect-Borne Viruses

Integrated Solutions *i.e.*, sustainable virus management requires a combination of cultural, ecological, genetic, and molecular strategies should be used because viruses are often transmitted before insecticides can kill the vector.

1. Resistant and Tolerant Crop Varieties: Deploying resistance reduces the viral load at the field level. TYLCV-resistant tomato hybrids widely used in India and the Middle East. Virus-indexed banana planting material used in BBTV-prone regions.

2. Physical and Cultural Barriers: Non-chemical barriers disrupt vector entry and virus spread. Insect-proof netting in nurseries prevents whitefly-mediated virus introduction. Reflective mulches repel aphids responsible for CMV and PVY (Whitfield *et al*., 2022).

3. Biological Control: Ladybird beetles and lacewing larvae reduce aphid numbers in vegetable crops. Predatory spiders help regulate planthopper populations in rice ecosystems.

4. Molecular Approaches: Modern tools like RNAi, Host-induced gene silencing (HIGS), CRISPR-based diagnostics (e.g., SHERLOCK) target vector-virus interactions directly (Whitfield *et al*., 2022).

5. Surveillance and Forecasting: Early detection prevents severe outbreaks. Yellow sticky traps monitor whitefly and aphid activity. Remote sensing identifies stress patterns correlated with viral infections (Zhao *et al*., 2023). Mobile apps and extension advisories provide real-time vector alerts.

Conclusion

Insect-borne plant viruses represent a sophisticated tri-trophic interaction involving plants, viruses, and vectors. Their rising prevalence reflects a combination of ecological changes, evolving vector biology, and global agricultural intensification. Although virus management is challenging, the integration of resistant varieties, biological control, molecular innovations, and advanced surveillance can significantly reduce crop losses. Building resilient crop systems will require continuous research and sustained adoption of integrated pest and disease management strategies.

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Importance of Natural Flocculant for Water Treatment and Mechanism

Article ID: 72532

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Introduction

The role of natural flocculant has attracted many researchers for past decades as they can be easily modified to achieve desirable characteristics. The merits of utilizing plant-based flocculant in lieu of synthetic polymers includes low flocculant dosage, low sludge volume, biodegradability, larger number of surface charges, eco-friendly, excellent settling rate and generation of less metal concentration in the treated wastewater when compared with synthetic coagulant such as alum causing Alzheimer's disease.

Coagulation and Flocculation

Colloidal particles possess charge on their surface which leads them to be stable and remain in suspension state making it hard to be removed by sedimentation process. By addition of some chemicals this charge can be neutralized and get it settled which can be easily filtered. If destabilization of stable colloidal particles is induced through charge neutralization by addition of inorganic chemicals (Al^{3+}, Fe^{3+} e.t.c), the process is called coagulation. Flocculation, however, is a process whereby dispersed particles are aggregated to form large floc by the action of high molecular weight polymer. The advantages of Flocculation include low doses (in ppm level), cheap and non-toxic. Flocculants are basically classified as below:

Inorganic Flocculants: This includes mostly hydrolysable salts of aluminum and iron.

Organic (polymeric flocculants): This includes water soluble high weight linear polymers and can be further classified as below:

1. Cationic flocculants: eg. Poly DADMAC (Poly diallyl dimethyl ammonium chloride), ammonium (including amines), sulfonium and phosphonium quaternaries [6]

2. Anionic flocculants: eg. Polystyrene sulphonic acid (PSSA).

3. Non-ionic flocculants: They don't carry any charge on their polymeric structure, eg. CMS-g-PAM (Carboxymethyl starch grafted PAM) [6].

4. Natural Polymer: eg. Agar, starch and guar gum, etc.

5. Amphoteric flocculants. They contain both cationic and anionic functional groups.

Mechanism of Flocculation

There are many theories proposed to explain the mechanism of flocculation which are discussed in brief:

1. Charge Neutralization Mechanism: Charge neutralization by double layer compression is accomplished when flocculation is effective through an increase in solution ionic strength. The formula as given by Gouy-Chapman model of the electrical double layer, the expression for Debye-Huckel length is given as [7]; $K = (4 \times 10^{-3} e^2 N I / \varepsilon K T)^{1/2}$

Where, e = Electronic charge, N = Avogadro's number, I = Ionic Strength, ε = Electrical permittivity of the solvent, K = Boltzman constant, T = Absolute temperature.

2. Bridging Mechanism: This theory states that when long chain polymers in small dosage are added to a colloidal suspension, they get adsorbed onto two or more particle surfaces and thus form bridge between them [7] (Figure 1a). At polymer dosage lower than the optimized dosage, there is no adequate bridging between the particles. Similarly at higher dosages, there is insufficient particle surface for attachment of the polymer segments leading to destabilization. Flocs generated by this method is larger and stronger than those produced by addition of salts.

3. Electrostatic Patch Mechanism: This mechanism offers better explanation of flocculation for high charge cations on negatively charged particles than above mechanisms. For a system of high cationic charge in anionic colloidal suspensions, the high interaction energy favours a flattened adsorbed configuration (Figure 1.b) that reduces the formation of loops and trains, which can bridge the suspended particles. In such cases, surface charge particles cannot be neutralized individually with oppositely charged polymer segments. The charges on the polymer first form 'island' patches of charge, surrounded by areas of opposite charge. Particles with polyelectrolytes adsorbed in this "patch-wise" manner can interact in such a way that oppositely charged areas of different particles come in contact giving rise to strong attraction [8].

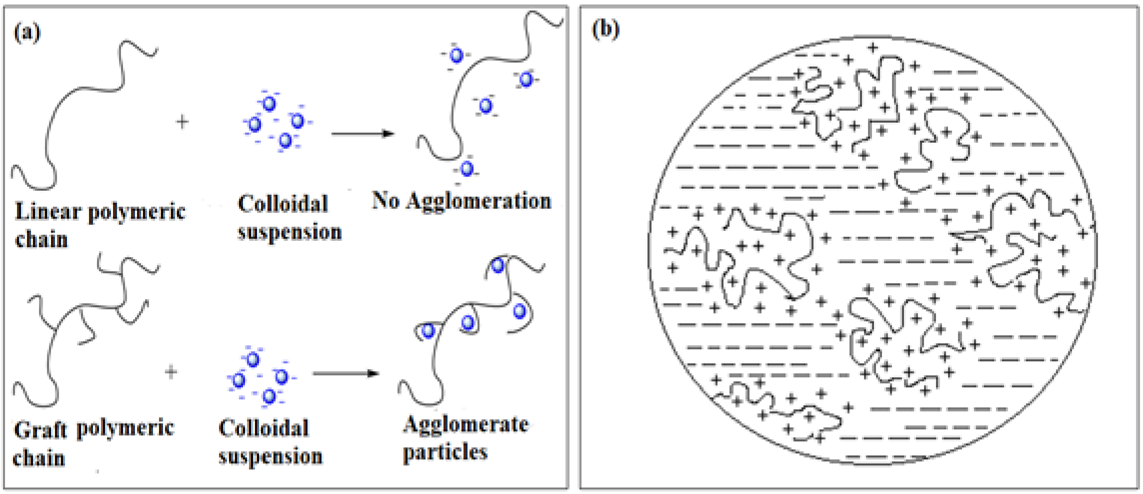

Figure 1: Schematic illustration of flocculation by a) bridging mechanism and b) electrostatic patch mechanism.

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Enhancing Soil Fertility in Organic Farming: The Power of *Insitu* Green Manuring Crops

Article ID: 72533

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Introduction

The role of natural flocculant has attracted many researchers for past decades as they can be easily modified to achieve desirable characteristics. The merits of utilizing plant-based flocculant in lieu of synthetic polymers includes low flocculant dosage, low sludge volume, biodegradability, larger number of surface charges, eco-friendly, excellent settling rate and generation of less metal concentration in the treated wastewater when compared with synthetic coagulant such as alum causing Alzheimer's disease.

Concept of Green Manuring

Green manuring is a proactive approach to managing soil fertility. It involves intentionally growing specific crops often during fallow periods or as intercrops within crop rotations solely for the purpose of enriching the soil. Instead of harvesting these crops for consumption, they are incorporated back into the soil to return valuable nutrients and organic matter.

Benefits of Green Manuring

Green manuring provides numerous benefits that contribute to soil fertility and agricultural sustainability:

1. Improvement of Organic Matter: Decomposition of green manure crops increases soil organic matter, enhancing structure and aeration.

2. Nutrient Cycling and Availability: Green manure crops capture, recycle and release nutrients, preventing leaching losses and ensuring their availability for subsequent crops.

3. Weed Suppression: Dense canopy cover suppresses weed growth by shading and competing for resources.

4. Soil Erosion Control: Vigorous root systems stabilize the soil and reduce erosion caused by wind and water.

5. Pest and Disease Management: Some green manure crops possess bio-fumigant properties that release natural compounds capable of suppressing soil-borne pathogens, pests and weeds.

Types of Green Manure Crops

1. Leguminous Crops: Leguminous crops such as Sunhemp *(Crotalaria juncea)*, Dhaincha *(Sesbania aculeata)*, Cowpea *(Vigna unguiculata)* and Horsegram *(Macrotyloma uniflorum)* form symbiotic associations with nitrogen-fixing bacteria in their root nodules. They enrich the soil with atmospheric nitrogen and contribute.

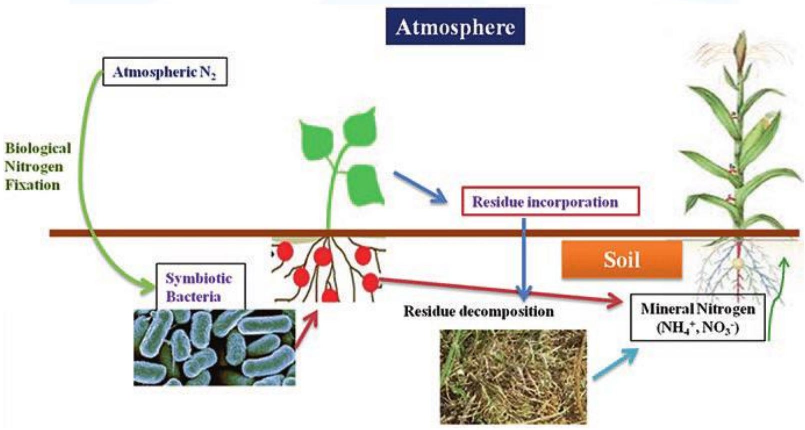

Fig.1: Mechanism of Nitrogen fixation by Leguminous green manuring crop

2. Non-Leguminous Crops: Non-leguminous crops, such as cereals and Oilseed crops are mainly used for their biomass production. These crops scavenge and accumulate nutrients from the soil as well as contribute substantial amounts of organic matter upon incorporation in the form of their biomass.

Fig.2: Different Green manuring crops

Incorporation Techniques

Incorporating green manure crops into the soil is a critical step in maximizing their benefits. The timing and method of incorporation greatly influence nutrient release, decomposition rate and overall soil health.

Timing of Incorporation

Green manure crops should be incorporated at the flowering stage, before seed set. At this stage, the biomass is at its peak and nutrient concentration is optimal and succulent for facilitating faster decomposition. Typically, incorporation is recommended at 40-45 days after sowing.

Method of Incorporation

Several techniques can be used, depending on crop type, soil condition, and equipment availability:

1. Ploughing: Traditional method where crops are turned into the soil using a plough, ensuring rapid mixing and decomposition.

2. Disking: Use of a disk harrow to chop and incorporate crop residues into the soil.

3. Rotary Tilling: Rotary tillers use rotating blades to thoroughly mix residues and soil.

4. Mulching: Crop residues are left on the soil surface as mulch, helping retain moisture, suppress weeds, and promote gradual decomposition.

5. Integration with Crop rotation: Incorporation should be synchronized with the crop rotation schedule to ensure nutrient availability aligns with the needs of the subsequent crop.

Challenges and Considerations

Despite its numerous advantages, green manuring also presents challenges. These include proper crop selection, timing of incorporation, potential competition with cash crops and availability of suitable equipment. Addressing these factors through careful planning and management ensures smooth integration of green manuring into organic farming systems.

The Future of Green Manuring in Organic Farming

Green manuring holds tremendous potential for the future of organic farming. It enhances soil fertility, improves nutrient management, mitigates climate change effects and promotes biodiversity and sustainability. With technological advancements and increased awareness, farmers can strategically incorporate green manuring into cropping systems to achieve higher productivity and long-term soil health.

Conclusion

Green manuring crops are powerful tools for enhancing soil fertility in organic farming. Through the incorporation of plant biomass, they improve organic matter content, nutrient availability, soil structure, and microbial activity. By selecting appropriate crops, timing incorporation effectively, and adopting sound management practices, organic farmers can sustainably enhance soil health and achieve higher productivity, contributing to a resilient and eco-friendly agricultural system.

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Novel Innovations in the Floriculture Industry: Pathways to a Sustainable and High-Value Future

Article ID: 72534

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Abstract
The floriculture industry, a dynamic component of global horticulture, has experienced transformative technological, genetic, and market-driven innovations over the past decade. These innovations address challenges related to climate change, resource scarcity, post-harvest losses, and shifting consumer preferences. This article examines the most recent advancements in floriculture, including smart cultivation systems, genome editing, nanotechnology, post-harvest biotechnology, and digital market integration. Their potential impacts on productivity, sustainability, and global trade are critically analyzed.

Introduction
Floriculture—encompassing the cultivation, processing, and marketing of ornamental plants and cut flowers—has grown into a multi-billion-dollar global industry. Traditionally reliant on manual labor and conventional cultivation practices, the sector now faces unprecedented pressures: rising temperatures, water scarcity, pest resistance, increasing logistical costs, and demand for year-round flower availability. In response, innovations emerging from biotechnology, digital agriculture, material science, and controlled-environment horticulture are reshaping the production paradigm.

Genetic Innovations and Breeding Technologies
1. CRISPR-Cas Gene Editing: CRISPR has enabled precise modification of ornamental traits such as flower color, scent intensity, vase life, and disease resistance. For example:

a. *Rosa spp.* and *Chrysanthemum spp.* varieties with enhanced resistance to powdery mildew.
b. Novel pigments (e.g., blue roses) produced through metabolic pathway engineering.

2. Marker-Assisted and Genomic Selection: High-throughput sequencing has accelerated breeding cycles by identifying quantitative trait loci (QTLs) associated with stress tolerance and post-harvest longevity.

3. Haploid Induction and Doubled Haploids: These techniques allow rapid fixation of desirable traits, thereby reducing conventional breeding times by 50–70%.

Smart Cultivation and Controlled Environment Agriculture (CEA)
1. Precision Agriculture in Floriculture: Use of IoT-enabled sensors for monitoring soil moisture, nutrient levels, vapor pressure deficit (VPD), and canopy temperature have drastically improved input-use efficiency.

2. Vertical Farming and Hydroponics/Aeroponics: These systems minimize land use and allow year-round production of high-value species (e.g., tulip, gerbera, orchids) with optimized environmental parameters.

3. AI-Driven Growth Modeling: Machine-learning algorithms predict flowering time, disease outbreaks, and resource requirements, enabling real-time crop management.

Nanotechnology Applications
1. Nano-Fertilizers and Nano-Pesticides: Nanoparticles improve nutrient uptake efficiency, reduce leaching, and combat pests with significantly lower chemical loads.

2. Nano-Coatings for Vase Life Enhancement: Silver nanoparticles and chitosan-based nano-films prolong post-harvest freshness by reducing microbial load in vase water.

Biotechnology in Post-Harvest Management

1. **Ethylene Inhibitors:** Compounds such as 1-MCP (1-methylcyclopropene) effectively delay senescence in ethylene-sensitive flowers like carnations and lilies.

2. **Cold Chain Optimization Technologies:** Smart packaging with embedded sensors tracks humidity, temperature, and mechanical shock during transportation, reducing losses by up to 30%.

3. **Edible and Biodegradable Coatings:** Aloe vera, starch, and polysaccharide coatings create semi-permeable barriers to respiration, improving shelf life without chemical preservatives.

Innovations in Sustainable and Eco-Friendly Floriculture

1. **Solar-Powered Greenhouses:** Integration of bifacial solar panels and photovoltaic glazing allows energy-neutral production systems.

2. **Bio-Based Growing Media:** Cocopeat, wood fiber, and composted organic waste are replacing peat moss to reduce environmental impact.

3. **Circular Production Systems:** Waste flowers are converted into natural dyes, essential oils, compost, and bio-enzymes, promoting zero-waste floriculture.

Digitalization and Market Innovations

1. **Blockchain for Supply Chain Transparency:** Ensures traceability of flowers from farm to consumer, reducing fraud and enhancing certification credibility.

2. **E-Commerce and Global Flower Auctions:** Platforms such as digital flower auctions and AI-powered demand forecasting systems have modernized trade, reducing dependency on physical markets.

3. **Consumer-Centric Innovation:** Development of hypoallergenic flowers, long-lasting blooms, and customizable genetically designed varieties caters to emerging lifestyle trends.

Challenges and Future Prospects

While innovations are rapidly evolving, challenges include regulatory hurdles for genetically modified ornamentals, high initial investment costs for smart greenhouses, and the need for skilled labor. Collaborative research, supportive policy frameworks, and capacity-building among growers will be crucial for widespread adoption.

Future trends likely to dominate include:
1. Synthetic biology for designer flowers
2. Robotics for harvesting and grading
3. Carbon-neutral floriculture clusters
4. AI marketplaces for global flower trading.

Conclusion

Novel innovations in the floriculture industry are fundamentally transforming cultivation, post-harvest management, and market dynamics. Through the integration of biotechnology, digital technologies, and sustainable practices, the sector is transitioning toward a high-efficiency, resilient, and environmentally responsible future. Continued interdisciplinary research and innovation will determine how effectively floriculture meets global challenges and consumer expectations in the coming decades.

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From Fragmentation to Collective Power - How FPOs are Reshaping India's Smallholder Agriculture

Article ID: 72535

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Introduction

Agriculture remains the backbone of India's rural economy, yet farmers especially smallholders owning less than two hectares continue to face structural constraints. Fragmented landholdings, weak market access, high input costs, and limited bargaining power have left small farmers vulnerable and unable to benefit from rising agricultural markets. A viable solution to these challenges lies in collective action - organizing farmers into groups that enable economies of scale. Past attempts, including Commodity Interest Groups (CIGs), Self-Help Groups (SHGs), and agricultural cooperatives (Venkatkumar *et al*., 2017), have achieved only partial and geographically limited success.

In this context, Farmer Producer Organizations (FPOs) have emerged as a promising institutional mechanism to enhance smallholder performance by integrating them more effectively into markets. FPOs help transform scattered individual producers into functioning business entities with collective bargaining strength. India currently has over 10,000 FPOs, benefiting roughly 4 million farmers and increasing their incomes by an estimated 20–25% (Yazhini *et al*., 2025).

Why Farmer Aggregation Matters?

A single small farmer has minimal leverage when negotiating input purchases or crop sales. When farmers aggregate, however pooling produce, inputs, and information they can secure bulk discounts, negotiate better output prices, access institutional credit, and invest in post-harvest infrastructure. This collective efficiency drives the economic success of FPOs: pooling volumes reduces transaction costs, streamlines quality control, and opens doors to larger buyers and formal markets. Government assessments repeatedly highlight improved bargaining power and market access as the most visible benefits of FPO membership (NABARD Technical Report, 2025).

Why do FPOs Matter?

1. Collective access to inputs and technologies: FPOs enable bulk procurement of quality seeds, fertilizers, and machinery, reducing input costs for members. They also serve as platforms for agricultural extension, helping farmers adopt improved technologies such as high-yielding varieties, drip irrigation, or basic grading equipment that may be unaffordable individually. National level evaluations consistently report improved access to inputs and services as a major outcome of FPO formation (NABARD Technical Report, 2025).

2. Inclusion of women and marginalized producers: Many FPOs are designed to enhance the participation of women and vulnerable groups. Evidence indicates that these organizations strengthen women's involvement in decision making and income earning activities. Evaluations have also highlighted women led FPOs and all-women producer companies as high impact models (NITI Aayog, 2024).

3. Improved access to formal finance and credit: Financial institutions prefer lending to organized producer companies rather than numerous small farmers. As a result, working capital loans, input credit, and credit guarantees are easier to facilitate through FPOs. NABARD and allied agencies have reported increased credit flows to FPOs, enhancing financial inclusion for members (NABARD Impact Report, 2023–24).

4. Processing and value addition: By investing in collection centers, grading units, storage or primary processing facilities, FPOs enable farmers to capture greater value. Reduced post-harvest losses, improved produce quality, and the ability to sell processed goods help stabilize incomes and mitigate seasonal price fluctuations. National policy now actively promotes FPO led value addition (GOI, 2024).

5. Better price realisation and reduced middleman leakage: Case studies reveal that FPO members often receive higher net prices because organizations sell in bulk to processors or through e-market platforms, bypassing multiple intermediaries. A 2023 study of dry chilli farmers in Andhra Pradesh documented significant improvements in price realisation and household welfare following FPO participation (Kumar *et al.*, 2023).

India's FPO Surge

The Government of India launched a Central Sector Scheme to promote 10,000 FPOs nationwide. As of June 30, 2024, 8,875 FPOs were registered under this scheme. The broader ecosystem, however, is much larger. According to the National Association of Farmer Producer Organisations (NAFPO), nearly 43,900 FPOs existed by March 2025, including those promoted by state governments, NGOs, and private sector actors. This expansion is supported by the National Policy on FPOs (June 2024), which formalizes support measures, market linkages, and digital integration to strengthen FPO operations (PIB, 2024).

Challenges

Despite their potential, FPOs are not a panacea. Key barriers include limited business and managerial skills within organizations, weak and inconsistent market linkages for commodity crops, governance issues, and heavy dependence on external support during initial years. Occasional instances of misuse and fraud signal the need for stronger oversight and institutional accountability. FPOs must therefore be recognized not merely as legal entities but as institutional responses to systemic fragmentation. Success depends on sound governance, market orientation, and professional support systems capable of scaling collective action.

Conclusion

When designed and managed effectively, FPOs enable smallholders to overcome structural disadvantages and transition from subsistence farming to commercially viable enterprises. By building collective strength, enhancing access to inputs, services, and markets, and enabling value addition, FPOs have the potential to transform rural livelihoods. For millions of India's small farmers, this shift from vulnerable individuals to empowered collectives can mean the difference between marginal survival and sustainable enterprise.

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5 Flowering Plants You Can Collect Seeds to Fill Your Summer Garden with Bold Blooms

Article ID: 72536

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Cosmos

First on the list is cosmos, a gorgeous summer-flowering plant that will fill your garden with bold hues come the summer months. And right now it's the prime time to collect seeds so you are ready to grow cosmos come spring.

'September through to October is the perfect time to collect seeds from your cosmos plants,' explains Lucie Bradley, garden expert at Easy Garden Irrigation.

'When the petals have fallen from the flowers and the seed heads dried and gone brown, it is when you should rub the heads to get the seeds to fall into your hand. You should then be able to separate the dark seeds from any other debris and place them into a paper bag or envelope ready to store.'

Sun Flowers

With huge yellow heads, sunflowers are a sure fire way to add joy to your garden border ideas. But not only do they frame your garden beautifully, sunflowers are great food sources for your local wildlife, so make sure you leave a few seeds for the garden birds!

'You can tell when sunflower seeds are ready to harvest as the flower will have turned brown, the seeds appear plump, and the seeds should come out easily,' says Richard Barker, commercial director of LBS Horticulture.

'To harvest the seeds, cut the flower from the stem and remove the chaff. The chaff can drop off by itself, but you may need to remove it manually to expose the seeds.'

'Mature sunflower seeds should come away from the flower easily when you rub them with your finger, but if this does not happen, then they will need more time to mature. If this is the case, leave the flower to dry out for a little longer, and check the seeds again in a few days.'

Dahlias

Dahlias are some of the most popular plants out there, famed for their show-stopping petal formation and bold, bright colours. You can grow dahlias from seed if you collect the seeds now, ready to be sown between February and April.

'Easy to handle, dahlia seeds are a bark brown or black oblong shape, approx. 1.3cm long. These seeds are in seed pods which form once the dahlia bloom fades and dries, which you will see happening in September through to October,' says Lucie.

'The simplest way to collect dahlia seeds is to snip off the full flower head once it has turned brown and dried out. Leave the collected heads to finish drying somewhere warm and dry for about 10 to 14 days, when you can then break up the seed heads to get at the long dark seeds ready to store until it's time to plant next year.'

Zinnias

Zinnias are sun-loving plants, beginner-friendly and produce some of the most Instagram-worthy blooms in the garden. Once you've mastered how to grow zinnias, you'll definitely want to start collecting their seeds to enjoy these beautiful flowers for summers to come.

‘Once the flowerhead has faded and dried, you can collect the seeds from zinnia plants (as long as it is not a hybrid variety). When the seeds have ripened to a dark brown, you can cut the flowerhead off the plant,' explains Richard.

'Hold the flowerhead over a piece of paper, and agitate it gently or hit it against the surface of the paper to remove the seeds. Discard any petals and then leave the seeds to dry out for a few days.'

Marigolds

Marigolds are superhero plants. Beautiful to look at and naturally repelling pests, it’s a plant you definitely want to keep in your garden.

‘Resembling a fine pointed sliver or stick, marigold seeds have a very dark brown lower half, whilst the top half will be very pale yellow or white and feathery at the end,' says Lucy.

'These seeds are tightly packed into the seed pod of the marigold flower and are ready to collect once the flower petals have faded and fallen off and the remaining seed pod has dried, turned brown and starts to droop on the stem, indicating the seeds are mature.'

‘Simply snip off the seed pods and place them into a paper bag and leave for a few days somewhere warm and dry to ensure they are completely dry.'

'You should then be able to rub the seed heads between your fingers to release the tightly packed seeds. Once released, leave to thoroughly dry before storing.’
Will you be collecting seeds from your garden this autumn? We'd love to know how you get on.

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Emerging Role of Non-Rhizobial Endophytes in Promoting Plant Health

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Summary
Legume crops play an important role in sustainable agriculture by forming root nodules with symbiotic association with the nitrogen-fixing rhizobia. Studies in the last few decades showed that these nodules are more complex harbouring diverse bacteria. Along with the rhizobia, a wide range of non-rhizobial endophytes (NREs) also inhabit these nodules. These beneficial bacteria – commonly from genera such as *Bacillus, Pseudomonas, Paenibacillus, Agrobacterium, Enterobacter,* etc. contribute significantly to plant nutrition, stress tolerance and disease protection. A comprehensive understanding on their origin, transmission and diversity is essential to identify next generation bioinoculants. They offer tremendous potential to improve legume productivity and promote sustainable agriculture.

Introduction
The global population is expected to reach 9 billion by the year 2050. To meet the increasing food demand, it is important to increase crop productivity through sustainable alternatives. Legumes contribute significantly to agroecosystem resilience by hosting nitrogen-fixing rhizobia in root nodules. However, nodules also harbor a diverse community of non-rhizobial endophytes (NREs), many of which exhibit plant-growth-promoting and biocontrol traits. These endophytes—belonging to genera such as *Bacillus, Pseudomonas, Paenibacillus, Enterobacter,* and *Agrobacterium*—are increasingly recognized for their ecological and agricultural importance. Their ability to fix nitrogen, solubilize nutrients, enhance stress tolerance, and contribute to pathogen suppression positions them as promising allies in reducing dependence on chemical inputs.

Discovery and Prevalence of NREs
Initially, legume nodulation was attributed solely to α-proteobacterial rhizobia. Studies by Moulin et al. (2001) and Peix et al. (2015) revealed that β-proteobacteria such as *Burkholderia* and *Methylobacterium* can also induce nodules, widening the spectrum of bacteria associated with legume symbiosis. Subsequent studies showed that nodules contain diverse non-symbiotic bacteria—now collectively referred to as NREs—that coexist with rhizobia and contribute to plant health. Across legumes, *Bacillus* and *Pseudomonas* are the most frequently reported NREs, followed by *Paenibacillus, Enterobacter, Pantoea,* and *Microbacterium*. Soybean, *Phaseolus*, *Vigna*, *Lens*, and *Medicago* species host particularly diverse NRE communities. Although they do not initiate nodulation independently, many NREs enter nodules via rhizobia-induced infection threads and may enhance nodulation when co-inoculated with compatible rhizobia. In some cases, strains of *Agrobacterium* possess symbiosis-related genes (e.g., *nifH, nodA*) enabling nodulation-like behaviors.

Diversity and Host Specificity
Legume genera display clear patterns of endophyte association, indicating selective recruitment and niche specialization. For example, *Glycine* nodules commonly contain *Bacillus, Pseudomonas, Agrobacterium, Nitrobacter,* and *Ochrobactrum*, while *Phaseolus* hosts *Actinobacteria, Acidobacteria,* and *Cyanobacteria*. Model legumes such as *Medicago* exhibit enrichment for *Actinobacteria, Micromonospora,* and *Pseudomonas*. Environmental factors (soil type, management practices) and host genetic determinants shape these communities. Genotype-dependent filtering of NREs, such as in *Medicago truncatula*, highlights the complexity of plant–microbe interactions. Despite advances in microscopy and culture-based isolation, the molecular pathways enabling NRE entry remain unclear. Many isolates lack canonical nodulation genes such as *nodC*, suggesting that NREs may rely on rhizobial infection threads or physical

entry points like root cracks. However, comprehensive molecular studies are needed to clarify these mechanisms.

Functional Roles of NREs

1. Biofertilization: Numerous NREs contribute to nitrogen fixation, either autonomously or synergistically with rhizobia. Strains of *Paenibacillus, Klebsiella, Arthrobacter, Pseudomonas,* and *Bacillus* have demonstrated nitrogenase activity, accounting for up to 47% of total nitrogen fixed in some systems. NREs also solubilize inorganic phosphate, produce siderophores that mobilize iron, and synthesize phytohormones that enhance root development and nutrient uptake.

2. Stress Tolerance: NREs mitigate abiotic stresses such as salinity, drought, osmotic stress, and acidity by producing osmolytes, antioxidants, and ACC deaminase, which lowers ethylene levels under stress. Genera like *Achromobacter, Chryseobacterium, Enterobacter,* and *Paenibacillus* have shown strong stress-ameliorating effects in legumes.

3. Biological Control: Many NREs exhibit antagonistic activity against fungal and bacterial pathogens. *Pseudomonas fluorescens, Rahnella aquatilis, Serratia marcescens,* and *Acinetobacter calcoaceticus* suppress pathogens including *Fusarium solani, Aspergillus flavus,* and *Phytophthora sojae* through siderophore production, lytic enzymes, antibiotics, and competitive exclusion (Table 1).

4. Phytostimulation: IAA-producing NREs modulate root architecture, delay senescence, and enhance symbiotic nitrogen fixation. Co-inoculation with NREs such as *Bacillus megaterium* or *Methylobacterium oryzae* increases nodule number, leghemoglobin content, and nitrogenase activity.

5. Phytoremediation: Endophytes from genera *Pseudomonas, Ensifer, Microbacterium,* and *Stenotrophomonas* promote legume growth in heavy-metal-contaminated environments by reducing metal uptake and stabilizing pollutants, while others degrade xenobiotics as carbon sources.

Table 1. Antagonistic potential of nodular non-rhizobial endophytes:

S. No.	Nodule Endophytic Bacteria	Plant Pathogen	Reference
1	*Acinetobacter calcoaceticus* DD161	*Phytophthora sojae*	Zhao et al., 2018
2	*Bacillus subtilis*	*Sclerotium roflsii*	Deva et al., 2024
3	*Streptomyces tendae, Pseudomonas koreensis*	*Fusarium oxysporum Botrytis cinerea*	Hnini et al., 2024
4	*Paenibacillus polymyxa*	*Fusarium graminearum, Magnaporthe oryzae, Rhizoctonia solani, Sclerotinia sclerotiorum, Botrytis cinerea*	Ali et al., 2021
5	*Brevundimonas, Sphingobacterium*	*Fusarium oxysporum, Pythium ultimum, Phytophthora sp, Rhizoctonia solani*	Chen et al., 2020
6	*Serratia marcescens*	*Aspergillus flavus*	Wang et al., 2013

Scope, Applications, and Methodological Challenges

Co-inoculation of rhizobia with compatible NREs enhances nodulation, nitrogen assimilation, root architecture, antioxidant activity, and biomass. However, such synergism is host-dependent; beneficial effects in one legume–rhizobium combination may not translate to others. Harnessing NREs therefore requires a mechanistic understanding of host specificity and compatibility.

Metagenomics and high-throughput sequencing have revealed NRE community structure across nodules, rhizosphere, and endosphere, identifying seed-borne transmission routes and environmental influences such as fire disturbance. Yet, DNA yield and quality, unculturable taxa, and incomplete reference databases limit resolution. Combining culture-based isolation, metagenomics, 16S rRNA libraries, fluorescent tracking, and other omics approaches is essential for reliably identifying true NREs and elucidating their ecological roles.

Conclusion

This review highlights the diverse associations between legumes and their nodule-inhabiting non-rhizobial endophytes. The specificity and variability of these communities point to complex host–microbe interactions, with *Bacillus* and *Pseudomonas* emerging as dominant and functionally versatile NREs. Their contributions to nitrogen fixation, nutrient mobilization, stress tolerance, disease suppression, and phytoremediation underscore their potential in sustainable crop production. Targeted exploitation of NREs—supported by integrative molecular and cultivation-based approaches—offers promising avenues for enhancing legume productivity and resilience under varying environmental conditions.

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AI-Powered Laser Weeding: Transforming Modern Agriculture

Article ID: 72538

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Introduction

Weeds have long been one of the most persistent challenges in agriculture, competing with crops for essential resources such as water, nutrients, and sunlight. Traditional weed management strategies—manual removal and chemical herbicides—are either labor- Intensive or environmentally harmful. In recent years, AI-powered laser weeding has emerged as a revolutionary solution. By combining artificial intelligence, robotics, and laser technology, this innovation promises to reduce costs, improve crop yields, and minimize environmental damage.

The Technology Behind AI-Powered Laser Weeding

1. Artificial Intelligence and Computer Vision:

a. High-resolution cameras and sensors scan the field in real time.
b. AI algorithms, trained on thousands of plant images, distinguish weeds from crops with up to 90% accuracy.
c. Machine learning continuously improves detection as the system encounters new weed species.

2. Laser-Based Weed Elimination:

a. Once identified, weeds are targeted with precision lasers that burn plant tissue at the root.
b. The targeting system achieves 5 mm accuracy, ensuring crops remain unharmed.
c. Unlike mechanical weeding, lasers do not disturb the soil structure.

3. Automation and Robotics:

a. Robots or tractor-mounted systems operate autonomously, reducing reliance on manual labor.
b. Some systems, like the Rakshak robot in India, are powered by tractor batteries, while others, such as Carbon Robotics' Laser Weeder in the USA, use advanced robotics with deep learning integration.

Case Studies

Rakshak Robot (India)

a. Developed by Rahul Arepaka, founder of Harvested Robotics.
b. Designed to help Indian farmers reduce dependence on chemical herbicides.

Key benefits:

d. Cuts weed control costs by ₹ 60,000 per season.
e. Promotes soil health by avoiding chemical degradation.
f. Operates with high precision even in diverse crop fields.

Carbon Robotics Laser Weeder (USA)

a. A commercial product using deep learning and robotics.
b. Capable of eliminating weeds as small as the tip of a pen.

Benefits:

a. Reduces weeding costs by up to 80%.
b. Increases crop yield and quality.
c. Payback period of 1–3 years, with a lifespan of 7–10 years.

Benefits of AI-Powered Laser Weeding

Aspect	Traditional Weeding	AI-Powered Laser Weeding
Labor Requirement	High	Low (automated)

Chemical Use	Heavy herbicides	None
Precision	Low–Medium	High (5 mm accuracy)
Cost Efficiency	Recurring costs	Long-term savings
Soil Health	Degraded by chemicals	Preserved
Scalability	Limited	High

Challenges and Limitations

Despite its promise, AI-powered laser weeding faces several challenges:

1. High Initial Investment: Advanced robotics and AI systems are expensive, limiting accessibility for small-scale farmers.

2. Training Needs: Farmers require technical knowledge to operate and maintain these machines.

3. Energy Demand: Lasers consume significant power, raising sustainability concerns.

4. Field Variability: Dust, uneven terrain, and crop diversity can affect detection accuracy.

Conclusion

AI-powered laser weeding represents a paradigm shift in agriculture, offering farmers a sustainable, cost-effective, and eco-friendly solution to weed management. By eliminating the need for herbicides, it not only reduces costs but also protects soil health and biodiversity. With successful implementations in India and the USA, this technology is proving its potential to transform farming practices worldwide.

Future Prospects

Looking ahead, AI-powered laser weeding is expected to evolve in several ways:

1. Wider Adoption: As costs decrease, small and medium-scale farmers will adopt the technology.

2. Integration with Drones: Future systems may use aerial drones for weed detection and targeted laser elimination.

3. Renewable Energy Use: Solar-powered or hybrid systems could make laser weeding more sustainable.

4. Global Expansion: From India's Rakshak to America's Carbon Robotics, AI laser weeding is poised to become a global standard in precision agriculture.

5. Data-Driven Farming: Integration with IoT and big data could allow predictive weed management, optimizing crop yields further.

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Drainage Water Recycling in Crop Production

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Introduction

Though the earth has 1351 million km³ of water, only 3% is usable freshwater, and agriculture consumes nearly 70% of it. By 2050, food grains production needs to be increased by 60%, but about 6 billion people may face water scarcity due to declining per capita water availability. Since agricultural water withdrawal can rise only 10%, improving irrigation efficiency and finding alternative water sources is essential. Water reuse is recommended by the Food and Agriculture Organization (FAO) of the United Nations to enhance water productivity and reduce pollution in the face of climate change. Increasing unpredictable rainfall causes waterlogging and crop loss, with 11.6 million ha in India affected annually and 25,000 ha of irrigated land lost to salinity every year. Capturing drainage water and reusing it for irrigation has emerged as a promising solution. Drainage Water Recycling (DWR) collects excess field water into ponds or reservoirs and reuses it during water shortages. As a closed loop system, DWR returns stored water back to the same or nearby fields through suitable irrigation methods, promoting sustainable crop production.

Hydrology of Drainage Water Recycling System

Understanding the hydrology of Drainage Water Recycling (DWR) systems is essential, as it involves interactions among soil, weather, crops, drainage design, and irrigation management. Unlike conventional irrigation systems, DWR is used in poorly drained soils with shallow water tables, which influence root growth and contribute to evapotranspiration. However, the stored drainage water alone may not fully meet irrigation needs, making supplemental water management important. In these soils, water moves downward through infiltration and upward from the water table by capillary rise, known as upward flux. This upward movement can significantly support crop water use but varies with soil type, water table depth, and crop characteristics, and is difficult to measure accurately. Additionally, proper understanding of reservoir water balance is crucial for efficient DWR system design and performance.

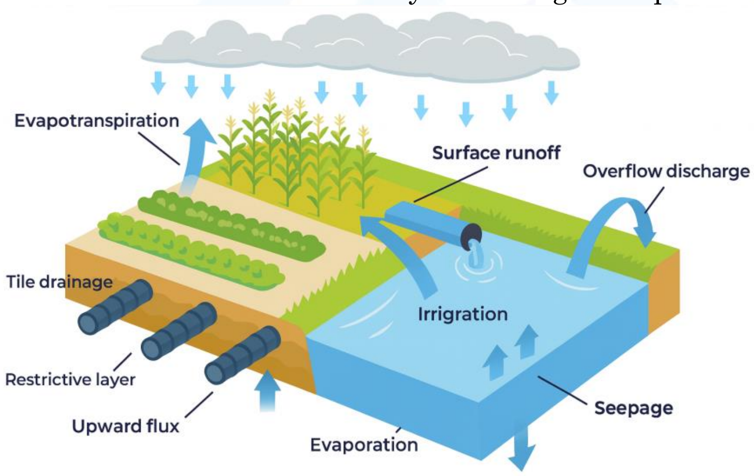

Fig 1: Hydrology of drainage water recycling system

Benefits of Drainage Water Recycling

1. Provides supplemental irrigation, leading to higher and more stable crop yields.
2. Improves downstream water quality by reducing nutrient losses.
3. Enhances water storage in agricultural landscapes.
4. Reused drainage water supplies nutrients that benefit crops.
5. Supports crop diversification and alternative cropping systems.

6. Reduces nitrogen and phosphorus concentrations in reservoirs through natural processes like denitrification and sediment deposition.

Benefits of AI-Powered Laser Weeding

Aspect	Traditional Weeding	AI-Powered Laser Weeding
Labor Requirement	High	Low (automated)
Chemical Use	Heavy herbicides	None
Precision	Low–Medium	High (5 mm accuracy)
Cost Efficiency	Recurring costs	Long-term savings
Soil Health	Degraded by chemicals	Preserved
Scalability	Limited	High

Water Quality Benefits

1. Lowers pollutant discharge from fields, reducing environmental contamination.
2. Proven reductions in water pollution:
    a. 40–70% less nitrogen loss
    b. 12–36% less phosphorus loss
3. Modeling studies indicate 24–39% reduction in downstream nutrient delivery.
4. Acts as a natural treatment system by retaining water and allowing nutrient removal during storage.

Complementary Benefits

1. Helps control floods by capturing excess surface runoff.
2. Provides additional drainage capacity during heavy rainfall.
3. Creates habitats for fish, amphibians, reptiles, and other wildlife.
4. Supports installation of floating solar panels (floatovoltaics) for renewable energy.
5. Acts as an additional water source for various on-farm uses.
6. Enables cultivation of bioenergy crops around water storage areas.

Challenges and Demerits

1. Requires high construction costs and may reduce productive land area.
2. Economic returns can be uncertain, depending on location and water availability.
3. Needs specialized management for poorly drained soils and suitable site selection.
4. Regular monitoring of water quality is essential.
5. Risk of nitrate accumulation, leading to eutrophication and algal blooms.
6. Possible buildup of pesticide residues and pollutants in storage water.
7. Potential bioaccumulation and biomagnification in aquatic organisms.
8. Increased salinity and pH changes may threaten aquatic ecosystems.
9. Salts can cause clogging in pipes and micro-irrigation systems.

Table 1. Methods of water recycling drainage:

Method	Description	Purpose/Key benefits
Direct use	Drainage water is reused directly when salinity is within crop tolerance.	Supports irrigation needs with minimal yield reduction.
	Freshwater applied during early sensitive stages, then drainage water later.	Protects crops from early stage salinity stress.
Conjunctive use	Drainage water is mixed with good quality water.	Maintains acceptable irrigation water quality for salt sensitive crops.
Cyclic use (Intraseasonal & Interseasonal)	Planned rotation of freshwater and saline drainage water during crop growth.	Enhances water availability while minimizing salinity damage.

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	Freshwater during sensitive stages; saline water when crop tolerance increases.	Efficient water use during both seasons.
IFDM (Integrated Farm Drainage Management)	Zone-wise reuse based on crop salt tolerance (crops → trees → halophytes).	Maximizes reuse while reducing drainage volume and salinity impact.
	Final saline effluent disposed in solar evaporator to extract salts.	Prevents environmental contamination.
Reverse Osmosis (RO) powered by solar energy	Solar powered RO filtration removes salts and impurities.	Produces clean irrigation water and improves water quality.

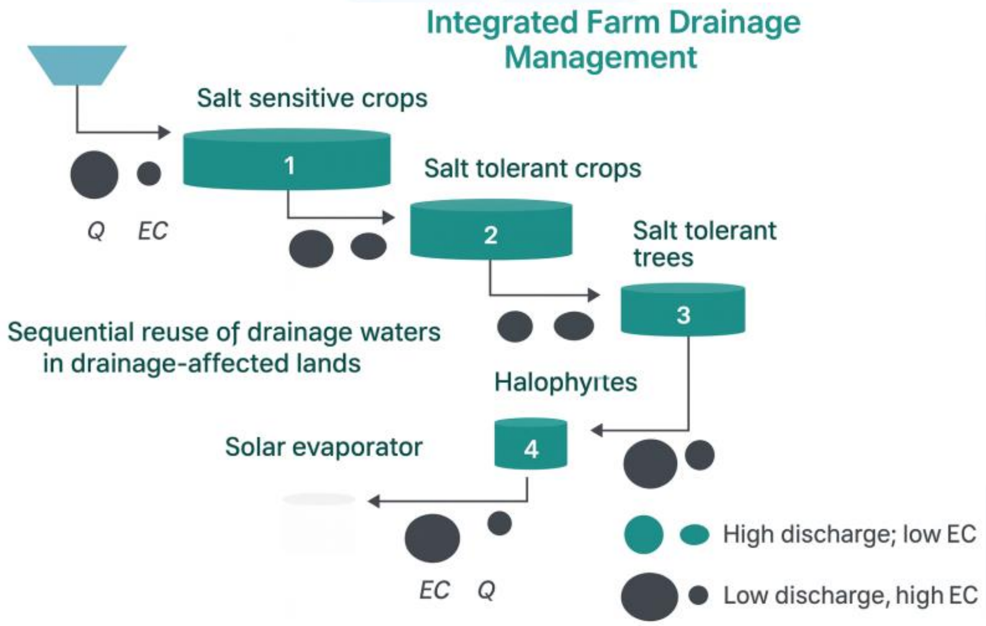

Fig 2: Integrated Farm Drainage Management

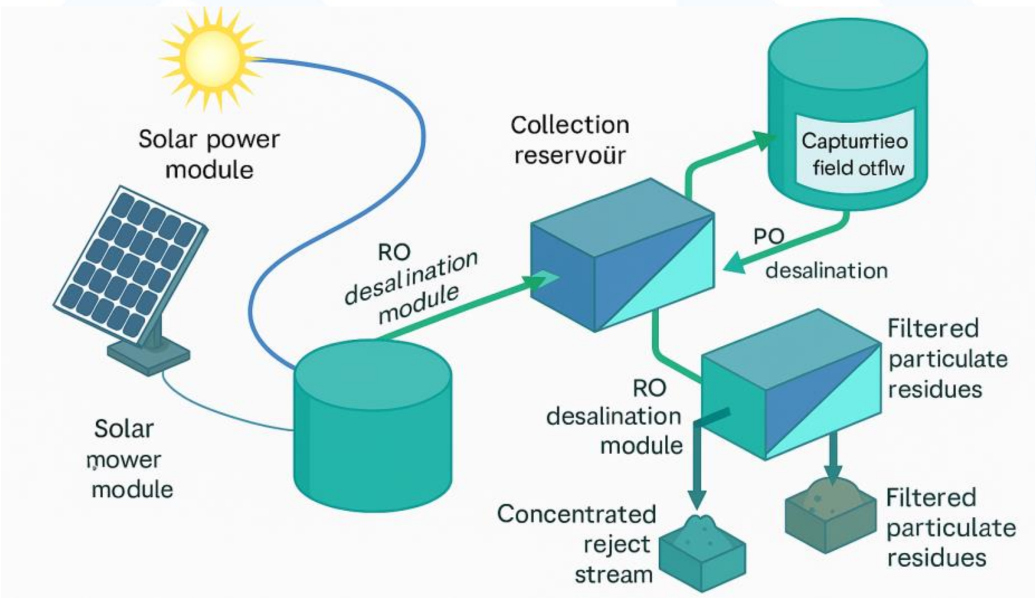

Fig 3: Reverse osmosis powered by photovoltaic systems

Studies on Drainage Water Treatment and Recycling

Research on treatment and reuse of agricultural drainage water demonstrates its potential for nutrient management, water saving, and improving crop productivity. Zero-valent iron (ZVI) and zeolite filters showed high nitrate removal (94%) and ammonium retention efficiency up to 400 PVs, suggesting a cost effective filtration approach for nutrient recycling (Florea *et. al.,* 2021). Biological measures such as oat and rye cover crops also reduced nitrate losses in drainage water by 26–48% through enhanced nitrogen uptake (Kaspar *et. al.,* 2012). Reverse osmosis (RO) systems powered by solar energy have been used to improve drainage water quality by removing excess salts, though nutrients must be replenished after treatment (Miller *et. al.,* 2020). Similar improvements in water quality and yield were observed in hydroponics using RO treated drainage effluent (Martin-Gorriz *et. al.,* 2021).

Drainage water recycling (DWR) in field crops has shown significant agronomic benefits. Reusing rice field drainage water saved 20–32% irrigation water without reducing yield in Malaysia (Ahmad *et. al.,* 2021). At ICAR-IIWM, India, integrating drainage reuse with SRI management improved rice yield by 29% and water productivity, and when combined with aquaculture and horticulture, profitability increased further (Thakur *et. al.,* 2015). Similar integrated systems such as rice–fish–poultry farming enhanced farmers' income and ensured food and nutritional security (Kathiresan, 2018). Drainage water storage ponds have also enabled successful lotus and water chestnut cultivation, providing additional revenue (Chowdhury *et. al.,* 2018).

In areas with saline drainage water, mixing with freshwater or alternate irrigation improved maize yield and water productivity while aiding leaching of salts from root zones (Nasrollahi *et. al.,* 2017). However, studies also reported possible yield penalties in sensitive crops like alfalfa under high drainage water use, though alternate irrigation strategies helped maintain yield with 50% freshwater savings (Nindwani *et. al.,* 2014). Use of fish farm drainage water for potato increased yield and water productivity but raised concerns of emitter clogging in drip irrigation systems due to suspended solids and salts (Eid and *Hoballah*, 2014).

Case studies show that storing surface runoff and tile drainage water can support supplemental irrigation sufficient to offset drought-induced yield losses (Reinhart, 2017), though drainage storage may increase salinity in local groundwater if unmanaged. Economically, integrated DWR based systems proved superior, resulting in significantly higher net returns and water productivity (Thakur *et. al.,* 2015). Additional income from aquaculture and vegetable cultivation around drainage ponds further increases profitability for farmers adopting DWR (Sahoo *et. al.,* 2006).

Table 2. Scientific findings on drainage water treatment and recycling:

S. No.	Treatment/Intervention	Major findings	Reported by
1	Zero-valent iron + zeolite filtration for nitrate removal	94% nitrate removal; high ammonium retention up to 400 PVs; cost-effective nutrient removal system	Florea *et. al.,* (2021)
2	Oat and rye cover crops in drainage areas	Reduced nitrate concentration by 26% (oat) and 48% (rye) in drainage water	Kaspar *et. al.,* (2012)
3	Reverse osmosis recycling for lettuce nutrient solution	Improved water quality, but nutrient depletion requires supplementation for plant growth	Miller *et. al.,* (2020)
4	Rice field drainage water reuse for irrigation	20–32% water saving without yield reduction and supported critical growth stages	Ahmad *et. al.,* (2021)
5	Drainage water reuse + System of Rice Intensification + Aquaculture + Horticulture	Rice yield improved by 29%, further increased by 8% with integration; significant increase in water productivity and net returns	Thakur *et. al.,* (2015)
6	Lotus and water chestnut cultivation in drainage ponds	Additional farmer income; supported paddy in adjacent fields	Chowdhury *et. al.,* (2018)
7	Rice + Fish + Poultry integrated system using drainage	80% livelihood improvement; reduced fertilizer use; enhanced productivity and nutrition	Kathiresan, (2018)

8	Mixing saline drainage water with river water for maize irrigation	Half-alternate irrigation improved yield, water productivity and leaching of surface salts	Nasrollahi *et. al.,* (2017)
9	Fish farm drainage water for potato irrigation	Higher yields and IWUE under sprinkler system; however, higher emitter clogging risk under drip	Eid and *Hoballah*, (2014)
10	Blending canal and drainage water for alfalfa	50% water saving with alternate irrigation; high drainage use reduced yield due to salinity	Nindwani *et. al.,* (2014)
11	Solar powered RO recycling for hydroponic tomato	Higher yield (6.63 *vs* 4.88 kg/m²); improved environmental benefits with 72% reduction in eutrophication	Martin-Gorriz *et. al.,* (2021)
12	On farm reservoir storing runoff and tile drainage	Supplemental irrigation increased crop yield; pond refills multiple times per season	Reinhart, (2017)
14	Vegetable cultivation + Aquaculture using drainage	Enhanced economic returns from diversified income sources	Sahoo *et. al.*, (2006)

Conclusion

Drainage Water Recycling (DWR) has shown strong potential in improving water use efficiency, crop productivity, and nutrient recovery. Zero-valent iron and zeolite filtration systems effectively remove nitrates and retain up to 70% of converted ammonium, offering scope for industrial utilization. Recycled nutrient solutions in protected cultivation significantly enhance plant growth, increasing marketable leaves by nearly 71% and leaf fresh weight by 110%. Field studies indicated that supplemental irrigation through DWR boosted grain yields by 113% in rice, 61% in corn, and 31% in soybean while saving 20–32% irrigation water in rice fields. Furthermore, modeling studies project 27–30% additional yield benefits under future climate scenarios, highlighting DWR as a promising climate-resilient water management strategy in agriculture.

Future Line of Work

Future research focusing on evaluating the quality of drainage water collected under field waterlogging conditions, along with detailed assessment of the volume captured, storage potential, and its reuse efficiency are needed. Additionally, establishing safe and optimal recycling intervals for different crops is essential to ensure sustainable and productive use of drainage water in agriculture.

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Application of UAV-Mounted Multispectral Sensors in Agriculture

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Abstract

The increasing demand for food production, together with challenges posed by climate change and limited natural resources, has necessitated the adoption of advanced technologies in agriculture. Among these, Unmanned Aerial Vehicles (UAVs) equipped with multispectral sensors have emerged as powerful tools in precision agriculture. This article explores the role and applications of UAV-mounted multispectral sensors in enhancing agricultural productivity and sustainability. UAVs provide cost-effective, flexible, and high-resolution monitoring of crop and soil conditions, while multispectral sensors capture critical spectral data that can be processed into vegetation indices such as NDVI, GNDVI, and SAVI. These technologies enable a wide range of applications, including crop health monitoring, irrigation management, nutrient optimization, weed and pest detection, yield estimation, and soil condition assessment. The integration of UAVs and multispectral sensors enhances efficiency, reduces input costs, and supports sustainable farming practices by enabling site-specific management. However, challenges such as high initial investment, technical expertise requirements, data processing demands, and regulatory restrictions limit their widespread adoption. Despite these barriers, ongoing innovations in UAV technology, sensor design, and data analytics hold significant potential to expand their accessibility and utility. Ultimately, UAV-mounted multispectral sensing represents a transformative approach to addressing global agricultural challenges, improving food security, and promoted sustainable farming systems.

Keywords: UAVs, multispectral sensors, remote sensing, crop health monitoring, vegetation indices.

Introduction

Agriculture today faces unprecedented challenges arising from climate variability, growing food demand, and the need to optimize limited natural resources. The global population is projected to approach 10 billion by 2050, placing immense pressure on agricultural systems to increase productivity while ensuring sustainability. Traditional farming practices, though effective in the past, are often inadequate in addressing issues such as resource inefficiency, environmental degradation, and yield variability under changing climatic conditions. To overcome these challenges, the adoption of precision agriculture technologies has emerged as a transformative approach. Precision agriculture enables farmers to collect, analyze, and apply data-driven insights for better decision-making at the field level. The Unmanned Aerial Vehicles (UAVs), commonly known as drones, have gained prominence due to their ability to provide real-time, high-resolution, and site-specific information. UAVs offer significant advantages over conventional ground-based monitoring and satellite imaging, particularly in terms of flexibility, cost-effectiveness, and spatial accuracy. Among the various sensing technologies integrated with UAVs, multispectral sensors have proven especially valuable for agricultural applications. These sensors capture data across different spectral bands, including visible and near-infrared wavelengths, which are essential for assessing plant health, detecting stress, and monitoring field conditions. In the processing of this spectral information into vegetation indices such as the Normalized Difference Vegetation Index (NDVI), farmers can make informed decisions regarding irrigation, fertilization, pest management, and yield forecasting. Thus, the mounted of UAV platforms and multispectral sensors represents a powerful tool for addressing the critical challenges of modern agriculture. It enhances efficiency, reduces resource wastage, and supports sustainable farming practices, ultimately contributing to global food security.

UAVs in Agriculture

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, are aircraft systems that operate without an onboard human pilot and are either remotely controlled or autonomously guided through pre-programmed flight paths. In the perspective of agriculture, UAVs serve as versatile platforms for carrying sensors, cameras, and other instruments to collect valuable spatial and temporal information about crop and soil conditions (Sahni et al., 2024, Kumar et al., 2024). Their application in precision farming has expanded rapidly due to their ability to deliver high-resolution data at relatively low operational costs compared to traditional methods.

Types of UAVs

UAVs deployed in agriculture can be broadly categorized into three types:

1. **Fixed-wing UAVs**: Characterized by airplane-like wings, they are suitable for covering large agricultural fields due to their longer flight endurance and higher speeds. However, they typically require runways or launch systems for takeoff and landing.

2. **Rotary-wing UAVs**: Also known as multirotor drones, these UAVs provide greater maneuverability and are capable of vertical takeoff and landing. They are especially useful for smaller fields, detailed inspections, and hovering over specific areas for targeted data collection.

3. **Hybrid UAVs**: Combining the endurance of fixed-wing designs with the vertical takeoff and landing capability of rotary-wing systems, hybrid UAVs are increasingly being adopted for diverse agricultural tasks requiring both range and flexibility.

Multispectral Sensors: An Overview

Multispectral sensors are critical components in modern agricultural monitoring systems, particularly when integrated with UAV platforms. These sensors capture reflected electromagnetic radiation across discrete spectral bands rather than just the visible light detectable by the human eye. The principle of multispectral imaging lies in measuring reflectance from vegetation at different wavelengths, which provides insights into crop health, stress levels, and overall field conditions. In the analyzing variations in reflectance, farmers can obtain quantitative indicators of plant vigor and detect issues such as nutrient deficiencies, water stress, or pest infestations at an early stage.

Spectral Bands in Agriculture

Several spectral regions are especially relevant for agricultural applications:

1. **Visible (RGB) bands**: These include red, green, and blue wavelengths, which correspond to the range detectable by human vision. RGB imagery is valuable for general crop monitoring, visual inspection, and mapping field boundaries.

2. **Near-Infrared (NIR) band**: Plants strongly reflect NIR radiation due to their internal leaf structure. Healthy vegetation typically shows high NIR reflectance, making this band essential for assessing biomass and crop vigor.

3. **Red-edge band**: Located between the red and near-infrared regions, the red-edge is particularly sensitive to changes in chlorophyll content. This band is highly effective in detecting subtle stress in plants before visible symptoms appear.

Common Vegetation Indices Derived

The combination of reflectance values from different spectral bands enables the calculation of vegetation indices, which are mathematical indicators used to quantify plant health and field variability. Some commonly used indices include:

1. **Normalized Difference Vegetation Index (NDVI)**: Derived from red and NIR reflectance, NDVI is one of the most widely used indices for assessing vegetation greenness and vigor.

2. **Soil-Adjusted Vegetation Index (SAVI)**: An enhancement of NDVI that minimizes the influence of soil background, making it particularly useful in areas with sparse crop cover.

3. Green Normalized Difference Vegetation Index (GNDVI): Utilizes green and NIR bands to evaluate chlorophyll concentration and is highly effective for detecting nitrogen deficiencies in crops.

Through these indices, multispectral sensors provide actionable data that guide site-specific agricultural management. By integrating spectral information with UAV-based platforms, farmers can monitor crop performance dynamically, enabling early intervention and precise input application.

Integration of UAVs and Multispectral Sensors

The integration of multispectral sensors with UAV platforms has significantly advanced the scope of precision agriculture by enabling real-time, high-resolution monitoring of crops. This synergy ensures that spectral data can be collected efficiently across large areas with minimal manual effort, thereby facilitating informed decision-making for agricultural management. Successful integration requires careful consideration of hardware compatibility, flight operations, and data processing techniques.

Mounting Techniques and Sensor Compatibility

Multispectral sensors can be mounted on various UAV platforms depending on their design and payload capacity. Rotary-wing UAVs often carry lightweight, compact multispectral cameras using gimbals that stabilize the sensor during flight, ensuring image clarity and consistency. Fixed-wing UAVs, on the other hand, are typically equipped with integrated or belly-mounted sensors that provide broader coverage. Compatibility between the UAV and the sensor is crucial, as factors such as weight, power consumption, and communication interfaces directly influence flight performance and data quality. Increasingly, modular UAV designs allow for flexible sensor integration, enabling farmers and researchers to select sensors based on specific crop-monitoring objectives.

Data Acquisition Process

The process of data collection using UAV-mounted multispectral sensors involves meticulous planning to ensure accuracy and reliability. Flight planning software is typically employed to define flight paths, altitude, and overlap between images, ensuring adequate coverage of the target field. During the mission, the UAV captures images at specific spectral bands while maintaining geo-referenced positioning through GPS systems. Calibration panels are often used before and after flights to correct for varying light conditions, ensuring that reflectance data is consistent and comparable over time. Geo-referencing aligns the captured imagery with field coordinates, allowing precise mapping of spatial variability across the farm.

Software Platforms for Image Processing and Analysis

The real-time multispectral data collected by UAVs require specialized software tools for processing and analysis. Image stitching software combines overlapping images into orthomosaics, creating seamless field maps. Advanced platforms further process this data to generate vegetation indices such as NDVI, GNDVI, and SAVI, which highlight crop stress, vigor, and nutrient distribution. Cloud-based platforms and Geographic Information Systems (GIS) are increasingly being used to store, analyze, and visualize large datasets, providing user-friendly dashboards for farmers. These tools not only enhance interpretation but also enable integration with variable-rate technologies for site-specific management of irrigation, fertilization, and pesticide application.

Applications in Agriculture

The use of UAV-mounted multispectral sensors has opened new avenues for precision agriculture by providing actionable insights that support site-specific management practices. By capturing crop and soil data across multiple spectral bands, these systems enable farmers to detect variability within fields and respond with tailored interventions. The following applications illustrate their wide-ranging utility in modern agriculture.

Crop Health Monitoring

Multispectral imagery allows for early detection of crop stress, nutrient deficiencies, or diseases that may not be visible to the naked eye. Indices such as the Normalized Difference Vegetation Index (NDVI) and Red-Edge Chlorophyll Index provide accurate indicators of chlorophyll concentration and plant vigor. Early identification of stressed areas enables farmers to implement corrective measures promptly, thereby minimizing yield losses and reducing input costs.

Irrigation Management

The water scarcity and inefficient irrigation practices pose major challenges in agriculture. UAV-mounted multispectral sensors can detect subtle changes in canopy reflectance related to water stress, particularly through the near-infrared and red-edge bands. This information allows farmers to optimize irrigation schedules, apply water only where necessary, and avoid over-irrigation. As a result, water use efficiency is improved, supporting both crop productivity and sustainable resource management.

Nutrient Management

Efficient nutrient application is critical for maximizing crop yields while minimizing environmental impacts. Multispectral data can be used to assess nutrient levels especially nitrogen by analyzing vegetation indices such as the Green Normalized Difference Vegetation Index (GNDVI). These insights support variable-rate fertilizer application, ensuring that nutrients are applied precisely where and when they are needed. This not only improves crop health but also reduces fertilizer wastage and leaching into the environment.

Weed and Pest Detection

Uncontrolled weed growth and pest infestations can significantly reduce agricultural productivity. UAV-mounted multispectral sensors can map infestations by identifying areas with abnormal reflectance patterns. By distinguishing between crop and weed species or detecting stressed zones caused by pest activity, farmers can target pesticide and herbicide applications only where necessary. This approach reduces chemical usage, lowers costs, and minimizes environmental contamination.

Yield Estimation

Accurate yield prediction is essential for farm management and supply chain planning. Multispectral imagery enables estimation of biomass, leaf area index, and canopy cover, all of which are correlated with crop yield. UAV-based monitoring throughout the growing season provides continuous updates on crop development, helping farmers forecast productivity and make informed decisions regarding harvest planning and market strategies.

Soil Condition Assessment

Although multispectral sensors primarily capture crop canopy data, they can also be used to assess soil conditions indirectly. Bare soil imagery provides insights into soil variability, organic matter content, and moisture levels. In the mapping these variations, farmers can develop soil management strategies tailored to specific zones, leading to improve field uniformity and long-term soil health.

Benefits to Farmers and Agriculture

The integration of UAV-mounted multispectral sensors into agricultural practices offers significant benefits to farmers by enhancing efficiency, productivity, and sustainability. These systems enable precise monitoring of crop and soil conditions, allowing resources such as fertilizers, pesticides, and water to be applied only where needed, thereby reducing input costs and minimizing environmental impacts. By supporting site-specific management, they promote sustainable farming practices that conserve resources while maintaining soil and crop health over the long term. Furthermore, the availability of real-time, high-resolution data empowers farmers to make informed decisions quickly, whether in response to emerging crop stress, irrigation needs, or yield forecasting. Collectively, these advantages not only improve farm profitability but also contribute to greater food security and resilience in the face of climatic and resource-related challenges.

Conclusion

The integration of UAV-mounted multispectral sensors in agriculture represents a significant advancement in the transition toward data-driven, sustainable farming systems. By combining the flexibility and spatial precision of UAVs with the analytical capabilities of multispectral imaging, farmers gain access to real-time, high-resolution insights into crop health, soil conditions, and field variability. These technologies enable early detection of stress, optimization of irrigation and nutrient management, accurate yield estimation, and targeted pest and weed control, all of which contribute to enhanced productivity and resource efficiency. At the same time, their adoption supports sustainable practices by reducing input wastage and minimizing environmental impacts. However, challenges such as high initial investment, technical expertise requirements, data management complexities, and regulatory constraints must be addressed to ensure broader accessibility, especially for smallholder farmers. Looking ahead, continued innovation in UAV endurance, sensor technology, artificial intelligence, and user-friendly data platforms is expected to expand the applicability of these tools. Ultimately, UAV-mounted multispectral sensors have the potential to transform modern agriculture into a more resilient, efficient, and sustainable system capable of meeting the growing global demand for food security.

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Harnessing Cold Plasma for Longer-Lasting Fruits - A New Era of Smart, Clean, and Safe Post-Harvest Technology

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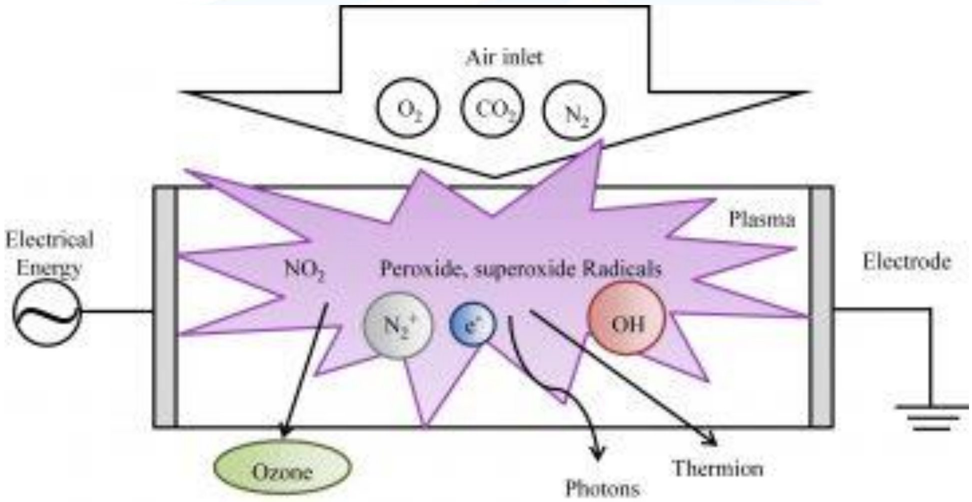
Ensuring the freshness and quality of fruits after harvest has always been a major challenge for growers, traders, and consumers. In many parts of the world, a large portion of fruits never reach the market in good condition due to rapid microbial spoilage, moisture loss, and temperature fluctuations during storage and transportation. These losses not only reduce farmers income but also increase food waste at a time when sustainable food systems are urgently needed. As consumers demand cleaner, safer, and chemical-free produce, the search for modern post-harvest solutions has brought cold plasma technology into the spotlight. This innovative, eco-friendly method is now emerging as one of the most promising tools for extending fruit shelf life without compromising quality.

Science Behind Cold Plasma

Cold plasma may sound complex, but the concept is simple and fascinating. Plasma is often described as the "fourth state of matter," formed when gases are energized to produce a mixture of electrons, ions, and reactive molecules. Unlike the extremely hot plasma seen in lightning or welding, cold plasma operates close to room temperature, making it gentle enough for delicate fruits. When this energized gas comes in contact with fruit surfaces, it interacts with microorganisms and weakens their structure, significantly reducing the growth of spoilage-causing organisms. Importantly, this process does not leave any chemical residues, does not heat the fruit tissue, and does not alter flavour or nutritional composition.

Why Post-Harvest Spoilage Happens and How Cold Plasma Helps

Fruits remain biologically active even after harvest—they continue to respire, soften, and lose moisture. This natural physiological process makes them more vulnerable to spoilage under warm or humid conditions. Microorganisms present on the fruit surface take advantage of these changes, multiplying rapidly and causing visible decay. Traditional methods like refrigeration, waxing, chlorine washing, or chemical fungicides can slow this deterioration, but each comes with limitations. Some methods are costly, some leave chemical residues, and others offer only partial protection. Cold plasma, in contrast, works by directly targeting surface microorganisms while also influencing natural plant responses that slow ripening and senescence. This dual action makes it a powerful alternative for maintaining quality during storage and transport.



How Cold Plasma is Applied in Post-Harvest Handling

Cold plasma can be delivered through two main approaches, both suitable for commercial and small-scale use. In the direct treatment method, fruits are placed inside a chamber where the plasma surrounds their surface, forming reactive molecules that act against microbial cells. This treatment is quick, often lasting only a few minutes, and requires no additional chemicals. The second approach uses plasma-activated water, where water is exposed to cold plasma to enrich it with reactive species. This specially treated water can then be used to wash fruits, offering gentle decontamination while maintaining natural appearance and freshness. Both methods are energy-efficient, safe, and adaptable to different stages of the supply chain.

Advantages for Shelf Life, Quality, and Food Safety

One of the most remarkable advantages of cold plasma is its ability to extend shelf life without altering the fruits natural characteristics. Treated fruits tend to maintain their firmness, colour, and freshness for longer periods, even under ambient storage conditions. Cold plasma reduces microbial load more effectively than many conventional sanitizers, providing a safer alternative to chemical treatments that may leave residues. It also helps in minimizing physiological disorders, reducing water loss, and delaying softening all of which contribute to better visual and nutritional quality. For consumers, this means fresher and safer fruits with longer storage life at home. For producers and retailers, it means reduced losses, improved market value, and access to distant or premium markets.

Cold Plasma as a Sustainable Post-Harvest Innovation

Sustainability is at the heart of modern agriculture, and cold plasma aligns well with global efforts to create eco-friendly food systems. The technology requires only electricity and air or inert gases, resulting in minimal environmental impact. Because it eliminates or reduces the need for chemical fungicides and sanitizers, it supports clean-label and organic markets. Cold plasma also helps reduce food waste a key global challenge by slowing spoilage and maintaining quality over longer periods. Lower carbon emissions from reduced cold storage requirements and reduced dependency on synthetic chemicals further strengthen its role as a green post-harvest solution.

Challenges

While the potential of cold plasma is immense, certain challenges must be addressed for large-scale adoption. The initial cost of equipment can be high, especially for small and medium enterprises. Standardized treatment protocols are still being developed to ensure uniformity and safety across different fruit types and storage conditions. Awareness among farmers, exporters, and packhouse operators remains limited, and training is essential to ensure proper handling and usage. Despite these constraints, ongoing research, improved designs, and greater interest from the agri-food industry are rapidly overcoming these limitations. As the technology becomes more affordable and user-friendly, cold plasma is expected to become a mainstream post-harvest tool.

A Promising Future for Fresh, Safe, and Market-Ready Fruits

Cold plasma represents a major leap forward in post-harvest horticulture. By combining scientific innovation with practical advantages, it offers a powerful solution to the age-old problem of fruit spoilage. Its ability to extend shelf life, enhance safety, reduce waste, and support sustainable agriculture makes it a transformative technology for the future. As global food systems continue to evolve, cold plasma stands out as a smart, clean, and reliable method that can benefit farmers, retailers, and consumers alike. With continued research and wider adoption, cold plasma has the potential to revolutionize the way fruits are preserved—ushering in a new era where freshness lasts longer and quality remains uncompromised.

Conclusion

Cold plasma technology marks an exciting turning point in post-harvest horticulture. At a time when consumers demand safer produce and farmers struggle with post-harvest losses; this clean and innovative method offers a practical and sustainable solution. By gently reducing microbial spoilage, preserving natural freshness, and extending shelf life without chemicals, cold plasma bridges the gap between scientific advancement and everyday food safety. Its ability to maintain quality while reducing waste makes it especially valuable in today's resource-conscious world. Although challenges like cost and awareness still exist, rapid progress in research and technology is steadily paving the way for wider adoption. As the horticulture sector moves toward smarter and more eco-friendly approaches, cold plasma stands out as a breakthrough that can transform how fruits are handled, stored, and enjoyed. It represents not just a technological innovation but a promising step toward a future where long-lasting, high-quality fruits are easily accessible to all.

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Beyond the Naked Eye: AI-Powered Hyperspectral Imaging Redefines Fruit Quality

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In today's fast-moving food market, consumers expect fruits to be fresh, clean, and safe every time they pick something from the shelf. Yet, identifying true quality has always been challenging. Fruits may look perfect from the outside but still have hidden defects, bruises, or early stages of spoilage. Until recently, most quality checks relied on human eyes and basic sorting techniques, which can miss subtle internal problems. Now, a fascinating blend of hyperspectral imaging and artificial intelligence (AI) is transforming how fruit quality is evaluated—making the process more accurate, scientific, and reliable than ever before.

Seeing Beyond the Surface with Hyperspectral Imaging

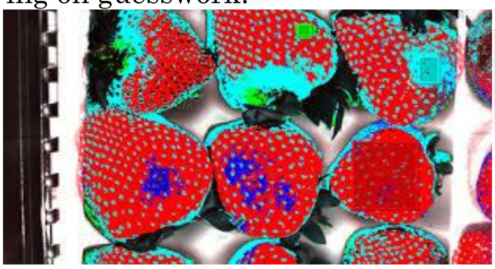
Hyperspectral imaging is often described as a technology that allows us to "see the invisible." While normal cameras capture images in three colours—red, green, and blue—hyperspectral cameras capture hundreds of wavelengths at once. This allows them to detect chemical and structural information hidden beneath the fruit's surface. Every fruit has a unique spectral signature that reflects its maturity, sugar level, firmness, and internal composition. Hyperspectral sensors record all this information instantly, without cutting or damaging the fruit. The result is a powerful tool that can reveal early-stage rots, bruises, or nutrient imbalances long before they become visible.

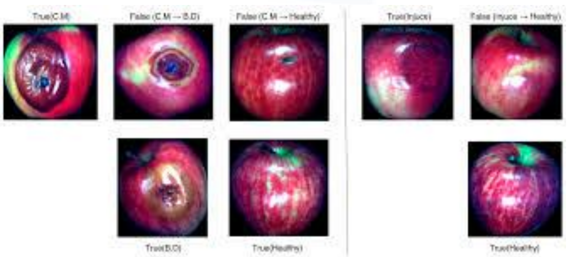
How AI Turns Images into Intelligent Decisions

Collecting hyperspectral images is only the first step. The real magic happens when AI analyses this huge amount of data. Machine learning algorithms study thousands of spectral patterns and learn to identify what "good quality" and "poor quality" look like. Deep learning models take it a step further by learning subtle patterns that even trained experts may not notice. Together, AI and hyperspectral imaging can classify fruits by ripeness, detect early fungal infections, predict shelf life, and even estimate internal sweetness—without touching or harming the fruit. This makes the grading process faster, more consistent, and far more accurate than human inspection alone.

A New Era of Smart Sorting and Packaging

In packhouses and warehouses, smart hyperspectral systems are now being integrated into conveyor belts and automated sorting lines. As fruits pass under the sensor, they are scanned in milliseconds, and AI instantly decides whether they belong in premium, regular, or processing-grade categories. This ensures that only top-quality fruits reach high-value markets, while those that might spoil early are diverted to juice, jam, or other processing industries. Such precision prevents waste, increases profits, and builds trust between producers and consumers. Even small farmers benefit when quality sorting is done scientifically instead of relying on guesswork.





Better Shelf-Life Predictions for Retailers

One of the biggest challenges in the fruit supply chain is predicting how long produce will stay fresh. With hyperspectral imaging, the internal condition of each fruit can be assessed more accurately. AI models use this information to estimate storage life, helping retailers decide which batches should be sold first and which can be stored longer. This prevents premature spoilage, reduces financial losses, and ensures customers always get fruits at their best. By combining real-time data with predictive algorithms, retailers can make smarter decisions that improve both quality control and sustainability.

Enhancing Consumer Confidence and Food Safety

Consumers are increasingly concerned about chemical residues, hidden defects, and the freshness of the fruits they buy. Technologies like hyperspectral imaging offer an extra layer of assurance by enabling non-destructive testing. Instead of cutting, squeezing, or relying on dyes, fruits can now be evaluated scientifically without any physical contact. This enhances food safety, maintains hygiene standards, and supports the demand for clean, high-quality produce. Over time, such technologies will help build greater transparency in the food supply chain, ultimately benefiting both producers and consumers.

The Future: Affordable, Portable, and More Powerful

What once seemed like space-age technology is rapidly becoming more accessible. Researchers are developing compact hyperspectral cameras and mobile-phone-based versions that farmers may one day carry into orchards. With AI becoming faster and more affordable, the cost of these systems is gradually decreasing. As cloud computing, IoT, and automation integrate further into agriculture, hyperspectral imaging will become a standard tool—not just in packhouses, but also in farms, markets, and supermarkets. The future of fruit quality assessment will be faster, cleaner, and more reliable, driven by intelligent systems that ensure every fruit delivered is as fresh and safe as promised.

Conclusion

Hyperspectral imaging and AI together are rewriting the rules of fruit quality assessment. By capturing detailed information beyond what the human eye can see and converting it into actionable insights, these technologies offer a smarter way to grade, sort, and predict fruit quality. They reduce waste, improve efficiency, support food safety, and strengthen trust throughout the supply chain. As the world moves toward smarter post-harvest systems, hyperspectral imaging and AI stand out as game changers—ushering in a future where freshness is not a guess but a guarantee.

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Edible Coatings: A Simple Tool to Cut Postharvest Losses

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Introduction

Edible coatings are thin, consumable polymeric layers that function as semi-permeable barriers to gases (O_2, CO_2, C_2H_4), moisture and solute migration on fresh produce. They create a localized modified atmosphere that reduces respiration rate, delays ripening and suppresses microbial activity. Their performance is influenced by coating composition, film thickness, gas-permeability properties, commodity physiology and storage environment. Applied through dipping, spraying or brushing, edible coatings must use GRAS (Generally Recognized as Safe) food-grade materials. Their primary scientific roles are to control mass transfer, slow metabolic processes and maintain physicochemical quality during postharvest storage.

Characteristics of Ideal Edible Coatings

An ideal edible coating:
1. Remains stable and continuous under high relative humidity and adequately covers the entire product surface.
2. Does not deplete oxygen or cause excessive carbon dioxide build-up; around 1–3% oxygen is needed to avoid anaerobic respiration.
3. Reduces water vapour permeability and thus weight loss.
4. Improves appearance (gloss), maintains structural integrity and helps retain flavour and aroma.

Types of Edible Coatings

Edible coatings are based mainly on polysaccharides, proteins, lipids or their combinations. No single group alone provides all required barrier properties, so blends are often used.

1. Polysaccharide-based coatings (starch, pectin, cellulose, chitosan, alginate): Excellent oxygen and aroma barriers and provide good mechanical strength but are poor moisture barriers because of their hydrophilic nature. Their ordered hydrogen-bonded structure and low solubility give strong oxygen barrier properties, allowing ripening delay and shelf-life extension without severe anaerobiosis.

2. Protein-based coatings (soy protein, whey protein, casein, corn zein, egg albumin, collagen, wheat protein): Similar to polysaccharides, they are very good oxygen, aroma and oil barriers and give structural integrity but are not strong moisture barriers. Their dense network and specific amino acids (e.g., cysteine) can inhibit polyphenol oxidase and reduce browning. Whey protein with fatty components shows improved moisture barrier properties.

3. Lipid-based coatings (beeswax, mineral oil, vegetable oil, acetylated monoglycerides, carnauba wax, paraffin wax, surfactants): Provide good water vapour barrier due to low polarity but limited oxygen barrier because of microscopic pores and higher solubility and diffusivity. They are often opaque and relatively inflexible.

4. Composite coatings: Combinations of polysaccharides, proteins and lipids improve overall performance. For example, plasticized protein films have good mechanical properties, and a casein–acetylated monoglyceride film on lightly processed apples and potatoes can reduce moisture loss and oxidative browning for longer periods.

Examples of Edible Coating Systems

Nature Seal (NS): Cellulose-based coating for fresh-cut apples and potatoes that forms a moist, low-pH film, slows browning and nutrient loss, and limits oxygen entry to extend shelf life.

Chitosan coatings: Cationic polysaccharide from crustacean shells that delays ripening, reduces respiration and water loss, maintains firmness and vitamin C, and suppresses mould growth.

Corn-zein coatings: Corn protein film that is a strong oxygen barrier, delays colour change, reduces weight loss and ethanol buildup, and helps maintain firmness.

Mineral oil-based coatings: Strong moisture barrier used on crops like bell pepper to reduce water loss, wilting and shrivelling, keeping fruits firm and fresh.

Wax coatings (paraffin, beeswax, carnauba): Food-grade waxes that replace natural wax, reduce water loss, seal minor injuries and restore surface shine.

Whey protein and casein coatings: Milk-protein films, plasticized with agents like glycerol or sorbitol, that improve flexibility, reduce spoilage, extend shelf life and act as oxygen barriers to delay browning.

Carbohydrate–lipid coatings (Pro-long, Semperfresh): Sucrose ester– and CMC-based systems with mono-/diglycerides that form selectively permeable barriers, reducing water loss, gas exchange, ripening and spoilage during storage and marketing.

Additives and their Roles

Additives commonly incorporated into coatings or films include:

1. **Soy protein:** Improves moisture and gas barrier properties of cellulose-based systems like Nature Seal.
2. **CMC (carboxymethyl cellulose):** Enhances antioxidative potential of casein and whey films and can chelate metals, reducing polyphenol oxidase activity.
3. **Ascorbic acid:** Delays browning when added to coating solutions.
4. **Sodium benzoate and potassium sorbate:** Control microbial populations.
5. **Acidulants and beeswax:** Improve control of browning and microbial growth; beeswax can also decrease respiration rates.
6. **Plasticizers (glycerol, sorbitol, stearic acid):** Glycerol and sorbitol reduce respiration rate and weight loss and increase flexibility; stearic acid improves moisture barrier and reduces white blush in carrots.
7. **Emulsifiers/surfactants:** Improve uniform coverage and film formation, enhance ripening control and can aid dissolution of components like chitosan (with glacial acetic acid), leading to better colour development and reduced pathogen invasion.

Methods of Application

1. **Dipping:** Most common; produce is dipped for 5–30 seconds, suitable for beans and highly perishable fruits like strawberries and berries.
2. **Brushing:** Often used for wax coatings on larger fruits.
3. **Spraying:** Common in packinghouses for uniform coverage.
4. **Extrusion and solvent casting:** Used mainly in industrial processing to form films.

Aspect	Advantages	Limitations
Shelf life	Delay ripening and senescence; extend storage and marketing period.	Overly thick coatings can restrict gas exchange and cause off-flavours (ethanol accumulation).
Quality	Better retention of colour, flavour, acids, sugars and firmness; reduced shrivelling and weight loss.	If gas balance is poorly managed, may lead to physiological disorders or textural defects.
Safety	Use food-grade, edible, often biodegradable materials; can replace some synthetic coatings.	Protein- or nutrient-rich coatings can support microbial growth if the cold chain is broken.
Functionality	Provide moisture and gas barriers; can carry antimicrobials, antioxidants and nutrients.	Formulation and application need commodity-specific optimisation; data still limited for many.

Economics	Reduce postharvest losses, storage diseases and disorders; improve marketable yield.	Additional processing steps and materials may increase handling complexity and cost.
Appearance	Improve gloss and overall visual appeal, enhancing consumer acceptance.	Non-uniform or cracked films can look patchy and may negatively affect appearance.

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Dairy Farming in Haryana

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Dairy Farming in Haryana: A Pillar of Rural Economy

Dairy farming is a cornerstone of Haryana's agricultural sector and a vital driver of its rural economy, providing a stable source of income and employment to a large number of farmers. With favorable agro-climatic conditions, fertile land for fodder cultivation, and a strategic location close to major markets like Delhi, Haryana is recognized as one of the best states for dairying in India.

This article explores the economic importance of dairy farming in Haryana, the prominent breeds, the challenges faced by farmers, and the governmental support aimed at modernizing this key sector.

Economic Significance and Production

Dairy farming is central to the socio-economic life of Haryana, contributing significantly to the state's agricultural GDP and providing livelihood to a vast rural population.

Milk Production: The state produces an estimated 115.29 lakh tonnes of milk annually (2023), contributing about 5.25% of India's total milk production (as of 2023).

Per Capita Availability: Haryana has a high per capita per diem availability of milk, which significantly exceeds the national average.

Livelihood: Dairy farming offers year-round employment, which is crucial for small and marginal farmers and landless laborers, enhancing their socio-economic status. Market Growth: The Haryana dairy market is projected for substantial growth, indicating an expanding and robust sector.

Key Breeds of Haryana

The state is home to some of the country's most prominent milch breeds, known for their high productivity, which is the backbone of its strong dairy sector.

Murrah Buffalo: This breed is the most dominant and prized dairy animal, often called the "Black Gold" of India. It is renowned globally for its high milk yield and high butterfat content.

Indigenous Cows: Breeds such as Sahiwal (known for its milk production and heat resistance) and Hariana cows are significant contributors.

Crossbred Cows: The use of crossbred cows is increasing, particularly in larger commercial setups, due to their higher milk production potential compared to pure indigenous cows.

	
Murrah Buffalo	**Sahiwal cow**

The Cultivation and Management Process

Dairy farming requires specialized management, focusing on animal health, nutrition, and reproduction.

Housing: Proper housing is essential to protect animals from weather extremes and ensure hygiene, often using well-ventilated sheds.

Fodder and Feeding: Farmers focus on providing a balanced diet, including green fodder (like maize, jowar, and berseem) and concentrated feed, which directly impacts milk quality and yield.

Breeding: Modern dairy farms utilize Artificial Insemination (A.I.) services to improve breed quality and genetic potential, particularly for Murrah buffaloes and high-yielding cow breeds.

Health Care: Regular veterinary check-ups, timely vaccinations, and deworming programs are critical to prevent common diseases and maintain herd health.

Challenges Faced by Dairy Farmers

Despite its growth, the dairy sector in Haryana faces several operational and economic constraints.

High Input Costs: The high cost of compound feed and fodder is a major constraint, directly reducing farmers' profit margins.

Credit and Finance: Many small farmers struggle with the high initial investment required for quality animals and modern equipment, often facing challenges with high-interest rates on loans.

Climate Vulnerability: Similar to crops, dairy operations are sensitive to extreme weather, and unpredictable climate change can stress animals and reduce milk production.

Marketing and Prices: Farmers often face problems related to poor marketing facilities, lack of efficient transportation, and less remunerative prices for their milk due to market complexities and the role of middlemen.

Technical Knowledge: A lack of specialized dairy training and knowledge about the control of contagious diseases hinders productivity improvement.

Government Initiatives and Support

The Haryana government has implemented various schemes to promote and modernize the dairy sector, focusing on breed improvement, financial assistance, and infrastructure.

Hi-Tech and Mini Dairy Units Scheme: This scheme provides financial assistance (subsidies and interest subvention) for establishing modern, commercially viable dairy units of various sizes (e.g., 4, 10, 20, and 50 milch animals).

Rashtriya Gokul Mission (RGM): A central scheme focused on the conservation and development of indigenous bovine breeds like Hariana and Sahiwal through genetic upgradation.

Intensive Murrah Development Programme: A specific program to promote and develop the Murrah buffalo breed, including providing incentives for rearing superior male calves for breeding purposes.

Veterinary and A.I. Support: Provision of free vaccination and subsidized Artificial Insemination (A.I.) services to improve breed quality and ensure animal health.

Way Forward and Future Prospects

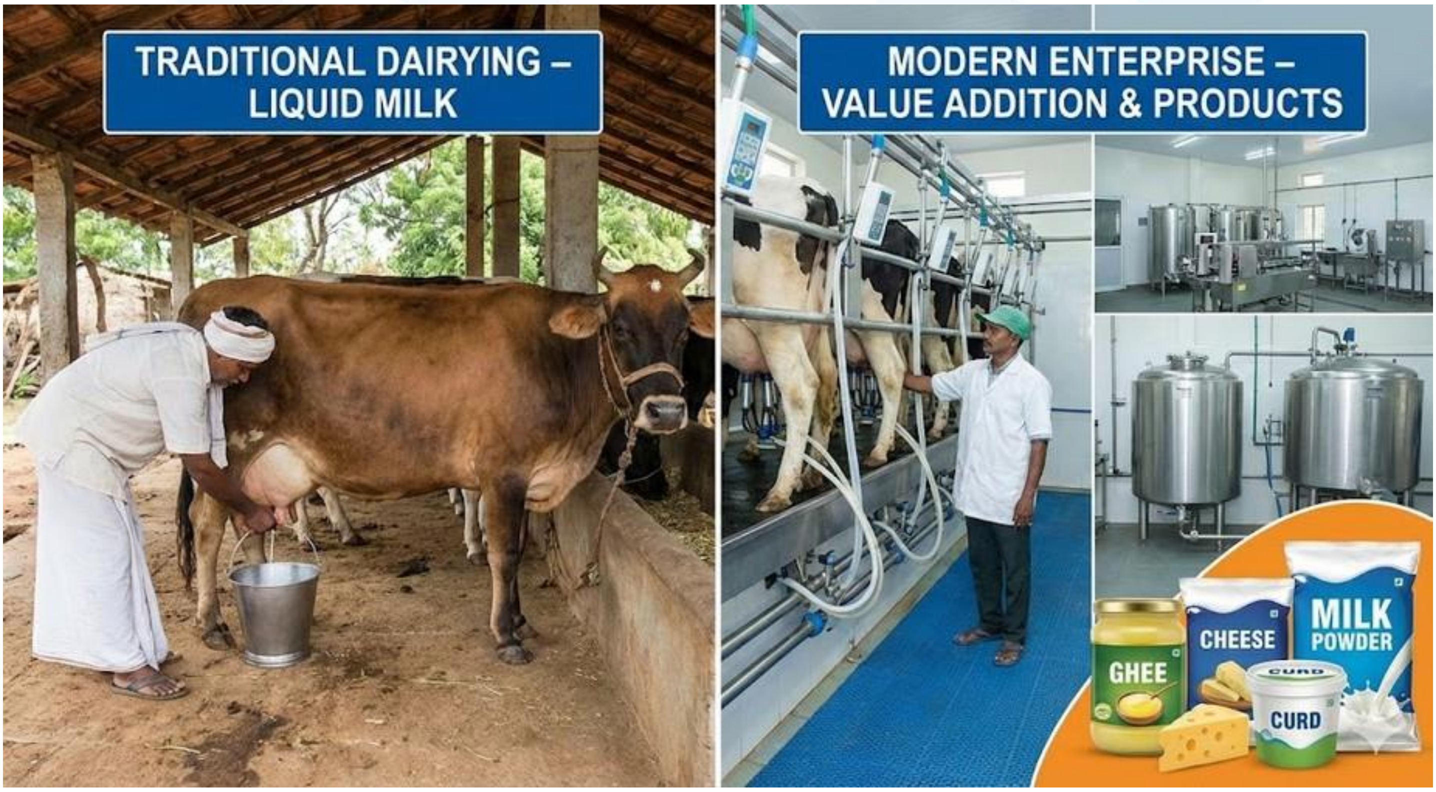
For sustainable success, the Haryana dairy sector needs to transition to a commercially viable and modern enterprise. Key focus areas include:

Value Addition: Encouraging farmers to move from just selling liquid milk to producing and marketing value-added products like cheese, ghee, curd, and milk powder, which fetch higher margins.

Fodder Security: Investing in research for high-yielding, resilient, and affordable fodder varieties to secure feed supply.

Infrastructure: Strengthening the cold chain, transportation, and bulk milk chilling centers to reduce spoilage and improve market access.

Skills and Training: Providing specialized training to farmers in modern dairy management, nutrition, and disease control.



Conclusion

Dairy farming in Haryana is more than a traditional activity; it is a story of economic transformation and resilience. Fueled by the genetic superiority of the Murrah buffalo and growing government support, the sector is key to rural prosperity. By adopting modern technology and embracing value addition, Haryana can strengthen its position as a leading dairy state in India, ensuring the crisp, white milk reaching consumers is the result of hard work and a deep connection between the land and its people.

Would you like me to find information on the subsidy amount provided under the Hi- Tech and Mini Dairy Units Scheme?

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Robust Statistical Models for Agriculture

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Introduction

Robust statistical models have become indispensable tools in modern agricultural research, where datasets are often affected by irregularities, non-normal distributions, missing values, measurement errors, and environmental variability. Agriculture is inherently influenced by complex biological, climatic, and management factors that introduce noise and anomalies into data. Traditional statistical methods tend to assume clean, normally distributed datasets, which rarely hold true in real-world agricultural experiments. Consequently, robust statistical approaches, designed to minimize the influence of outliers and model deviations, play a crucial role in improving the reliability, accuracy, and interpretability of agricultural analyses. These models ensure that agricultural decisions—whether related to crop improvement, climate adaptation, yield forecasting, or resource optimization—are grounded in stable and trustworthy statistical evidence.

Robust Methods for Design of Experiments

One of the major applications of robust methods in agriculture lies in field experimentation and crop varietal evaluation. Classical linear models, such as ANOVA and regression, are highly sensitive to outliers caused by extreme weather events, pest attacks, or operational errors in field trials. Robust regression techniques such as M-estimators, Least Trimmed Squares (LTS), and MM-estimators provide more stable parameter estimates under such deviations. These methods reduce the influence of aberrant observations and give more reliable insights into treatment differences, genotype performance, and agronomic responses. For instance, robust ANOVA procedures help detect true varietal differences even when plot yields exhibit high variability or contain atypical values due to localized stresses. This is particularly important in multi-location trials where heterogeneity across environments and differing soil fertility conditions often introduce outliers that can distort conclusions if traditional models are used.

Robust Multivariate Methods

Robust multivariate methods have also gained prominence in agricultural research, especially for analyzing complex datasets involving multiple correlated traits. Techniques such as robust principal component analysis (RPCA) and robust clustering allow researchers to explore multidimensional relationships without being misled by outliers that commonly occur in phenotypic or biochemical data. In plant breeding, for example, selection decisions often rely on trait combinations associated with yield, stress tolerance, or nutritional quality. RPCA can reveal stable underlying trait structures even in noisy datasets, aiding breeders in identifying superior genotypes. Similarly, robust cluster analysis helps categorize experimental plots, farmers' fields, or soil samples into meaningful groups without distortions caused by anomalous cases. As agriculture increasingly integrates high-dimensional data generated from remote sensing, phenomics, and genomics, robust multivariate methods offer a dependable analytical foundation.

Climate and Weather-Related Robust Modelling

Climate and weather-related agricultural modelling also benefit significantly from robust statistical approaches. Weather data often include extreme values or missing observations, which can severely distort trend analysis and forecasts. Robust time series models, such as robust ARIMA, state-space filters, and quantile-based forecasting methods, provide stable predictions under such irregularities. Robust smoothing techniques like LOESS and LOWESS are particularly useful in extracting long-term climate trends from noisy meteorological data. These approaches allow researchers to analyze rainfall patterns, temperature trends, and evapotranspiration estimates more reliably, which in turn enhances the accuracy of crop yield forecasting, drought preparedness, and climate risk management strategies. With increasing climate variability, robust models serve as powerful tools for building resilient agricultural systems.

Robust Models for Soil Science and Environmental

Soil science and environmental monitoring represent another domain where robust statistical models are essential. Soil nutrient measurements, contamination levels, and physicochemical properties often exhibit non-normal distributions due to spatial variability and sampling limits. Geostatistical robust methods—such as robust variogram estimation and robust kriging—help produce more accurate spatial predictions of soil properties. These techniques mitigate the impact of extreme values that may arise due to localized nutrient hotspots, contamination patches, or measurement errors. The resulting soil maps guide precision agriculture practices including site-specific fertilizer management, irrigation scheduling, and land-use planning. Robust spatial models contribute substantially to improving resource-use efficiency and minimizing environmental degradation.

Robust Models for Livestock Sciences

In livestock sciences, robust statistical approaches support reliable estimation of growth curves, production parameters, and disease incidence rates. Animal production data frequently contain extreme observations resulting from biological variation, seasonal effects, or farm-level management disparities. Robust nonlinear models provide stable estimates of growth patterns or lactation curves even in the presence of irregular data. In epidemiological studies, robust logistic regression and survival models help analyze disease risk factors more accurately by controlling the influence of outlier cases. These insights are crucial for designing effective health interventions, breeding programs for disease resistance, and farm management practices that enhance animal welfare and productivity.

Precision Agriculture Applications of Robust Models

With the rise of precision agriculture, robust statistical models have gained expanded relevance in analyzing sensor data, drone imagery, and Internet of Things (IoT)–based agricultural measurements. Sensor-generated datasets often contain noise due to hardware malfunction, environmental interference, or data transmission errors. Robust machine learning algorithms—including robust random forests, support vector machines with robust loss functions, and robust neural networks—provide dependable predictions of crop stress, nutrient deficiencies, and yield variability. These algorithms maintain performance even when data are contaminated with anomalies. In remote sensing applications, robust image analysis techniques improve classification accuracy for land use, crop mapping, and disease detection by reducing the impact of noisy or misclassified pixels.

Robust Econometric Model

Econometric modelling for agriculture also benefits from robust approaches. Price data, market arrivals, and farm income statistics often exhibit heavy tails, structural breaks, and outliers due to market shocks, climatic events, and supply chain disruptions. Robust econometric models, including quantile regression, robust cointegration tests, and heavy-tailed distribution models, provide more accurate insights into agricultural market dynamics. These models help policymakers and agribusiness stakeholders design strategies that withstand uncertainties and market volatilities.

Bayesian Robust Model

Furthermore, Bayesian robust modelling has emerged as a powerful framework in agricultural research. By incorporating prior information and using heavy-tailed or contamination-resistant likelihood functions, Bayesian robust methods improve inference in situations where data quality may be compromised. Applications include pest population modelling, disease spread forecasting, and yield prediction under uncertain conditions. The flexibility of Bayesian models allows integration of expert knowledge, which is particularly valuable in agricultural systems characterized by limited or imperfect data.

Missing Data in Agriculture

Another important aspect of robust methods in agriculture is their ability to handle missing data, which frequently occur in long-term experiments, surveys, and monitoring programs. Robust imputation techniques, such as robust EM algorithms and median-based imputation strategies, maintain the structural integrity of datasets while avoiding the biases introduced by traditional mean imputation or naive deletion methods. This ensures that analyses of socio-economic data—such as farmer income, adoption behavior, and market trends—are reliable and reflective of underlying realities. Since agricultural policy decisions often depend on such data, robust methods indirectly contribute to better policy formulation and program implementation.

Conclusion

Overall, robust statistical models enhance the credibility of agricultural research by providing analytic techniques that remain reliable under real-world conditions. These methods protect against misleading conclusions and support sound decision-making across diverse agricultural domains, including crop science, soil science, climate analysis, livestock management, market economics, and precision farming. As agriculture continues to evolve in response to climate change, technological advancements, and global food security challenges, the demand for robust analytical tools will only increase. Their ability to handle uncertainty, adapt to complex data structures, and provide stable estimates ensures they will remain essential components of scientific and practical agricultural research.

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Effect of Heavy Metal Contamination in Soil

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Introduction

Soil is a fundamental component of the ecosystem, and its susceptibility to heavy metal contamination arises from its ability to both adsorb and release these substances (Inobeme *et al*., 2023). The rapid build-up of heavy metals in soil environments has emerged as a major environmental concern, largely driven by human activities such as industrial operations, intensive agricultural practices, and growing urbanization. Pollution refers to the introduction of harmful substances into the environment, and these toxic chemical agents degrade ecosystems, adversely affecting both living organisms and physical environmental elements. Their accumulation significantly alters the natural structure and composition of the soil.

Soil pollution is not restricted to any single region; it has become a global challenge. International frameworks such as the United Nations' Sustainable Development Goals (SDGs) and earlier Millennium Development Goals (MDGs) emphasize soil restoration and the reduction of heavy metal contamination. Heavy metals present in the soil disrupt its natural ecological balance. Consequently, global efforts are now focused on detecting and eliminating heavy metal pollutants to safeguard food security and achieve the goal of zero hunger.

Heavy metals in trace amounts are essential for normal plant functioning; however, when present in elevated concentrations, they pose severe risks to both plants and animals. Elements such as copper, manganese, cobalt, zinc, nickel, and iron act as micronutrients and are crucial for plant growth and development. In contrast, metals like mercury, cadmium, lead, and arsenic have no known biological role and are highly toxic even at minimal concentrations. Numerous studies have shown that metals such as manganese, iron, chromium, cobalt, selenium, and nickel are required only in small quantities and are therefore classified as essential nutrients. The lack of these elements for plant uptake is associated with the emergence of various deficiency disorders (Fazekasova and Fazekas, 2019).

Essential heavy metals contribute significantly to the physiological and biochemical processes of both plants and animals. They form integral parts of many key enzymes and play critical roles in oxidation–reduction reactions within biological systems. Several of these metals also function as cofactors in oxidative enzyme activities involving ferroxidases, dopamine-related enzymes, cytochromes, superoxide dismutase, and monoamine oxidases. Inside living organisms, these metals influence a wide range of cellular structures, including mitochondria, cell membranes, the nucleus, the endoplasmic reticulum, and lysosomes (Li *et al*. 2019).

Basic Concept of Heavy Metals

Heavy metals are naturally occurring elements characterized by high atomic mass and densities typically five times greater than that of water. Their widespread presence across the globe has increased as a result of extensive use in industrial activities, agricultural practices, and various other environmental applications (Bayrakli *et al*. 2023).

Environmental Sources of Heavy Metal Pollution

Heavy metals are naturally occurring elements distributed widely throughout the Earth's crust. However, the extensive rise in their use has led to a significant increase in metallic pollutants within both terrestrial and aquatic ecosystems. Environmental contamination and human exposure have escalated sharply due to various anthropogenic activities, including metal mining and smelting, industrial manufacturing, pharmaceutical applications, and the domestic and agricultural use of metals and metal-based compounds (He *et al*. 2005).

Industrial activities—including metal refining, coal-fired power generation, petroleum combustion, nuclear energy production, operation of high-tension transmission lines, and the manufacture of plastics, textiles, microelectronics, as well as wood preservation and paper processing—also contribute significantly to environmental pollution (Hazrat *et al*. 2019).

Applications of Heavy Metals

Although heavy metals are widely recognized for their toxic effects, they also possess several useful applications that have contributed to their rising accumulation in soils. Their specific uses depend on their physicochemical characteristics, including mechanical strength, density, durability, reflectivity, and electrical conductivity. Owing to their high density, heavy metals are utilized in fields such as mechanical engineering, sports equipment manufacturing, nuclear science, and military weaponry. They also serve as ballast materials in aircraft, boats, and various vehicles. Additionally, because dense substances can absorb greater amounts of radiation, heavy metals are frequently used for radiation shielding.

Essential Micronutrient Metals and Non-Essential Heavy Metals

Essential heavy metals play important roles in living organisms and are required only in very small quantities. In contrast, non-essential heavy metals have no recognized biological function. Metals such as copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) are typical examples of essential heavy metals, whereas cadmium (Cd), lead (Pb), and mercury (Hg) are highly toxic and are considered biologically non-essential (Martin and Johnson, 2012. Elements including cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), magnesium (Mg), nickel (Ni), zinc (Zn), and selenium (Se) function as essential micronutrients and are required for normal physiological and biochemical processes in living organisms (Kim *et al*. 2015). A deficiency of these elements can lead to various disorders. Since they are needed only in minute amounts, they are often referred to as trace elements, but they can become toxic when their concentrations exceed safe limits (Chalkiadaki *et al*. 2014). The classification of heavy metals as essential or non-essential may also vary among different groups of organisms, such as plants, animals, and microorganisms, meaning that an element essential for one group may not be essential for another (Rezania *et al*. 2016).

Effects on Soil Characteristics

Heavy metals and metalloids enter soils both naturally from parent geological materials (lithogenic sources) and through various human activities (Arunakumara *et al*. 2013). Their presence and distribution within soils are influenced by several factors, including the composition of the parent rock, the extent of weathering, and the physical, chemical, and biological properties of the soil, along with prevailing climatic conditions (Walker *et al*. 2012). Because metals are non-biodegradable, they persist in the environment for long periods. They cannot be decomposed and often remain in soils and sediments until they are transferred to other environmental compartments. Furthermore, heavy metals can react with other soil constituents, forming new compounds or transforming into more toxic forms. A notable example is the conversion of inorganic mercury into highly toxic methyl mercury by microbial activity in water, sediments, and soils (Semu and Singh, 1995).

In some agricultural systems, farmers apply sewage sludge to soils, which may contain elevated levels of heavy metals—particularly when the sludge originates from industrial sources. Elements such as copper, zinc, lead, cadmium, and chromium have been detected at high concentrations in soils where such sludge is used (Gupta *et al*., 2012). Smelting activities also contribute to localized contamination through atmospheric deposition, leading to soil pollution. Areas near smelters often exhibit dead vegetation and an absence of soil organisms like earthworms and woodlice, which play a key role in organic matter decomposition. Historically, leaded gasoline, lead-based shotgun pellets, and lead fishing weights have contributed to widespread lead contamination in many environments (Chibuike and Obiora, 2014). Some of these products have since been banned, although lead still enters food chains for example, when birds ingest shotgun pellets and accumulates in wetlands from fishing weights.

Soil characteristics influence the mobility and retention of heavy metals. Higher clay content, greater organic matter, and a neutral to alkaline pH enhance metal binding to soil particles. Conversely, acidic soils increase metal solubility, promoting leaching into deeper soil layers beyond the reach of plant roots, which can ultimately lead to nutrient deficiencies in crops (Semu and Singh, 1995).

Importance of Maintaining Soil Fertility

Soil quality plays a critical role in sustaining agricultural productivity as well as overall environmental health. High-quality soil enhances crop performance, increases resilience to climatic fluctuations, and ultimately supports greater agricultural output. Evaluating soil quality involves examining parameters such as pH, organic carbon content, and the levels of nitrogen, phosphorus, potassium, and essential micronutrients. Research indicates that different land-use practices influence soil quality in varying ways, with agricultural soils often exhibiting better quality than those under plantation systems. Techniques such as principal component analysis, along with assessments of standard soil indicators, are useful tools for evaluating soil quality and identifying appropriate management strategies.

Soil quality is vital across diverse ecosystems, including agricultural lands, forests, and disturbed environments such as reclaimed mine areas. Studies have shown that simply adding organic materials to mine soils does not always result in sustained improvements in soil quality. In agricultural ecosystems, soil organic carbon (SOC) is particularly important for maintaining soil fertility, protecting soil and water resources, and regulating nutrient cycling, water dynamics, and biological activity. According to Zornoza *et al*. (2007), the nitrogen content and bioavailability of plant litter play a significant role in shaping microbial community structure within soil ecosystems.

Agronomic Implications for Plant Growth and Yield

The accumulation of heavy metals has a direct impact on plants, altering their metabolic processes by modifying enzyme activities, impairing growth, and degrading overall soil quality (Timothy and Williams, 2019). Studies on Krebs cycle activity have shown that metals such as iron, manganese, and zinc can influence this metabolic pathway by either inhibiting or stimulating specific enzymes, thereby affecting cellular energy production in plants. Additionally, the consumption of medicinal plants contaminated with heavy metals has been reported to cause even more severe health effects (Rojczyk-Gołebiewska and Kucharzewski, 2013).

Impacts on the Environmental

Microbial Impacts in Soil: Microorganisms play a vital role in sustaining soil ecosystem balance by driving nutrient cycling and decomposition processes. However, long-term exposure to heavy metals can adversely affect these microbial communities. Such contamination can lead to declines in microbial diversity, activity, and biomass, along with shifts in their overall community structure. Heavy metals may also interfere with key microbial processes such as nitrogen fixation and carbon mineralization, resulting in nutrient imbalances and reduced soil fertility (Sharma and Nagpal, 2020). Consequently, plant growth and productivity may decline, ultimately compromising the health of the entire ecosystem. Therefore, evaluating the effects of heavy metal buildup on soil microorganisms is essential.

The addition of heavy metals is increasing day by day due to anthropogenic activities. We are ingesting these heavy metals by different means. Food security is the most concerning agenda. According to Islam *et al*. (2007), heavy metals are accumulating in the soil, destroying the soil's natural environment; due to anthropogenic activities, bioaccumulation is alarming in the food chain, and human activities like the use of detergents, mining, effluents of industries, vehicle exhaust are the main causes of heavy metal deposition in the soil. The plants uptake the heavy metals from the soil and transport them into the leaves or fruits. Consumption of these vegetables and fruits is causing serious health issues in human life.

Table 1: The amount of metals that are permissible according to WHO and FAO:

Element of heavy metals	Regulatory threshold for heavy metal concentration (mg/kg)
Cd	0.2
Cu	73.3
Ni	67.9
Fe	425.5
Pb	0.3
Zn	99.4

Islam Et Al. (2007)

Contamination Both Surface and Groundwater Resources

Ghosh *et al*. (2012) reported that long-term irrigation with sewage and untreated wastewater leads to the transfer of heavy metals into agricultural crops and vegetables. Their findings emphasize the need to remove heavy metal contaminants from wastewater before it is used for irrigation. Similarly, Alghobar *et al*. (2017) observed significant heavy metal accumulation in tomatoes irrigated with sewage water in Mysore, India. In another study, Xue *et al*. (2019) examined the concentrations of heavy metals in wheat and maize grown under groundwater and sewage water irrigation. Their results highlighted the importance of treating sewage water prior to its agricultural use to minimize contamination risks.

Health Implications for Humans

Human exposure to heavy metals can occur through ingestion, inhalation, or direct skin contact. Metals such as mercury, cadmium, arsenic, and lead have been implicated in many recent cases of human poisoning. Major exposure pathways include occupational contact in industrial settings, contaminated food packaging materials, and ingestion of lead-based paint. Heavy metal toxicity has been linked to a wide range of health conditions, including Alzheimer's disease, cancer, Parkinson's disease, respiratory disorders, impaired vision, depression, neurological issues, and dementia (Li *et al*. 2019). Their findings also indicated that prolonged exposure to high levels of cadmium can cause sperm cell mortality, reduced semen quality, and hormonal imbalances. Cadmium toxicity has further been associated with increased cases of kidney stones, liver impairment, lung diseases, and heart failure. Similarly, exposure to elevated concentrations of arsenic promotes the formation of free radicals and oxidative stress in cells, contributing to kidney dysfunction and disturbances in enzymatic activities.

Conclusion

Heavy metal contamination in soils represents a significant environmental and public health concern worldwide. While certain heavy metals are essential micronutrients required in trace amounts for plant growth and physiological functions, their excessive accumulation disrupts soil properties, impairs microbial activity, and adversely affects plant metabolism and crop productivity. Anthropogenic activities including industrial operations, mining, wastewater irrigation, and vehicle emissions have accelerated the build-up of toxic metals in soils, leading to bioaccumulation in the food chain and posing serious health risks to humans, such as neurological disorders, kidney and liver dysfunctions, and reproductive impairments.

Soil characteristics, including pH, clay content, and organic matter, influence the mobility and retention of heavy metals, highlighting the importance of monitoring and managing soil quality. Sustainable soil management, proper wastewater treatment, and adherence to permissible heavy metal limit as recommended by WHO and FAO are crucial to minimizing environmental contamination and safeguarding agricultural productivity. Overall, the mitigation of heavy metal pollution is essential for maintaining ecosystem balance, ensuring food safety, and promoting long-term human and environmental health.

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Contribution of Hydroponic, Aeroponic, and Aquaponic Techniques to Advanced Vegetable Production

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Introduction

Hydroponics, often referred to as soilless cultivation, is an alternative farming system in which plants are grown in nutrient-enriched aqueous solutions, either with or without the support of inert substrates such as cocopeat, coconut coir, sand, or rock wool. The concept of hydroponics was introduced by William Gericke in the early 1930s. The term originates from the Greek words *hydro*, meaning water, and *ponos*, meaning labor. This method has been successfully adopted for the cultivation of a wide range of crops, including vegetables and ornamental plants (Cuba et al., 2015).

Aeroponics represents an advanced form of soilless agriculture where plant roots are suspended in air and periodically supplied with a fine mist of nutrient-rich solution. The term is derived from the Latin words *aero* (air) and *ponic* (work). This technique eliminates the need for soil or solid growing media and is primarily practiced in controlled environments such as greenhouses. Aeroponics has been utilized for the production of various crops, including fruit plants, and is associated with several advantages as well as certain limitations (Sharma et al., 2018). Aquaponics is an integrated production system that combines hydroponic crop cultivation with recirculating aquaculture for fish rearing. This bio-integrated approach has emerged as a sustainable food production model. The system was initially developed by researchers at the New Alchemy Institute of North Carolina State University during the late 1970s and early 1980s. Subsequently, the University of the Virgin Islands adopted this technology in 1980, demonstrating its suitability for local food production in diverse regions. Although aquaponics has proven technically feasible, substantial gaps remain in understanding its economic and operational viability, particularly in densely populated countries such as India. Aquaponics offers a holistic framework by linking aquaculture with hydroponics, where nutrient-rich fish waste functions as a natural fertilizer for plants, and plants, in turn, purify the water before it is recirculated back to the fish tanks. Microorganisms play a vital role in this system by transforming fish excreta and organic residues into nutrients readily available for plant uptake. This symbiotic interaction results in an efficient and sustainable production system (Surnar et al., 2015).

The growing pressure on natural resources poses a serious threat to future drinking water availability. Human-induced activities contribute significantly to greenhouse gas emissions, resulting in climate warming and declining groundwater reserves. These challenges intensify the difficulty of meeting the food requirements of an additional three billion people by 2050. In light of limited water resources and shrinking agricultural land, alternative farming strategies have become indispensable. Vertical farming has been proposed as a viable solution to overcome the limitations associated with conventional horizontal agriculture (Butler & Oebker, 1962).

Classification of Hydroponic Systems

The innovative method known as hydroponics offers flexible ways to grow horticultural crops in unconventional settings. Hydroponic systems are categorized based on their nutrient delivery techniques and structural designs, each with specific advantages and disadvantages in modern agriculture (Rajasegeret al., 2023).

1. Drip System: This system delivers nutrient solution directly to each plant's roots from a reservoir using a pump, making it easy to control moisture. Plants are often placed on growth media that is only partially absorbent, encouraging a steady drip of nutrients.

2. Wick System: The most basic and uncommon type of hydroponic system, the wick system requires neither an electric motor nor a pump. Nutrient solutions are delivered to plants via capillary action. Larger or multiple wicks can be used to control the water reaching the plant. This method is effective for small plants, spices, and herbs but not for water-intensive crops (Kumari and Kumar, 2019).

3. Deep Water Culture System: This is the simplest hydroponic method. Plants are placed on a floating platform made of Styrofoam or similar material in a nutrient solution. Aquarium air pumps provide external oxygen to the roots. This method is commonly used for green crops.

4. Nutrient Film Technique (NFT) System: In this system, a continuously operating water pump delivers the nutrient solution to the growth tray without the use of a timer. The structure is designed with a slight gradient, enabling the solution to pass over the plant roots and return to the reservoir by gravity. Plants are cultivated in channels or tubes with their roots immersed in the hydroponic nutrient solution, which can increase their vulnerability to fungal diseases (He, 2011). This technique is widely adopted for the commercial cultivation of lettuce and other leafy vegetables.

5. Ebb-Flow (Flood and Drain) System: Considered the first commercial hydroponic system, this method uses the flood and drain principle. A water pump pushes the nutrient solution into the system, and gravity returns the excess water to the reservoir for recycling.

6. Aeroponic System: This is the most technologically advanced hydroponic farming method. Plants are grown with their roots suspended in the air, receiving constant misting of nutrient solution every few minutes. Unlike other systems that run the pump for brief periods, the aeroponic system requires a short cycle timer.

Various Vegetables of plants grown under soil less hydroponic system:

Sr. No.	Type of crops	Name of the crops
1.	Vegetables	Tomato, Chilli, Brinjal, Green bean, Beet, Winged bean, Bell pepper, Cucumbers, Melons, green Onion
2.	Leafy vegetables	Lettuce, Spinach, Celery, Swiss chard, Atriplex

Benefit of Hydroponic Vegetable Production

Hydroponic systems enable the production of high vegetable yields within limited land areas by allowing precise control over environmental conditions that favor plant growth. Essential minerals and water are supplied continuously according to plant requirements, ensuring optimal nutrient availability. This technique is particularly suitable for regions affected by adverse environmental conditions such as drought, desertification, and other degraded ecosystems (Polycarpou et al., 2005). Crops grown under hydroponic systems can be cultivated throughout the year, including during the off-season. Modern commercial hydroponic operations often incorporate automation and robotic technologies, reducing the need for several conventional farming practices such as weeding, irrigation, pesticide application, and soil tillage (Manzocco et al., 2011). The incidence of pests and diseases can be effectively controlled, and weed infestation is virtually eliminated. Consequently, hydroponic cultivation generally results in higher yields compared to conventional soil-based agriculture (Choi et al., 2011).

If you want, I can also provide:

a. A **shortened version** for review articles,
b. A **popular science rewrite**, or
c. **Bullet points** highlighting key advantages for presentations or exams.

Limitations of Hydroponic Vegetable Production

Despite its advantages, this system has several notable limitations. Successful commercial-scale production requires substantial technical expertise along with high initial investment costs. In hydroponic systems, all plants share the same nutrient solution, which facilitates the rapid spread of water-borne diseases from one plant to another. Elevated temperatures and inadequate oxygen availability can further restrict plant growth and may lead to significant crop losses. Precise management of pH, electrical conductivity (EC), and nutrient concentration is critical for optimal system performance. Additionally, a reliable supply of light and energy is essential for operating the system under protected cultivation conditions.

Types of Aeroponic Farming and Suitable Crops

High-Pressure Aeroponics (HPA): High-Pressure Aeroponics (HPA) systems, on the other hand, use high-pressure compressors to make a fine mist that surrounds plant roots and makes the droplets smaller (45–55 µm). This results in improved nutrient absorption, improved oxygenation, and enhanced plant growth. Additionally, HPA systems incorporate sophisticated filtration, sterilization, and biological support technologies, which enhance the longevity and maturation of the crop. When compared to growing plants in soil, high-pressure aeroponics has a lot of benefits, such as higher yields, better flavor profiles, and faster plant growth rates. HPA systems have the potential to produce up to three times more than traditional soil-based agriculture when maintained under optimal conditions.

Examples of Crops: - Leafy greens (Lettuce, Spinach, Kale)

Low-Pressure Aeroponics (LPA): Low-Pressure Aeroponics systems use low-pressure pumps or ultrasonic transducers to produce bigger droplets of roughly 100 µm in size. While this approach provides basic nutrition delivery, it frequently results in irregular root hydration and restricted nutrient absorption. LPA systems are thus more appropriate for small-scale applications, research contexts, or educational settings. On the other hand, the long-term efficacy of LPA systems may be compromised by their insufficient advanced purification and filtration capabilities. Low pressure aeroponics is the best for beginners and small-scale vegetable production.

Examples of Crops: - Lettuce, Herbs, Cucumbers, Beans, Peas etc

Ultrasonic Fogger Aeroponics: Fogponics, or fog and ponics (labor) can be defined as working fog. In its simplest meaning, in fogponic system, growers use the fog to grow plants. The fogponic system uses electric foggers to pump and vibrate under pressure to transform nutrient and water mix into humidity, like the humid atmosphere found in the rainforest. This creates a constant humid and nutrient-rich fog for plant roots. With fogponics, the root system can have a full coverage as the tiny droplet size of the gravity-defying fog can travel and penetrate all space around it.

Examples of Crops: - Leafy Vegetables (Arugula, Swiss Chard)

Contribution of Aeroponics to Enhance Vegetable Production

A holistic approach to agriculture's production management that promotes and enhances agroecosystems and biodiversity includes the aeroponic system. Because of how it affects the financial and technical aspects of agriculture, the system is widely known in the horticulture field. The aeroponic system, which is attracting the interest of all farmers, policymakers, marketers, and agricultural researchers, is the most effective of all agriculture systems. Chemical inputs like fertilizers, insecticides, herbicides, and other exceptional agrochemicals should be reduced by the grower. Farmers can grow a lot in rural areas thanks to aeroponic systems. The ranchers can foster a plant in their homes by getting ready counterfeit development environmental elements (Savvas, 2003).

Principles of Aquaponics

1. Nutrient Cycling: Waste products from one biological system can serve as nutrients for another. In aquaponics, the waste from fish tanks provides essential nutrients for the plants.

2. Integration of Fish and Plants: By growing plants and fish together, aquaponics enables the simultaneous production of both, enhancing overall yield and efficiency.

3. Water Recycling: Aquaponics systems continually recycle water through biological filtration and recirculation, ensuring that water is used efficiently and sustainably.

4. Local Food Production: Aquaponics supports local food production, improving access to fresh, healthy foods and contributing to the economic well-being of the community.

In an aquaponics system, hydroponic growing beds are supplied with nutrient-rich wastewater from fish tanks. This wastewater benefits plant roots, supports rhizobacteria that help remove nutrients from the water, and promotes fish health. The nutrients, derived from algae, decaying fish feed, and fish waste, could otherwise accumulate as toxins in the fish tanks, deteriorating water quality. Conversely, the hydroponic beds act as biofilters, removing phosphates, ammonia, nitrates, and nitrites from the water. The interaction between plant roots and nitrifying bacteria in the gravel is crucial for maintaining the nutrient cycle and ensuring the system's overall functionality.

Hydroponic BedTypes: There are various hydroponic bed types commonly used in aquaponics systems:

a. Media-Based Grow Bed (MGB)
b. Deep-Water Culture System (DWC)
c. Nutrient Film Technique (NFT)
d. Aeroponics.

Fish Selection

Among warm and cold-water species, tilapia, trout, perch, Arctic char, and bass are well-suited for recirculating aquaculture systems (RAS). However, tilapia is the most commonly used and adaptable species in industrial aquaponics systems in North America. Their ability to adjust to varying water parameters, such as pH, temperature, oxygen levels, and dissolved particles, contributes to their widespread use in these systems.

Technical Challenges of Aquaponics

1. Complex Interactions: Managing an aquaponics system involves extensive interactions between fish, plants, and microbes, requiring careful coordination.

2. Water Quality Maintenance: Neglecting water quality parameters, especially pH levels, can negatively impact the overall health of the system.

3. pH for Plants: Most plant species thrive in a pH range of 6 to 6.5, as this range supports better nutrient uptake.

4. pH for Fish: Fish generally require a pH range of 7 to 9 for optimal growth and health.

5. pH for Nitrifying Bacteria: The nitrifying bacteria in the system need a high pH level, usually above 7, to function effectively.

6. pH for Nitrobacter Bacteria: The ideal pH range for Nitrobacter bacteria is approximately 7.5.

7. Nutrient Source: After the nitrification process, fish feed remains the primary source of nutrients for balancing the nutrient levels in the aquaponics system.

8. Waste Management: Mechanical filtration should be used daily to partially solubilize solid waste. Filtered wastes can be mineralized externally and then reintroduced to the hydroponic beds.

Contribution of Aquaponics to Enhance Vegetable Production

Modern-day discussions on food security and sustainable food production have highlighted the "water-energy-foods nexus" approach as key to studying and handling the interactions among global beneficial aid structures. The nexus method acknowledges the interconnectedness of land, water, strength, capital, and labor and their associated drivers. An important component of the foods safety timetable in most African countries is to carry out an exercise or program that now assists food-insecure people to achieve some level of food self-sufficiency, primarily mineral safety. Fish may be very important for human minerals and fitness, and it is expected to play an important role in nutrition. Even in small quantities, fish can enhance the nutritional profiles of human diets by contributing vital amino acids that may be lacking in plant components (Pant et al. 2018).

Conclusion

Soilless cultivation technologies such as hydroponics, aeroponics, and aquaponics represent innovative and sustainable alternatives to conventional soil-based agriculture in the context of increasing population pressure, climate change, water scarcity, and declining arable land. These systems enable precise control over plant nutrition, water use, and environmental conditions, thereby enhancing productivity, resource-use efficiency, and year-round vegetable production. Hydroponic systems, with their diverse classifications such as drip, wick, deep water culture, NFT, ebb-flow, and aeroponics, offer flexibility for cultivating a wide range of vegetables and leafy greens in limited spaces. Aeroponic techniques, particularly high-pressure systems, further improve nutrient uptake, oxygen availability, and crop growth rates, resulting in superior yields and quality.

Aquaponics, through the integration of hydroponics and aquaculture, provides a bio-integrated and environmentally friendly production model where nutrient cycling, water reuse, and microbial activity create a balanced and self-sustaining ecosystem. This approach not only enhances vegetable production but also contributes to fish production, nutritional security, and local food systems. Despite their numerous advantages, these advanced farming systems face challenges related to high initial investment, technical complexity, energy dependence, disease management, and the need for precise monitoring of water quality parameters.

Overall, the adoption of soilless farming systems holds immense potential for achieving sustainable intensification of vegetable production, particularly in urban, peri-urban, and environmentally stressed regions. With continued technological advancements, capacity building, and supportive policy frameworks, hydroponics, aeroponics, and aquaponics can play a crucial role in ensuring future food and nutritional security while minimizing environmental impacts.

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Agronomic Interventions to Boost Productivity in Dryland Farming

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Abstract

Dryland farming continues to be a backbone of food production in many regions, yet it faces persistent challenges such as erratic rainfall, poor soil health and limited water availability. To overcome these constraints and enhance productivity, farmers increasingly rely on smart agronomic interventions that make efficient use of available resources. This article highlights practical and farmer-friendly approaches where it emphasis on low-cost, sustainable practices that help stabilize yields even under stress conditions. By adopting the resilient strategies, dryland farmers can improve crop performance, ensure better income and strengthen long-term sustainability of their production systems.

Introduction

Drylands are defined by limited water availability, which impacts both natural and cultivated ecosystems. This scarcity restricts the production of crops, livestock, wood, forage, and other plant resources, while also reducing the overall capacity of these regions to provide essential environmental services. Dryland agriculture relies heavily on rainfall, particularly in India, where the amount and distribution of monsoon rains largely determine crop yields. Since soil moisture is the primary limiting factor in these regions, and food production depends strongly on monsoon behavior, considerable efforts have been directed toward understanding and predicting monsoon variability. Yet the variability of the summer monsoon is still less predictable. Uneven distribution of precipitation often leads to scenarios whereby water inputs cannot adequately meet the growth of crops which threatens agricultural production (Wang *et al.*,2018). Dryland farming plays a vital role in agriculture, where an imbalance between precipitation and evaporation has caused soil water deficits (Wu *et al.*, 2017). Drylands account for about 40 % of Earth's cultivated land and feed more than a third of the world population (UNEP, 2012).

Constraints Associated with Dryland Agriculture

1. Climatic:

a. High wind velocity
b. Extreme thermal values
c. High heat waves
d. High ET
e. Scarcity and irregularity of rainfall.

2. Edaphic:

a. Poor physical condition
b. Low fertility of soils
c. Low soil moisture storage capacity
d. Soil salinity
e. Erosion.

3. Socio-economic:

a. Low farm income
b. Poor resource base of farmers

c. Poor risk bearing capacity.

4. Technological:

a. Less choice of crops and varieties
b. Lack of mechanization
c. Limited scope of crop diversification.

Agronomic Practices for Improving Production Under Dryland Condition

1. Tillage: Tillage is a physical operation of soil, which aims to destroy weeds in the incorporate crop residues and amendments into soil, reduce evaporation, increase infiltration and break hard layers to assist root penetration. There are different kinds of tillage operations such as conventional tillage, no-tillage, reduced tillage etc. Conventional tillage practices and crop residue removal will lead to a decrease in soil organic matter due to accelerated decomposition and loss of top soil, thereby adversely affecting soil properties. Recently, reduced tillage practices have been gaining popularity. Adoption of conservation tillage practices, which include no-tillage and several forms of reduced minimum tillage is a means to increase soil organic matter (SOM), mitigate CO_2 emissions and partly address the rising environmental problems associated with modern agricultural practices. Like several other factors, proper land preparation with different tillage practices plays an important role in improving the production of drylands by moisture conservation. Crop rotation and tillage system could affect crop yield due to their effects on water conservation and soil chemical and physical properties. Wang *et al.*(2020) suggest that long-term chisel plough tillage in dryland agroecosystems could serve as a promising soil management practice in increasing crop productivity and maintaining sustainability through enhancing N removal from crop biomass and decreasing N losses via N_2O emission and nitrate-N leaching.

2. Dead furrows: When all tillage operations are complete, it is advisable to leave a deep dead furrow at every 10 m interval. This should remain in position until the crop is harvested. Dead furrows aid in reducing the runoff velocity and they also conserve water.

3. Mulching: About 60 to 75 per cent of the rainfall is lost through evaporation. These evaporation losses can be reduced by applying mulches. Mulch is any material applied on the soil surface to check evaporation and improve soil water. Application of mulches results in additional benefits like soil conservation, moderation of temperature, reduction in soil salinity, weed control and improvement of soil structure.

Types of Mulches

Soil mulch or dust mulch: If the surface of the soil is loosened, it acts as a mulch for reducing evaporation. This loose surface soil is called soil mulch or dust mulch. Intercultivation creates soil mulch in a growing crop.

Stubble mulch: Crop residues like wheat straw or cotton stalks etc., are left on the soil surface as a stubble mulch. The advantages of stubble mulch farming are protection of soil from erosion and reduction of evaporation losses.

Straw mulch: If straw is used as mulch, it is called as straw mulch.

Plastic mulch: Plastic materials like polyethylene, polyvinyl chloride are also used as mulching materials. Plastic film mulch has been massively applied as a means of enhancing crop productivity in the global dry farming area (Gan *et al*., 2013). Wang *et al.*(2020) reported that plastic mulching significantly affected extracellular enzyme production and N fertilizer application significantly affected the composition of the soil microbial community in dryland agriculture. Mo *et al.* (2018) stated that usage of plastic mulching is capable of maintaining soil water moisture and elevating underground thermal conditions and eventually making positive contributions to crop growth and yield output due to summer crops in this area being typically subjected to simultaneous drought and cold stresses during the early stages of the growing season.

Vertical mulching: To improve infiltration and storage of rainwater in these soils, vertical mulches are formed. It consists of digging narrow trenches across the slope at intervals and placing the straw or crop residues in these trenches. The pruned plant material is placed in contour trenches formed between rows or in trenches around the plants in concentric circles each year in one circle.

Incorporation of Organic Matter

Indian soils are very poor in organic matter, especially in drought-prone areas. This can be improved by leaving the crop residue in situ (on the fields). Adding organic manures such as farmyard manure and compost every year as basal application to the soil improves the physical condition of the soil considerably. Soil-Air, Soil-Temperature and Soil-Moisture relationships are well balanced with the presence of organic matter. Organic matter improves the activities of soil microorganisms and also provides the much needed micro plant nutrients of all kinds, besides nitrogen, phosphorus and potash.

Selection of Drought-Resistant Varieties

It is important that varieties which have proven genetic character to withstand longer periods of drought are chosen so that the crops can do well even in situations where the intervals between rainy days are long.

Early Maturing Varieties

Where the distribution and the amount of rain is unpredictable, it is important to select varieties which have a shorter duration life cycle (seed to seed) to cut down the water requirements of the crop. In drought-prone areas, the success rate of short duration crops is greater than long-duration crops.

Strip Cropping

Raising Erosion Permitting Crops (EPC) with Erosion Resistant Crops (ERC) having abundant adventitious root system and providing high percentage of canopy in strips in a ratio of 2:1 or 3:1 helps in trapping soil from EPC strips to ERC strips. The increased resistance to runoff in ERC results in higher volume of water percolating through soil profile, due to increased time of (on-ground) concentration. The close-growing ERC strips are generally legumes which fix nitrogen in the soil and enrich it. The canopy of the ERC also protects the soil from beating action of rain drops. Strip cropping also helps in stabilizing crop production.

Reducing Deep Percolation Losses

Reduction in deep percolation is an important tool for enhancing yield of dry land crops. The water that is percolated to lower depths of soil can be conserved in soil root zone and can mitigate the problem of drought. Compaction of soil decreases deep percolation losses by decreasing drainage pores and increasing water retention and residual pores. Soil compaction increases bulk density and decreases hydraulic conductivity and percolation losses.

Alternate Land Use System

Despite evolving a number of production technologies, arable cropping in drylands continues to suffer from instability due to aberrant weather. To provide stability to farm income and also utilize the marginal lands for production of fodder, fuel wood and fibre, a number of alternative land use systems were evolved based on location specific experimentation and cafeteria studies (Singh *et al*, 2004).

Soil Conditioners

Soil conditioners are termed as materials which when added to the soil help in improving or maintaining its physical conditions with improved physical and chemical health of soil. Under different soil conditioners hydrophilic polymers are used to improve the moisture holding capacity of soil. Pusa Hydrogel is an indigenous product designed and developed by scientists of ICAR, New Delhi to enhance the crop productivity per unit available water and nutrients, particularly in moisture stress agriculture. *Jalshakti* (a hydrophilic polymer) is another soil conditioner, which when applied (mixed) in soil, improves moisture holding capacity of soil, increase infiltration of water, reduce evaporation from soil and prolong the availability of soil moisture to the crop may be useful. Experiments showed that application of *Jalshakti* increase the yield of crop and also improve the physical and chemical properties of soil (Dhar *et al.*, 2008).

Conclusion

With the right agronomic interventions, dryland farming can become more productive and resilient. Simple, low-cost practices like conserving soil moisture, using drought-tolerant varieties, timely sowing and better nutrient management can greatly improve yields. By adopting these smart strategies, farmers can strengthen their livelihoods and ensure more stable production even under challenging dryland conditions.

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Integrated Weed Management in Millets

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Abstract

Integrated Weed Management (IWM) is emerging as a crucial strategy for boosting millet productivity, especially as these climate-resilient crops gain global attention. Weeds compete aggressively with millets for nutrients, light, and water—causing significant yield losses if not managed early and effectively. IWM combines cultural, mechanical, biological, and judicious chemical methods to create a sustainable, eco-friendly approach to weed control. Practices such as timely sowing, use of clean seeds, crop rotation, intercropping, shallow cultivation, mulching, and selective herbicide application help suppress weed growth while preserving soil health and biodiversity. This holistic method not only reduces dependence on chemicals but also enhances millet yields, promotes resource efficiency, and supports long-term farm sustainability. As millets are increasingly recognized for their nutritional and environmental benefits, adopting IWM becomes essential for strengthening food security and empowering smallholder farmers.

Introduction

The word millet is derived from the French word “mille” which means that a handful of millet contains thousands of seed grains. Millets are the important staple food of resource for poor farmers in hot and drier regions of the developing world especially in Africa and Asia. Millets have agricultural superiority over other commercial crops attributed to their ability to adapt under marginal and less input demanding cultivation. Additionally, the C_4 photosynthetic pathway and ability to withstand environmental stress make them a suitable choice for future agricultural systems. The nutritional superiority over major cereals in terms of balanced micronutrient profile and bioactive flavonoids of diverse pharmaceutical uses makes them highly valuable crops.

Classification of Millets

1. **Major millets-** Sorghum, Cumbu/Pearl millet
2. **Minor millets-** Finger millet, Proso millet, Kodo millet, Barnyard millet, Foxtail millet, Little millet

Millets and their Special Characteristics

Millet	Common name	Botanical name	Special characteristics
Sorghum	Great millet, Jowar, Kafir corn, Guinea corn, Kaolin in China, and Milo in Spain	*Sorghum bicolor*	Tolerate moisture stress and high temperature better than any other crops
Pearl millet	Bajra, Cattail millet, Black millet, German millet	*Pennisetum glaucum*	Grow in arid and semi-arid region, richest source of folic acid
Finger millet	Ragi, Wimbi, Mandua, Nachni, Kapai, Nagli, Marua	*Eleusine coracana*	Wider adaptability, rich source of calcium
Proso millet	Cheena, Common millet, Broom millet	*Panicumm iliaceum*	Short duration, tolerant to heat and drought
Foxtail millet	Indian paspalum, Kangni, Water couch, Italian millet	*Setaria italica*	Short duration, tolerant to low soil fertility and drought
Kodo millet	Kodo, Ditch millet, Creeping paspalum	*Paspalum scrobiculatum*	Long duration, grown well in shallow and deep soil, rich in folic acid
Barnyard millet	Sawan, Jhingora, Kudraivali, Oodalu	*Echinochloa frumentacea*	Fastest growing, voluminous fodder
Little millet	Kutki, Samai, Samalu, Hog millet	*Panicum sumatrense*	Short duration, withstand both drought and waterlogging

Meena *et al.*, 2021

Importance of Weed Management in Millets

1. Millets are relatively weak weed competitors, especially in the early phases of growth.

2. Millets grow relatively slowly during their initial growth phase.

3. Only when the crop reaches the mid-development stage does it have adequate canopy cover to shade the weeds and suppress their growth.

Major Weeds in Millet Crops

Crops	Major weeds
Sorghum	*Digera arvensis, Convolvulus arvensis, Amaranthus viridis, Euphorbia hirta, Alternanthera pungens, Eclipta alba, Trianthema portulacastrum, Vernonia cinerea, Physalis minima and Cyperus rotundus*
Bajra	*Phyllanthus niruri, Alternanthera triandra, Cynodon dactylon, Commelina benghalensis, Panicum isachne, Amaranthus viridis, Celosia argentea and Cyperus rotundus*
Finger millet	*Panicum maximum Jacq., Setaria barbata (Lam.) Kunth, and Digitaria sanguinalis (L.) Scop Mimosa pudica L., Phyllanthus niruri L., Boerhavia diffusa L. and Synedrella nodiflora (L.) Gaertn*
	Digitaria marginata, Cyperus rotundus L., Ageratum conyzoides L., Dactyloctenium aegyptium L. Willd., Amaranthus viridis L. Celosia argentea L., Euphorbia hirta L., Alternanthera sessilis L., and Leucas aspera.
Foxtail millet	*Amaranthus viridis, Commelina benghalensis, Echinochloa colona, Cynodon dactylon, Sorghum halepense and Celosia argentea*
Kodo millet	Sedges like *Cyperus rotundus*; grassy weeds like *Cynodon dactylon, Eleusine indica, Echinocloa crusgalli, Dactyloctenium aegyptium, Digitaria marginata*; and broadleaved weeds like *Ageratum conyzoides, Alternanthera sessilis, Commelina benghalensis* and *Borroria hispida*.
Little millet	*Eleusine indica, Setaria glauca, Echinochloa colona, Echinochloa crusgalli, Amaranthus viridis, Commelina benghalensis, Phyllanthus niruri and Solanum nigrum.*

Critical Period of Crop-Weed Competition in Millets

Crops	Critical Periods (DAS)
Sorghum/Jowar	28-42
Bajra	15-30
Finger millet	25-42
Barnyard millet	25-30
Foxtail millet	20-35
Proso millet	Up to 35
Kodo millet	30-35

Mahapatra *et al*., 2023

The yield reduction in millets due to crop weed competition:

Crops	Reduction in grain yield (%)	References
Sorghum	23.5-27.4 %	Gharde *et al.*, 2018
Bajra	27.6 %	Gharde *et al.*, 2018
Finger millet	72 %	Kujur *et al.*, 2019
Kodo millet	56.6-67.3 %	ICAR-DWR, 2021
	55-61 %	Lekhana *et al.*, 2021
Little millet	59.6 %	ICAR-DWR, 2021
Barnyard millet	50 %	Shamina *et al.*, 2019

Weed Management Methods

Preventive methods: As we know that "Prevention is better than cure," so it is better to prevent the weed species to spread in the croplands and infest the crop. The strategies are as follows:

a. Use of weed-seed-free seeds of millets
b. Use of clean agricultural implements
c. Use of weed-seed-free irrigation water
d. The irrigation channel should be free of weed plants
e. Use of well-decomposed compost or farm yard manure
f. Maintenance of farm hygiene that prevents the every year production of seeds, tubers, and rhizomes of already present weed species on the farm.

Mechanical methods: The mechanical method of weed control is the physical method of weed removal from the field which is often adopted in millets. It helps in weed seed burial as well as the removal of weed plant and vegetative propagules from the soil of the cultivated field which reduces the weed thrust in the field eventually reducing the crop-weed competition and enhancing the crop yield. This method includes manual hand weeding, deep summer tillage, fallow-season tillage, pre-plant tillage and post-plant shallow tillage/intercultivation.

Cultural methods: Cultural methods of weed control are the environment-friendly methods that are adopted during crop husbandry in a standing crop through different cultural management such as plant population management through seed rate, crop spacing management, intercropping, crop rotation, mulching, management of time and method irrigation and nutrient application.

Stale seed bed:

a. It is based on the principle of destroying the germinated weed seed prior to the sowing of crops, depleting the seed bank in the surface layer of soil and subsequent reduction in weed seedling emergence. Stale seedbed technique reduces the weed seed bank by killing the emerged weeds by shallow tillage or use of non-selective herbicides or flaming. Patil *et al.* (2013) observed that SSB + inter cultivation at 20 and 35 days after planting (DAP) resulted in considerable reduction in total weed count and biomass in irrigated organic finger millet. Stale seedbed is a sustainable approach that reduces the dependence on herbicides and promotes environment friendly weed management.
b. Growing intercrops such as green gram, cowpea, soybean and groundnut could suppress the weed population by their high growth rate during the early period of crop growth, which eventually smothers the weeds so that the weed plants do not get adequate sunlight (Mahapatra *et al.*, 2023).
c. Higher seed rate, that is, 15 kg/ha registered lower weed dry weight, higher grain yield, B:C ratio and weed control efficiency than the recommended seed rate, that is, 10 kg/ha at 25 cm row to

row spacing in barnyard millet in a 3-year experiment at Ranichauri, Uttarakhand (Kumar *et al.*, 2019).

d. In barnyard millet, 25 cm × 10 cm **spacing** recorded higher seed yield with higher weed control efficiency than 30 cm × 10 cm and 40 cm × 10 cm spacing (Shamina *et al.*, 2019).

e. Different conservation practices such as the opening of conservation furrow and intercropping of red gram with finger millet increased the yield of finger millet reducing the weed population and dry weight (Sidar *et al.*, 2017).

f. Intercropping of pearl millet and green gram at a pair row ratio of 2:2 was found to be superior to the sole crop of pearl millet being the most profitable getting a higher net return and land equivalent ratio (Choudhary *et al.*, 2012).

g. Mulching at 21 days after sowing effectively control the weed infestation and increase the production of the harvest in pearl millet (Kaur and Singh, 2006).

Flaming

It is particularly useful for organic farming and small-scale agriculture, as it avoids the use of chemical herbicides. In flame weeding, flame produced by burning of natural gas or propane as fuel causes an increase in temperature within the weed which would result in the cell rupture and killing of weeds. Flame weeders include handheld single-torch flamers, as well as push-wheeled multiple torch flamers. They are very easy to operate and suitable for use in small farms. Flaming can be successfully adopted in row planted crops that are slow to germinate.

Chemical Methods

The chemical method is the most popular and easiest method of weed control as it saves cost, time, labor and controls the weeds effectively and efficiently. In finger millet, isoproturon at 0.5 kg/ha (pre emergence) and oxadiargyl at 0.08 kg/ha (Pre-emergence) at 3 DAS fb ethoxysulfuron at 0.012 kg/ha (post-emergence) at 30 DAS were reported to have broad-spectrum weed control (Kujur *et al.*, 2019).

Herbicides Recommended for Millets

Millets	Herbicides	Dose (kg/ha)	TOA	Weeds controlled	Remarks
Sorghum	Metalachlor	1.0-1.5	PRE	Grasses	For intercropping
Pearl Millet	oxadiazon	1.00	PRE	Broad spectrum	For sole crop only
Finger Millet	Isoproturon	0.50-0.75	PRE	Broad spectrum	
Kodo Millet	Bispyribacsodium	0.02	PoE 20 DAP	Effectively controls the grasses	For sole crop only
Foxtail millet	Carfentrazone	0.018	PoE	Effectively controls the sedges and BLWs	For sole crop only
Little millet	Isoproturon	1.00	PRE	Effectively controls the grasses and BLWs	For sole crop only

Integrated Weed Management in Millets

1. Herbicide resistance in weeds develops over time as a result of repeated usage, making weed management challenging.

2. To reduce weeds, integrated weed management (IWM), which combines a number of separate management tactics, has been created.

3. Instead of relying just on one method, IWM takes a holistic approach that integrates mechanical, cultural, and chemical methodologies.

4. IWM is more environmentally and financially sustainable.

Striga Control in Sorghum

Striga litura is the common root parasite on sorghum. Stimulating germination of seed in the soil and destroying by tillage after they germinate can effectively control striga. Use of trap crops (cotton, soybean, cowpea, chickpea, sunflower, pigeonpea) and catch crops (maize, millets) can control striga. The chemical Fenac 1.0-1.5 kg/ha or 2,3,6-TBA helps in control of striga.

Conclusion

In the future, millets are going to have high demand in the market. Weeds are difficult to be identified in the early stage of crop growth and in that period, weeds cause drastic loss of costly external inputs like water and fertilizer depriving the crop of millets of that. To reduce crop loss due to weed infestation in millets, timely and proper weed management strategies, namely, preventive methods, mechanical methods, cultural methods and chemical methods should be adopted in an integrated manner according to the prevailing situation of weed diversity, climatic conditions, and crop ecology. Across the current era of precision agriculture, precise weed management may also be used to intense weed control in bigger regions employing robots, drone technology and machine learning which will not only minimize the environmental impact of herbicide use but also sustainably boost profitability to the large millet growers.

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Flaming: A Clean Heat-Based Weed Control Technique

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Abstract
Flaming is emerging as an eco-friendly and innovative approach to weed management that relies on controlled bursts of heat rather than chemical herbicides. By exposing weeds to intense flames, the cell structure of plants is damaged, leading to their rapid death while leaving crop plants largely unharmed. This method offers farmers a sustainable alternative to excessive herbicide use, helping to reduce chemical residues in food, protect soil health and minimize environmental pollution. Flaming is particularly useful in organic farming systems and areas where herbicide resistance has become a challenge. Though it requires careful handling and suitable equipment, flaming represents a promising practice for integrated weed management and the move toward greener agriculture.

Introduction
Weeds remain a major constraint in crop production, causing considerable yield losses. Managing weeds without synthetic herbicides, as required in organic farming, is particularly challenging. Rising herbicide resistance, increasing costs, and concerns over contamination of surface and groundwater have heightened public scrutiny and led to stricter regulations on herbicide use. Consequently, weed scientists are exploring alternative and integrated approaches to reduce reliance on chemical control. Among these, propane-based flame weeding offers a promising option, as it avoids issues related to chemical residues in soil, water and food, while reducing dependence on herbicides, manual weeding and mechanical cultivation.

What is Flaming?
1. Propane flaming involves directing intense heat from a propane burner onto plant tissues to control weeds. It is an approved technique in organic farming and is gaining renewed attention for use in both organic and conventional production systems. Flaming is also useful in areas where herbicide use is restricted or undesirable, such as parks, city landscapes and other urban environments. Flame weeding equipment ranges from handheld single-torch units to push-type multi-torch models, making the method simple to operate and well suited for small farms. An increase of temperature to >50 °C inside the plant cells can result in the coagulation (denaturation and aggregation) of membrane proteins leading to loss of membrane integrity and consequently, flamed weeds die, or their competitive ability against the crop is severely reduced. The susceptibility of plants to flaming largely depends on their heat avoidance, heat tolerance, or both. The extent to which heat from the flames penetrates plants depends on the flaming technique and leaf surface moisture.

2. The effects of flaming on plants are influenced by several factors including temperature, exposure time, and energy input. Depending on the exposure time, protein denaturation may start at 45°C. Temperatures in the range of 95–100°C have been reported to be lethal for leaves and stems and should be applied for at least 0.1 s (Ascard *et al.*, 2007).

Determination of Flaming Efficacy
The efficacy of flame weeding was reported to be influenced by several factors, including the growth stages of the plant, the physical location of the growing point at the time of flaming, the presence of protective layers of hair or wax and lignification, the technique of flaming, the regrowth potential of plant species and the leaf relative water content of plant species (Ulloa *et al.*, 2011). Efficacy of flaming treatment can be easily determined at the field level by conducting a simple 'fingerprint test.' Immediately after flaming,

place a leaf between the thumb and index finger, and firmly press on it. If a darkened impression (fingerprint) is visible on the leaf surface, it is likely the evidence of a loss of internal pressure due to cell water leakage. Plant death occurs as a result of lost water through the broken cell walls and dehydration.

Response of Selected Weed Species to Flaming

The response of weeds to broadcast flaming differs according to species, growth stage and the amount of propane applied. Effective flame weeding relies on targeting weeds at the correct developmental stage and using an appropriate propane dose

1. Role of Plant size on weed species tolerance to flaming: Flaming is more effective for smaller weeds, at early growth stages, thin and delicate plant tissues at the early vegetative stage, younger plants. About 90% control of *Abutilon theophrasti* Medik. can be obtained with a single dose of 42, 56, and 102kg of propane ha^{-1} for the 5-leaf, 7-leaf, and 16-leaf stages, respectively (Ulloa *et al.*, 2010).

2. Role of plant type on weed species tolerance to flaming: Grasses are difficult to control with flaming than are broadleaf species as the growing point in grass species during early growth stages is below the soil surface and is thus protected from the flame. Broadleaf weeds, such as *Amaranthus rudis* Sauer, *Amaranthus retroflexus* L., *Convolvulus arvensis* L., *Kochia scoparia* (L.) Schrad., *Ipomoea hederacea* Jacq., *A. theophrasti* Medik., *Hibiscus trionum* L., and *Ambrosia artemisiifolia* L., can be effectively controlled (90%) with a single dose of about 16-70 kg of propane ha^{-1} when flamed at early growth stages ranging from 2-leaf to 14-leaves. Flaming has no residual soil activity and the heat cannot penetrate deeper into the soil profile; therefore, flaming does not provide control of root structures of perennial weeds.

Response of Selected Agronomic Crops to Flaming

The crop growth stage is critical in determining whether or not to use a flamer for weed control after crop emergence and the heat should be directed away from the growing point of the crop to avoid potential crop injury.

Tolerance of Maize Types to Flaming: Visual crop injury symptoms included initial whitening and then browning of leaves. Stunting of growth was especially evident when the plants were flamed with higher propane doses (44 and 85 kg ha^{-1}). Field maize flamed broadcast at the 5-leaf stage (V_5) was the most tolerant, whereas the 2-leaf (V_2) was the most susceptible stage, which had the highest visual crop injury and the largest loss of yield and yield components (Ulloa *et al.*, 2011).

Environmental Impacts of Flaming

Soil compaction resulting from traffic of tractor and flaming implement compared with chemical control as typically flaming needs to be conducted more often than herbicide application. Temporary increase in surface temperature of the soil during the flaming treatments. General carbon footprint that can contribute to the overall global warming. Flame weeding could impact the air quality to the greater extent than chemical control, as the combustion by-products of propane burning (e.g. CO, CO_2, nitrous and sulfur oxides) are known air pollutants. Such impacts are considered more important from the global warming standpoint than those associated with the use of herbicides such as volatilization and spray drift (Ascard *et al.*, 2007).

Advantages of Flaming

Flame weeding is an appealing alternative because it leaves no chemical residues, avoids drift hazards, and is effective even on herbicide-tolerant weeds. It does not harm water quality or disturb soil structure, unlike repeated mechanical cultivation, which can increase erosion and organic matter loss. Flaming is also cheaper than hand weeding and organic herbicides, and weeds are unlikely to develop resistance to the intense heat. Moreover, it can be used on wet or stony soils without bringing buried weed seeds to the surface, helping to substantially reduce hand-weeding needs in organic systems (Wszelaki *et al.*, 2007).

Disadvantages of Flaming

Despite its benefits, flame weeding has several limitations compared with conventional herbicides. Equipment costs are higher, crop selectivity is low, application speed is slower due to limited coverage, and it offers no residual weed control. While flame weeders cover fields at rates similar to mechanical cultivators, they are less efficient than chemical sprayers. Additionally, the high energy demand and carbon emissions associated with propane use are environmental concerns, although propane burns cleaner than many other fossil fuels, such as diesel (Merfield *et al*., 2009).

Conclusion

The threat of invasive weeds coupled with over-reliance on herbicides call for adoption of new weed control practices. Flaming offers an effective novel approach that may address these needs. Flaming similar to other weed management tactics should not be viewed as a stand-alone tactic. However, it can be successfully incorporated into an IWM plan and thus be used in concert with other tools for both organic and conventional crop production systems. More research is needed to perhaps develop new flaming equipment and methods, or to examine different positionings of the burners to avoid any significant crop damage and yield reductions.

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Landscape Ecology: Balancing Development and Conservation

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Introduction

In today's rapidly changing world, one of the greatest challenges humanity faces is how to balance economic development with the preservation of natural ecosystems. Expanding cities, highways, dams, mining and agriculture are reshaping landscapes at an unprecedented pace. While these activities fuel economic growth, they also fragment habitats, threaten biodiversity, and disturb ecological balance. Landscape ecology offers a scientific framework for understanding how human actions interact with natural patterns, aiming to create sustainable solutions that align development with ecological preservation.

What is Landscape Ecology?

Landscape ecology is a scientific discipline that examines the spatial patterns and ecological processes across heterogeneous land mosaics, encompassing both natural ecosystems and anthropogenically modified environments. It emphasizes the interactions between ecological components and human activities, addressing key questions such as:

1. How do land-use transformations influence biodiversity and ecosystem functionality?
2. What design principles can guide development to mitigate ecological disruption?
3. Which integrative strategies can reconcile conservation objectives with socio-economic demands?

Development Pressures on Landscapes

Modern development often comes at the cost of ecological integrity:

1. Urban Expansion: Growing cities encroach on forests, wetlands and agricultural land.

2. Infrastructure Projects: Highways, railways and dams fragment habitats, blocking animal movement.

3. Agricultural Intensification: Monocultures and excessive use of fertilizers degrade soil and biodiversity.

4. Mining and Industrialization: Extraction of resources alters landscapes permanently.

These pressures make it clear that unplanned growth leads to irreversible ecological losses. Landscape ecology provides tools to manage this tension.

How Landscape Ecology Helps

1. Habitat Connectivity: By maintaining corridors between fragmented habitats, animals like elephants, tigers and leopards can migrate safely, reducing human-wildlife conflicts.

2. Sustainable Land Use Planning: Integrating green belts, wetlands and urban forests in city planning ensures that development is nature-friendly.

3. Watershed and Soil Management: Healthy landscapes protect water resources, prevent floods and maintain soil fertility.

4. Restoration of Degraded Lands: Rewilding mined areas, planting along riverbanks and restoring wetlands bring back ecological balance.

5. Policy Integration: Tools like Environmental Impact Assessment (EIA) and Geographic Information Systems (GIS) help policymakers design smarter, sustainable projects.

Examples:

a. **Western Ghats, India:** A biodiversity hotspot facing pressure from plantations, dams and cities. Landscape-level conservation strategies here are crucial to protect unique flora and fauna.

b. Wildlife Corridors in Assam: Elephant corridors connecting fragmented forests help reduce human-animal conflicts.

c. Urban Green Spaces in Delhi and Bengaluru: Initiatives to create green lungs within cities showcase how ecology can be integrated with modern urban life.

These instances demonstrate that economic development and environmental conservation are not inherently antagonistic objectives; rather, they can be mutually reinforcing pursuits when guided by strategic, integrative planning and sustainable management practices.

The Way Forward

To truly balance development and conservation, we need:

1. Participatory Planning: Involving local communities in decision-making.

2. Green Infrastructure: Roads with underpasses for wildlife, eco-friendly buildings and renewable energy use.

3. Policy Support: Stronger laws that integrate conservation goals with economic projects.

4. Education and Awareness: Encouraging citizens to value landscapes as life-support systems, not just as land for exploitation.

Conclusion

Landscape ecology is more than an academic concept, it is a practical guide for sustainable living. It reminds us that every highway, dam or city expansion must be planned with the larger landscape in mind. When we see the land as a connected whole, we realize that our survival depends on the survival of ecosystems. Balancing development and conservation is not an option; it is a necessity. Landscape ecology offers us a path where economic growth and ecological integrity can go hand in hand, ensuring a future where both people and nature thrive together.

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Sensor-Based Remote Sensing Systems for Continuous Environmental and Agricultural Monitoring

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Abstract

Remote sensing is the science of collecting information on Earth's surface and environment without direct physical contact, by interpreting electromagnetic radiation by reflected by objects on the Earth's surface. Its scope has expanded from basic aerial photography to advanced multi-spectral, hyperspectral, thermal, and microwave observations that support decision-making across the agriculture sector. Advances in sensor technology, reduced platform costs, and cloud-based data processing have transformed remote sensing from a specialised research activity into an operational tool used worldwide for continuous environmental monitoring.

Remote sensing sensors are generally classified into passive and active systems. Passive sensors, such as RGB, multispectral, hyperspectral, and thermal cameras, rely on natural energy sources like reflected sunlight or emitted thermal radiation. Because of this, their performance is affected by lighting conditions and the atmosphere. In contrast, active sensors such as Light Detection and Ranging (LiDAR) and Synthetic Aperture Radar (SAR) transmit their own signals and record the returned response. This allows them to collect data consistently, even at night or under cloudy conditions. Both sensing approaches complement each other: passive sensors provide detailed spectral information about surface materials and vegetation health, while active sensors offer structural details and all-weather observations useful for three-dimensional mapping and soil or moisture analysis.

Keywords: Remote Sensing; Sensors, Agriculture, Environment, Satellite, Unmanned Aerial Vehicles.

Platforms for Sensor Deployment

Remote sensing sensors are deployed on various platforms, each offering distinct advantages. UAVs have become a key on-demand data acquisition tool, providing spatial resolution, flexible mission planning, and compatibility with RGB, multispectral, thermal, LiDAR, and compact hyperspectral sensors, making them ideal for precision agriculture and research

For regional to global monitoring, satellite platforms offer systematic, long-term, and wide-area observations. Consistent temporal data streams are ensured by the variety of sensing capabilities provided by contemporary satellite missions, which range from global SAR coverage to medium-resolution multispectral images. Satellites are essential for trend analysis and policy-level applications because of their extensive coverage and data continuity, even though they typically provide poorer spatial resolution than UAV.

The gap between UAVs and satellites is filled by airborne systems that use manned aircraft. They are frequently employed in operational surveys and high-fidelity research campaigns because they can transport hefty and high-quality sensor payloads over greater distances than UAVs, such as sophisticated Multispectral, hyperspectral scanners and LiDAR devices (Farhan *et al.,* 2024) (Figure 1).

This article reviews key remote sensing sensors, RGB, thermal, multispectral, hyperspectral, LiDAR, and SAR, highlighting their principles, data characteristics, advantages, limitations, and applications in agricultural sector, with emphasis on advances sensor–platform integration. It is structured around sensor classification, detailed discussions of major technologies, and an overview of data fusion, UAV–satellite synergy, and future directions such as miniaturisation and AI-enabled workflows.

Figure 1. Unmanned Aerial Vehicle with Multispectral and Thermal Sensor

Classification of Remote Sensing Sensors

Remote sensing sensors are typically categorized as passive or active based on how they obtain energy, with each type having a distinct function in environmental and agricultural applications (Sishodia *et al.*, 2020). In crop monitoring, vegetation analysis, and stress assessment, passive sensors such as RGB, multispectral, hyperspectral, and thermal, use reflected or emitted natural radiation. Although their use is limited by large data volumes and processing complexity, RGB sensors provide fine spatial detail for visual interpretation, multispectral sensors support vegetation index-based evaluation of crop health, and hyperspectral sensors enable in-depth analysis of plant biochemical properties. For irrigation and water stress management, thermal sensors offer useful surface temperature data. LiDAR and SAR are examples of active sensors that produce their own energy, allowing for reliable data collection in a variety of lighting and weather scenarios. While SAR is ideal for estimating soil moisture and monitoring floods in all weather conditions, LiDAR is especially useful for three-dimensional structural and biomass studies.

1. Comparison Based on Operating Principle: From an operational perspective, sensors differ significantly in three fundamental aspects. Energy source distinguishes passive sensors, which rely on solar or thermal radiation, from active sensors, which generate their own signal. Weather dependency is a major limitation of optical and thermal sensors, as clouds and atmospheric conditions can degrade data quality, whereas SAR and LiDAR operate reliably under most weather conditions. Penetration capability further differentiates sensors: optical sensors primarily capture surface reflectance, LiDAR partially penetrates vegetation canopies, and SAR microwaves can penetrate clouds and, to some extent, vegetation and soil. Understanding these differences is essential for selecting appropriate sensor combinations and designing robust remote sensing strategies.

Optical Sensors in Remote Sensing

Optical sensors are central to modern remote sensing, capturing reflected solar radiation in the visible to shortwave infrared regions to assess vegetation, land cover, and surface characteristics. Based on spectral resolution, they are commonly classified as RGB, multispectral, or hyperspectral sensors.

1. RGB Sensors: RGB sensors function within the visible region of the electromagnetic spectrum, recording reflected energy in three wide bands: blue (400–500 nm), green (500–600 nm), and red (600–700 nm). This range aligns closely with human visual perception, making RGB images easy to interpret and visually detailed. Owing to their simple construction and low energy demand, RGB cameras are extensively used on UAVs and are also integrated into many high-resolution satellite systems.

On UAV platforms, RGB sensors are commonly used for crop emergence assessment, plant counting, canopy cover estimation, weed mapping, and damage assessment after extreme events. Satellite-based RGB imagery supports high-resolution land use mapping and urban analysis, although its application in crop health monitoring is generally limited unless combined with additional spectral information (Aasen *et al.,* 2020).

Figure 2. RGB-Sensor (Sony ILCE-5100)

Data characteristics: RGB imagery typically provides very high spatial resolution, especially from low-altitude UAV platforms, often achieving centimeter-scale detail. The data are stored as three-band raster images with relatively small file sizes compared to multispectral or hyperspectral datasets. However, because RGB sensors capture only visible wavelengths, they have limited capability to detect physiological plant attributes such as chlorophyll content or crop water status (Aasen *et al.,* 2020).

Advantages and limitations: Low cost, simplicity of use, quick data capture, and simple processing workflows are the main benefits of RGB sensors. Because of these characteristics, RGB imaging is ideal for quick field evaluations, visual crop scouting, and plant geometry mapping. The primary drawback is the limited spectrum information, which lowers sensitivity to early disease symptoms that appear outside of the visual range, nutritional deficits, or mild crop stress (Hassler & Baysal-Gurel *et al.,*2019).

2. Multispectral Sensors:

Band configuration: Multispectral sensors capture information across a limited set of discrete spectral bands, typically ranging from four to ten. These bands commonly cover the visible region (blue, green, and red), along with near-infrared (NIR) and red-edge wavelengths (Vishwakarma et al., 2025a, 2025b) (Figure 3). The inclusion of NIR and red-edge bands is particularly important for vegetation studies, as they are highly sensitive to leaf internal structure and chlorophyll concentration, making them effective for assessing crop condition and plant health (Delegido *et al.,* 2021; Karad and Khose, 2021; Vishwakarma *et al.,* 2024).

Figure 3. Multispectral Sensor (MicaSense RedEdge-MX™)

Vegetation indices: Multispectral imagery enables the derivation of widely used vegetation indices for quantitative crop assessment. The Normalized Difference Vegetation Index (NDVI) is the most common indicator of plant vigor and biomass, while the Green NDVI (GNDVI) enhances sensitivity to chlorophyll content. The Soil Adjusted Vegetation Index (SAVI) reduces the influence of soil background effects, particularly in sparsely vegetated areas. Owing to their ability to provide spatially explicit and quantitative information on crop health, these indices are extensively applied in precision agriculture and environmental monitoring (Jiang *et al.,* 2021).

Role in crop health and land cover mapping: Multispectral sensors provide a well-balanced combination of spectral information, spatial detail, and manageable data volumes, making them effective for both UAV- and satellite-based monitoring. In agriculture, multispectral imagery is commonly applied to identify nutrient deficiencies (Khose and Mailapalli *et al.,* 2024), optimize irrigation practices, estimate crop yields, and differentiate crop types. At larger spatial scales, satellite multispectral data are essential for land cover classification, phenological monitoring, and assessing long-term vegetation dynamics. Their proven reliability and availability of standardized processing methods have established multispectral sensors as a core component of practical remote sensing applications.

3. Hyperspectral Sensors: Hyperspectral sensors acquire imagery across hundreds of closely spaced, continuous spectral bands, typically with bandwidths of about 5–10 nm. This exceptionally fine spectral resolution allows detailed representation of surface reflectance patterns throughout the visible and infrared regions (Li *et al.,* 2022). In contrast to multispectral systems, hyperspectral sensors preserve continuous spectral signatures, capturing subtle absorption features linked to specific biochemical and biological constituents.

The rich spectral detail of hyperspectral data enables precise differentiation of surface materials and crop attributes, including pigment composition, nitrogen levels, moisture stress, and disease-related biochemical variations. In agricultural applications, hyperspectral imagery has shown strong potential for early detection of crop stress, reliable crop type discrimination, and identification of diseases before visible symptoms develop, making it especially valuable for advanced monitoring and research-oriented studies.

Although hyperspectral sensing offers rich spectral information, it generates very large and complex datasets that pose challenges for data storage, transmission, and computational processing. Effective interpretation often requires advanced calibration procedures, dimensionality reduction methods, and machine-learning–based analytical techniques. In addition, the high cost of hyperspectral sensors and their sensitivity to atmospheric disturbances further constrain large-scale operational deployment (Li *et al.,* 2022).

At present, hyperspectral sensors are primarily utilized in research studies, experimental UAV platforms, and specialized satellite missions. However, continuous progress in sensor miniaturization, cloud computing infrastructure, and AI-driven data analysis is gradually expanding their practical applications. When integrated with multispectral and thermal datasets, hyperspectral sensing is expected to play an increasingly important role in future precision agriculture and environmental monitoring frameworks.

4. LiDAR Sensors:

Operating principle: LiDAR systems transmit short laser pulses toward the Earth's surface and measure the time taken for the reflected signal to return to the sensor. This time-of-flight information is converted into precise distance measurements, allowing the generation of high-resolution three-dimensional (3D) point clouds. LiDAR sensors typically operate in the near-infrared region and can be deployed on UAVs, airborne platforms, and, increasingly, satellites (Guo *et al.,* 2021).

Structural and topographic information: One of the most significant advantages of LiDAR is its ability to capture detailed vertical structure. In vegetation studies, LiDAR can penetrate gaps within the canopy, enabling accurate estimation of crop height, canopy volume, and vertical distribution of biomass. This structural information is difficult to obtain using passive optical sensors alone. In agricultural landscapes, LiDAR-derived digital terrain models are also used for drainage analysis, field leveling, and precision irrigation planning. LiDAR sensing is increasingly adopted in agriculture and environmental studies for its ability to deliver detailed three-dimensional structural information. UAV- and airborne LiDAR are widely used for canopy structure analysis, biomass estimation, yield modeling, and forest inventory, and their integration with optical or multispectral data improves crop growth and stress assessment by combining structural and spectral information. However, high system costs, intensive point-cloud processing requirements, and limited spectral capability constrain direct biochemical analysis without sensor fusion (Guo *et al.,* **2021).**

5. Synthetic Aperture Radar (SAR)

Operating principle: SAR systems operate in the microwave region of the electromagnetic spectrum and actively emit radar pulses toward the surface. By moving along the flight path and coherently processing the returned signals, SAR synthesizes a large antenna aperture, achieving high spatial resolution. SAR systems operate across different wavelength bands, commonly X-, C-, and L-band, each with varying penetration and sensitivity characteristics (Khose *et al.,* 2025). A key advantage of SAR is its ability to acquire data regardless of cloud cover, atmospheric conditions, or illumination. This makes SAR particularly valuable in regions with frequent cloud cover or during monsoon seasons, where optical data availability is limited. As a result, SAR has become an essential tool for continuous agricultural monitoring, flood mapping, and disaster assessment (Attema *et al.,* 2022).

Sensitivity to surface and moisture conditions: SAR backscatter depends on surface roughness, vegetation structure, and moisture, making it valuable for soil moisture estimation, crop growth monitoring, and phenological analysis. Time-series SAR data support tracking crop development and stress detection, although interpretation is challenging due to speckle noise and complex radar–surface interactions (Veloso *et al.,* 2021).

Operational use and challenges: Satellite SAR missions provide consistent and frequent coverage, supporting large-scale operational applications. While SAR data processing and interpretation require specialized expertise, recent advances in cloud computing and machine learning have improved accessibility and usability. Nevertheless, SAR remains less intuitive than optical imagery, and integration with optical or thermal data is often necessary to enhance interpretability and application relevance (Moreira *et al.,* 2021). LiDAR and SAR offer complementary strengths, with LiDAR providing detailed three-dimensional structural information and SAR enabling consistent temporal monitoring with sensitivity to moisture and surface properties under all weather conditions. Their integration with optical data enhances analysis accuracy and is increasingly recognized as a key approach for advanced remote sensing applications in precision agriculture and ecosystem monitoring.

6. Thermal Remote Sensing and their principle: Thermal remote sensing is based on measuring thermal infrared (TIR) radiation emitted by objects, providing direct information on surface temperature and surface–atmosphere energy exchanges. Unlike optical sensors that rely on reflected solar radiation, thermal sensors record emitted energy, making them particularly effective for assessing plant water status, stress conditions, and evapotranspiration dynamics. All objects above absolute zero emit electromagnetic radiation, and thermal infrared sensors exploit this principle to estimate physical properties such as temperature, emissivity, and moisture content.

In vegetation canopies, surface temperature is closely related to transpiration rates and stomatal conductance, allowing thermal imagery to serve as a reliable indicator of crop water stress and physiological activity (Colaizzi *et al.,* 2021). Most thermal remote sensing systems operate within the atmospheric window of 8–14 µm, where atmospheric absorption is minimal, enabling accurate land surface temperature retrieval under clear-sky conditions. Thermal sensors deployed on UAVs and satellites convert measured radiance into surface temperature using calibration, atmospheric correction, and emissivity estimation techniques to enhance accuracy.

Applications in the Agricultural and Allied Sector

Thermal remote sensing is extensively used in agriculture to assess crop water status, evapotranspiration, and plant stress. Water-stressed plants exhibit elevated canopy temperatures due to reduced transpiration, allowing early detection and improved irrigation management. Thermal data also support evapotranspiration estimation through energy balance models at both regional (satellite) and field (UAV) scale. Additionally, abnormal temperature patterns help identify diseases, nutrient stress, and heat stress, especially when integrated with optical data.

Comparative Analysis of Remote Sensing Sensors: Different remote sensing sensors provide complementary information based on their spectral, spatial, and physical interaction with the Earth's surface. A comparative understanding of these sensors is essential for selecting appropriate technologies and designing integrated sensing strategies.

Table 1. Comparison of major remote sensing sensors based on key characteristics:

Sensor type	Spectral range(nm)	Weather Dependency	Energy Source	Penetration Capability	Typical Applications
RGB	400-700	High	Passive	Surface only	Crop scouting, mapping, counting
Multispectral	Visible-NIR-Red-edge	High	Passive	Surface only	Crop health, NDVI, land cover
hyperspectral	Visible-NIR-SWIR	High	Passive	Surface only	Disease detection, material ID
thermal	8-14 µm	Moderate	Passive	Surface only	Water stress, ET estimation

LiDAR	Near-infrared laser	Low	Active	Partial canopy	3D structure, biomass
SAR	Microwave	Very Low	Active	Clouds, vegetation, soil	Soil moisture, floods

From this comparison, it is evident that optical sensors are highly effective for spectral analysis but are sensitive to atmospheric conditions, while active sensors provide structural and moisture-related information with strong weather independence. Consequently, multi-sensor integration has emerged as the most robust approach for operational remote sensing, especially in agriculture and environmental monitoring.

Challenges and Future Perspectives

Despite significant advances, the operational use of remote sensing sensors is constrained by challenges such as large data volumes and high processing complexity, particularly for hyperspectral, LiDAR, and SAR datasets. Ensuring data consistency through accurate calibration, atmospheric correction, and cross-platform harmonization remains difficult. Integrating multi-sensor data with differing resolutions and acquisition times is technically demanding, while UAV applications face regulatory limits, weather sensitivity, and restricted flight endurance. Translating complex remote sensing outputs into timely, actionable decisions also remains a key bottleneck.

Future Directions

Future developments are expected to emphasize sensor miniaturization, UAV–satellite integration, and AI-driven analytics. Advances in compact sensors, dense satellite constellations, deep learning, and cloud-based processing will enable faster, more accessible, and unified Earth observation systems.

Conclusions

Remote sensing has become a comprehensive observation system shaped by advances in sensor technologies and platform integration. Optical and thermal sensors provide spectral and functional information, while active sensors such as LiDAR and SAR add structural detail and all-weather monitoring capabilities. This review underscores that effective Earth observation relies on multi-sensor and multi-platform integration rather than any single technology, with continued progress in data fusion expected to strengthen applications in precision agriculture, climate adaptation, and sustainable resource management.

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CRISPR and Biosensor Technologies for Detection of Seed-Borne Diseases

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Introduction

Global food security, crop production, and seed quality are all severely compromised by seed-borne diseases. Pathogens transmitted through seeds can cause poor germination, seedling mortality, reduced vigour, resulting in yield loses and widespread disease outbreaks in the field. Conventional seed health testing methods, although reliable, are often time taking and may fail to detect pathogens present at low levels. Rapid, sensitive, and field-deployable diagnostic techniques are growing ever more vital as the importance of high-quality seed production, seed certification, and phytosanitary demands increasing. In recent years, **CRISPR-based diagnostics and biosensor technologies** have emerged as promising innovations for accurate and early detection of seed-borne pathogens, transforming the landscape of seed health testing.

Conventional Seed Borne Disease Detection Methods and Their Limitations

For the detection of seed-borne diseases, traditional methods such as blotter tests, agar plate assays, and grow-out tests are frequently used. Nevertheless, these techniques are time-consuming, labour intensive, and necessitate professional interpretation. Although molecular methods such as PCR have increased detection accuracy, their utility in large-scale and field-level seed testing is limited since they still require complex laboratory infrastructure. In the recent years many portable, rapid pathogen detecting devices have been developed for an early detection of seed borne diseases.

Recent Advances in CRISPR and Biosensor Technologies

1. CRISPR-Based Rapid Diagnostic Systems: Recent developments have shown how CRISPR-Cas systems, including Cas12 and Cas13, can be employed for detecting pathogens (Figure 1). Seed-borne fungi, bacteria, and viruses can be detected with extremely high sensitivity (within 30 to 60 minutes) using platforms like SHERLOCK that allow highly specific recognition of pathogen DNA or RNA sequences (Kellner et al.,2019).

2. Paper-Based and Lateral Flow CRISPR Assays: Low-cost, portable detection techniques have been developed by combining isothermal amplification methods with paper based CRISPR tests (Figure 1). These tests are appropriate for on-site testing in seed processing facilities and quarantine stations because they produce visual readouts that resemble lateral-flow strips (Zhou et al., 2023).

3. Electrochemical and Optical Biosensors: Electrochemical and optical biosensors using pathogen-specific antibodies or DNA probes have shown great potential in seed health diagnostics (Figure 1). These biosensors enable rapid, real-time detection with high sensitivity and minimal sample preparation, making them ideal for routine seed testing. Further, the ability to wirelessly and remotely capture, sense, and signal pathogenic organism presence, frequency, and quantity above and below can be estimated (Dyussembayev et al.,2021).

4. Nanotechnology-Enabled Biosensor Platforms: Signal amplification and biosensor sensitivity have been greatly improved by the incorporation of nanomaterials including carbon nanotubes, graphene oxide, and gold nanoparticles (Figure 1). Early diagnosis is made possible by nanotechnology-based biosensors that can recognize seed-borne diseases at exceptionally low levels (Narware et al., 2025).

5. Microfluidic and Lab-on-a-Chip Technologies: Microfluidic and lab-on-a-chip devices combine detection, amplification, and sample processing into a single platform (Figure 1). These small systems minimize contamination, use a few reagents, and enable simultaneous high-throughput screening of multiple seed-borne pathogens. These on-site detection of mycotoxins released from seed can be useful for early detection of pathogen (Zhang et al., 2021).

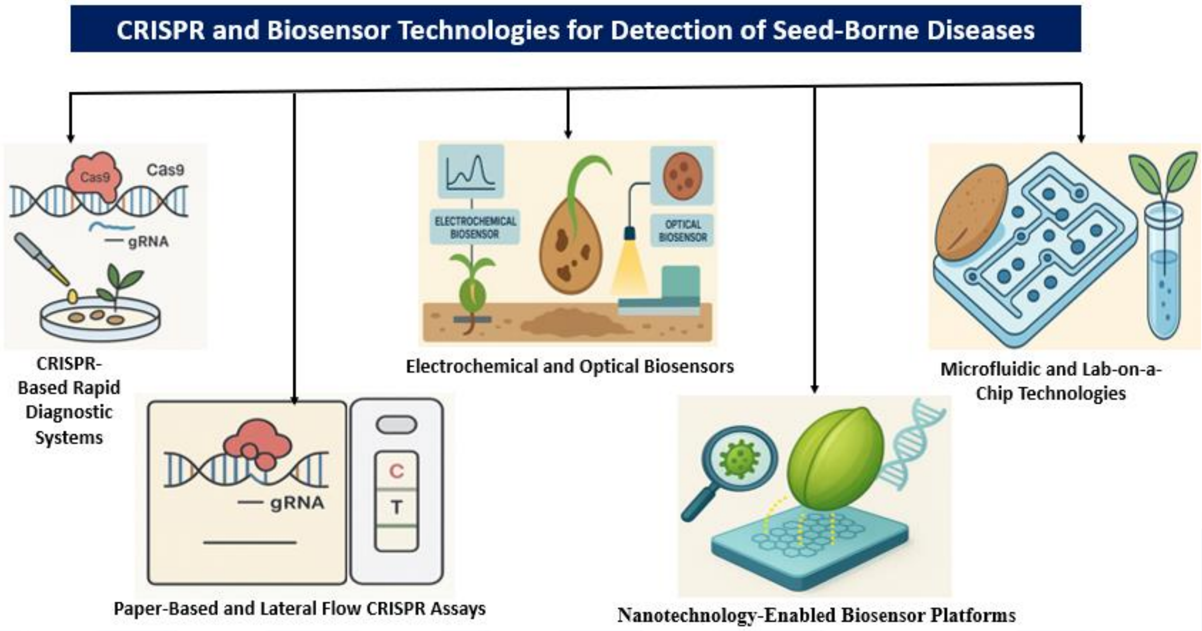

Figure 1: Recent Advances in CRISPR and Biosensor Technologies for detection of seed borne diseases

Conclusion

CRISPR-based diagnostics and biosensor technologies mark a major advance in the rapid and sensitive detection of seed-borne diseases. Their portability and suitability for on-site testing make them valuable tools for strengthening seed certification, quarantine inspections, and disease monitoring in seed storage godowns and processing plants. These technologies can enhance seed health, reduce post-harvest losses, and facilitate the production and distribution of high quality, pathogen-free seeds by enabling early detection and immediate action. Their regular use in official seed health and quarantine programs will require ongoing validation, standardization, and regulatory acceptance.

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Seed Priming to Enhance Biotic and Abiotic Stress Tolerance in Crops

Article ID: 72554

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Introduction

Seed priming is a pre sowing treatment that hydrates the seeds partially to activate preliminary metabolic activities without starting the entire germination process. This technique has emerged as a promising strategy to enhance seed germination, seedling vigour, and resilience against both abiotic stresses (such as drought, salinity, and temperature extremes) and biotic stresses (pathogens and pests). Seed priming is a low-cost, environmentally sustainable intervention that enhances crop establishment and stress tolerance through physiological and molecular modulation in response to unpredictability of the climate and increasing stress on agricultural systems (Jatana *et al.*,2024).

Mechanisms of Stress Tolerance Induced by Seed Priming

Seed priming enhances stress tolerance through multiple interconnected pathways. During priming, regulated hydration initiates energy metabolism, DNA repair, and antioxidant systems, which prepares seed for rapid response to subsequent stresses. Along with modulating reactive oxygen species (ROS) homeostasis and hormonal balances (e.g., abscisic acid and gibberellins), primed seeds also improves osmotic regulation and increases the synthesis of stress-related proteins that in turn contribute to higher germination rates and seedling vigour under stress conditions (Janah *et al.*,2025).

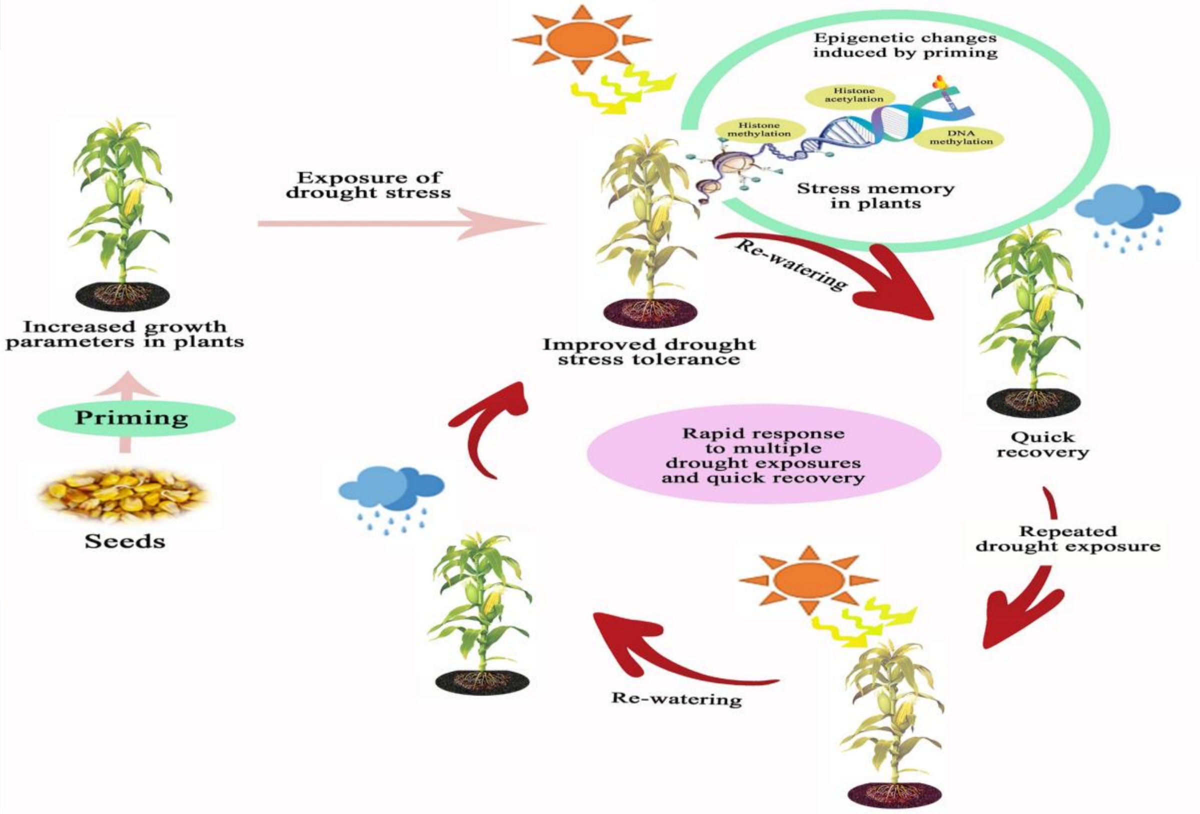
Additionally, priming triggers an event called "stress memory," in which early exposure to stressors develops epigenetic variations like DNA methylation and histone modifications that prepare plants for more robust reactions in the future. Though, more research is needed, preliminary findings indicate priming induced memory may improve stress tolerance even beyond the immediate developmental phases and may have promise for transgenerational resilience (Jatana *et al.*,2024).

Abiotic Stress Tolerance

Recent research highlights how priming might improve resistance against salinity and drought in major crops. For example, osmotic and hormonal priming improves water uptake, root architecture and antioxidant activity, leading to improved biomass accumulation and yield under drought stress in cereals. Priming with potassium nitrate, silicon dioxide and salicylic acid has been reported to improve early growth performance, uniform germination, and stress resilience across diverse cereal and horticultural crops (Janah *et al.*,2025).

In legumes such as *Phaseolus vulgaris* (common bean), salicylic acid seed priming significantly improved antioxidant defence and also, increased tolerance to salinity, demonstrating that chemical priming agents can robustly mitigate salinity induced oxidative stress (Karimi *et al.*,2025).

Additionally, nanopriming with materials like graphene oxide has grown more popular. According to recent studies, graphene oxide priming may modify physiological and molecular processes in groundnut, improving their tolerance to salinity and increasing their productivity in both controlled and in field. (Yan *et al.*,2024).



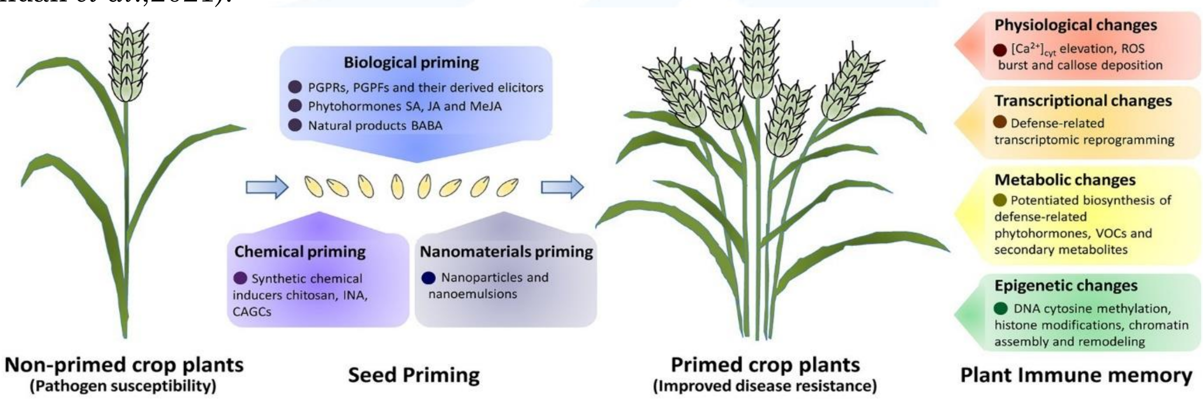
from Aswathi *et al.*,2022

Figure 1: Seed Priming to Enhance Abiotic Stress Tolerance in Crops

Biotic Stress and Cross-Tolerance

While earlier seed priming studies primarily addressed abiotic stress mitigation, emerging evidence demonstrates its capacity to confer cross tolerance to biotic stresses. Certain priming agents such as salicylic acid and jasmonic acid, which are key regulators of plant defence, can improve resistance against a spectrum of pests and pathogens by activating phytohormonal and secondary metabolite pathways. Seed priming has been linked to increased activation of defence signalling networks that confer tolerance to both abiotic and biotic stresses, although detailed molecular mechanisms were still under investigation (Jatana *et al.*,2024).

Also, a concept of integrated priming with beneficial microbes (biopriming) is rapidly evolving. Biopriming improves resistance by establishing early plant-microbe interactions that enhance systemic resistance and enhance utilization of nutrients. The microbes used in biopriming mobilize antioxidative defences and strengthen root systems, synergistically reducing disease incidence and improving drought tolerance (Marthandan *et al.*,2021).



- From Yang *et al.*,2022

Figure 2: Seed Priming to Enhance Biotic Stress Tolerance in Crops

Conclusion

Therefore, seed priming represents a versatile, easy, and effective approach for enhancing crop resilience in an era of climate change. By activating metabolic readiness, modulating stress-signalling pathways, and enhancing antioxidant capacity, seed priming improves tolerance to both abiotic and biotic stresses. Recent advancements in seed priming research, including nanopriming and green priming, along with emerging molecular insights into stress memory, have broadened the scope of this field and demonstrated strong potential for application in sustainable agriculture. However, optimizing priming procedures, validating their long-term effects, and understanding genotype-specific responses are essential to translate these advances into field-ready solutions. To fully realize the potential of seed priming in crop stress management, future research integrating omics technologies and multi-environment trials will be critical.

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Methylobacterium Spp.: Emerging Bioinoculants for Plant Growth Promotion and Stress Mitigation in Sustainable Agriculture

Article ID: 72555

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Summary

Methylobacterium spp., commonly known as pink-pigmented facultative methylotrophs (PPFMs), are ubiquitous inhabitants of the phyllosphere and represent a dominant fraction of the leaf-associated bacterial community. Their ecological success is primarily attributed to their unique ability to utilize methanol released from plant leaves during cell wall metabolism, along with other low-molecular-weight carbon sources present at micromolar levels on leaf surfaces. These bacteria exhibit remarkable metabolic flexibility, allowing them to persist under the temporally and nutritionally dynamic conditions of the phyllosphere. Beyond mere colonization, *Methylobacterium* spp. establish beneficial associations with plants by producing phytohormones such as indole-3-acetic acid, enhancing seed germination, root architecture, photosynthetic efficiency, and nutrient uptake, while also improving tolerance to abiotic stresses and suppressing certain pathogens. Their widespread occurrence across diverse plant species, combined with multiple modes of application, underscores their emerging importance as bioinoculants in sustainable agriculture.

Introduction

Bacteria commonly inhabit environments containing a wide range of carbon substrates, one such environment being the phyllosphere—the aerial surface of plants. The phyllosphere is frequently colonized by facultative methylotrophic bacteria, particularly members of the genus Methylobacterium. These bacteria are well adapted to utilize methanol as their primary carbon and energy source, while also metabolizing a limited number of alternative substrates such as organic acids and alcohols. Plant leaf surfaces release small quantities of carbon compounds, mainly sugars and organic acids, at micromolar concentrations through cuticular leaching. In addition to these non-volatile substrates, leaves emit volatile carbon compounds, especially methanol, which is produced during plant cell wall metabolism. Methanol is released through stomata, with maximum emission occurring in the early morning when stomata open, thereby providing a favorable niche for methylotrophic bacteria.

Accumulating evidence indicates that methanol is actively assimilated by *Methylobacterium* spp. and plays a significant role in enhancing their epiphytic fitness on plant surfaces. However, methanol availability in the phyllosphere is temporally restricted, with pronounced emission peaks occurring during the early morning hours. Consequently, *Methylobacterium* must exhibit metabolic flexibility to sustain growth and survival by utilizing alternative carbon sources during periods of reduced methanol release, such as later in the day or during nighttime when stomatal closure effectively limits methanol emission. This capacity to switch between carbon substrates is likely a key adaptive strategy enabling the persistence and competitive success of *Methylobacterium* under the dynamic and nutrient-limited conditions of the phyllosphere.

Pink-pigmented facultative methylotrophs (PPFMs) are aerobic, Gram-negative bacteria distinguished by their metabolic versatility. While they are capable of utilizing a broad spectrum of multicarbon substrates, their defining characteristic is the ability to grow on single-carbon compounds—including methanol, formaldehyde, and formate—as the sole sources of carbon and energy. These organisms can be readily isolated using methanol-based mineral media, reflecting their strong association with C_1 metabolism. Recent studies indicate that plant–*Methylobacterium* interactions span a continuum ranging from intimate, symbiotic associations to more transient epiphytic lifestyles, with intermediate endophytic colonization also being documented. Despite their widespread occurrence, the precise nature of these associations remains poorly resolved, and the ecological and biological significance of *Methylobacterium* spp. in plant systems is not yet fully understood. Nevertheless, leaf impression techniques on methanol-amended agar media have consistently revealed the presence of PPFMs across a diverse array of plant hosts, with detection reported in more than seventy plant species, underscoring their ubiquitous distribution in the phyllosphere.

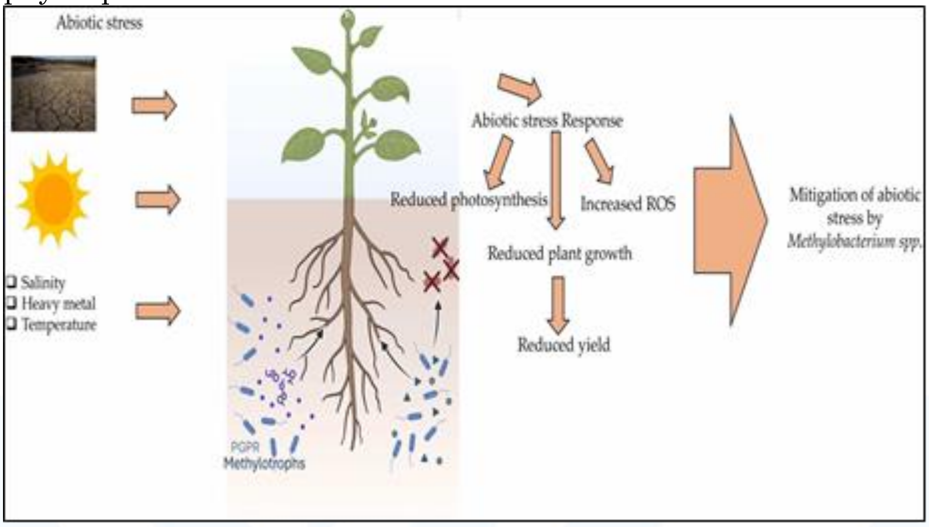

Fig.1. Role of *Methylobacterium* spp. in Mitigating Abiotic Stress and Enhancing Plant Growth and Yield"

Pink-pigmented facultative methylotrophs (PPFMs) are particularly abundant on the foliage of field-grown crops, with populations averaging approximately 10^6 colony-forming units per leaflet. In many cases, PPFMs constitute more than 80% of the total viable bacterial community recovered from leaf surfaces, highlighting their dominance within the phyllosphere microbiome. The prevalence of methylotrophic bacteria in soil environments is likely associated with the widespread presence of plant-derived polymers such as lignin and pectin, which serve as major precursors of methanol during decomposition. These substrates provide a continuous supply of C_1 compounds, thereby supporting the persistence and ecological success of methylotrophs in both aerial and terrestrial plant-associated habitats.

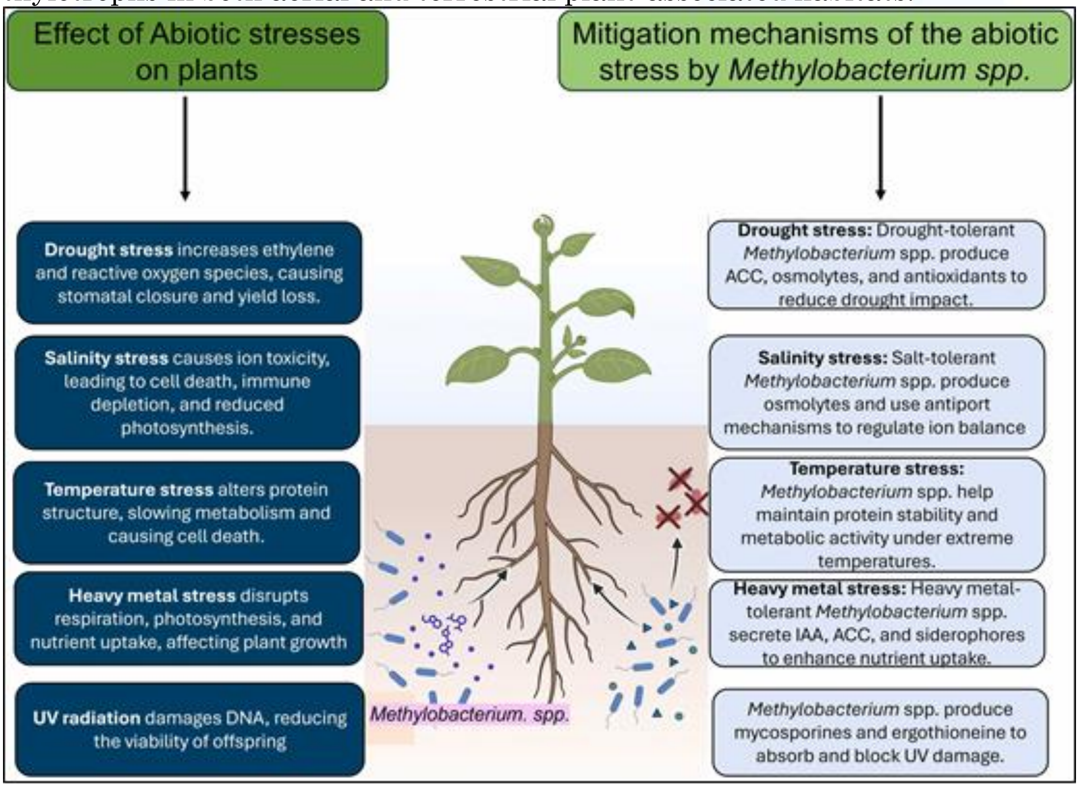

Fig.2 Role of *Methylobacterium* spp. in Mitigating Abiotic Stress

Despite extensive studies, the true species diversity within the genus *Methylobacterium* remains incompletely resolved, and their widespread occurrence across diverse natural habitats raises fundamental questions regarding habitat specificity versus functional redundancy among species. It is unclear whether distinct *Methylobacterium* species are adapted to particular ecological niches or whether they fulfill comparable ecological roles across different environments. Addressing these issues requires a comprehensive understanding of the spatial distribution of *Methylobacterium* strains within and across ecosystems, as well as detailed analyses of their community composition, structure, and temporal dynamics in natural habitats. Among methylotrophic bacteria, *Methylobacterium* extorquens AM1 stands out as one of the most extensively characterized species, serving as a model organism for methanol utilization due to its well-established genetic framework and thoroughly investigated physiological traits.

Characteristics of the Genus *Methylobacterium*

1. *Methylobacterium* belongs to the group of pink-pigmented facultative methylotrophs (PPFMs).
2. Cells are Gram-negative, aerobic, and typically rod-shaped.
3. Most species are motile, possessing polar flagella.
4. They produce pink to reddish pigmentation due to carotenoid compounds.
5. Members are facultative methylotrophs, capable of utilizing C_1 compounds such as methanol, formaldehyde, and formate as sole sources of carbon and energy.
6. They can also grow on multicarbon substrates, including organic acids and alcohols.
7. *Methylobacterium* spp. possess methanol dehydrogenase and specialized enzymatic pathways for methanol oxidation.
8. They are obligate aerobes and require oxygen for growth.
9. These bacteria are commonly found in the phyllosphere, but also occur in soil, water, and air.
10. They form epiphytic, endophytic, or occasionally symbiotic associations with plants.
11. Many species exhibit plant growth–promoting traits, such as production of indole-3-acetic acid (IAA) and enhancement of seed germination.
12. They are well adapted to nutrient-limited (oligotrophic) environments.
13. *Methylobacterium* extorquens AM1 is a well-studied model species for methylotrophic metabolism.

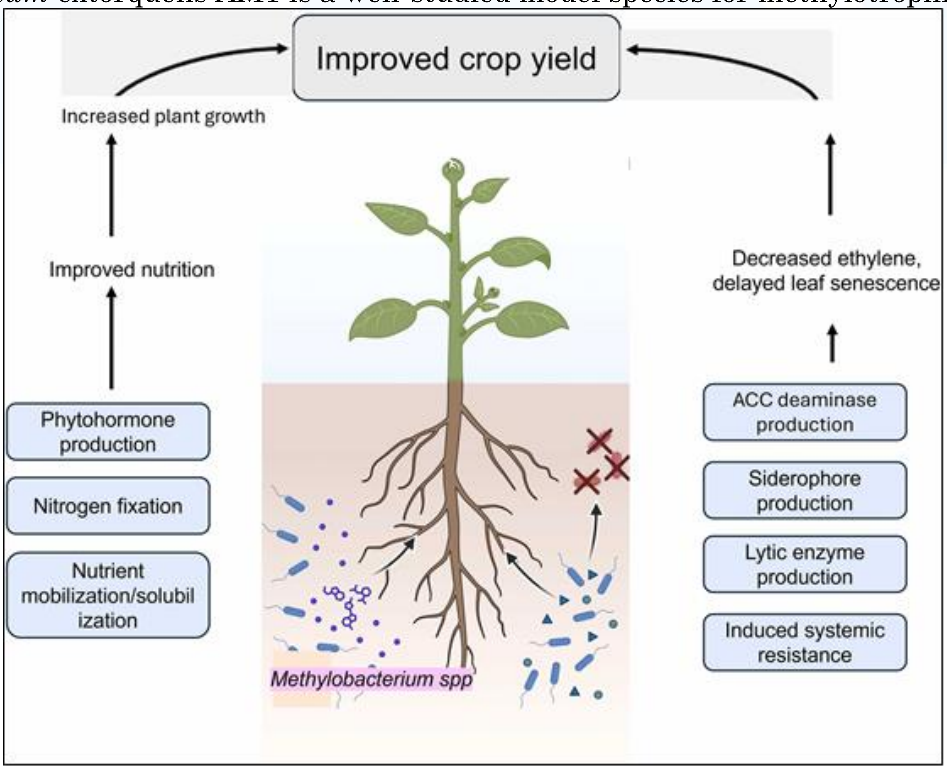

Fig. 3 Mechanisms of Plant Growth Promotion by *Methylobacterium* spp.

Plant and *Methylobacterium* Interaction

1. Promotes plant growth and development through the production of phytohormones, especially indole-3-acetic acid (IAA).
2. Enhances seed germination and seedling vigor in several crop species.
3. Improves root architecture, leading to better nutrient and water uptake.
4. Utilizes methanol emitted by plants, reducing carbon loss and creating a beneficial plant–microbe association.
5. Increases chlorophyll content and photosynthetic efficiency of plants.
6. Enhances nutrient availability and uptake, particularly nitrogen and micronutrients.
7. Improves tolerance to abiotic stresses such as drought, salinity, and temperature extremes.
8. Induces systemic resistance in plants against certain pathogens.
9. Suppresses phyllosphere pathogens through competitive colonization of leaf surfaces.
10. Contributes to overall plant health and productivity, especially under field conditions.

Methods of Application of *Methylobacterium* (PPFMs)

1. Seed Treatment:
   a. Seeds are coated or soaked in a suspension of *Methylobacterium* culture before sowing.
   b. Enhances seed germination, early seedling vigor, and root development.

2. Seedling Root Dip:
   a. Seedlings are dipped in a bacterial suspension prior to transplanting.
   b. Improves establishment and early growth of transplanted crops.

3. Foliar Spray
   a. Aqueous suspension of *Methylobacterium* is sprayed onto plant foliage.
   b. Effective for phyllosphere colonization and utilization of methanol emitted from leaves.

4. Soil Application
   a. Applied through soil drenching or mixed with organic manure or compost.
   b. Supports rhizosphere and soil colonization.

5. Drip Irrigation / Fertigation
   a. Bacterial suspension applied through irrigation systems.
   b. Ensures uniform distribution and efficient root-zone colonization.

6. Methanol Supplementation (in combination)
   a. Low concentrations of methanol may be applied along with foliar sprays to enhance bacterial activity.
   b. Improves bacterial survival and plant growth response.

7. Bioformulation-Based Application
   a. Applied as liquid or carrier-based biofertilizer formulations.
   b. Provides better shelf life and field performance.

Conclusion

Overall, *Methylobacterium* spp. represent a promising group of multifunctional plant-associated bacteria that bridge microbial ecology and sustainable crop production. Their efficient utilization of plant-derived methanol not only enhances their epiphytic fitness but also fosters a mutually beneficial plant–microbe relationship that translates into improved growth, yield, and stress resilience of crops. Despite their ubiquity, gaps remain in understanding species-level diversity, niche specialization, and functional redundancy within the genus, highlighting the need for further ecological and molecular investigations. Harnessing the full potential of *Methylobacterium* through optimized formulations and application strategies could significantly contribute to eco-friendly agriculture by reducing dependency on chemical inputs while enhancing plant productivity under both normal and stress conditions.

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Value Addition in Millets: Transforming Nutri-Cereals into Profitable Agri-Enterprises

Article ID: 72556

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Summary

Millets are among the oldest cultivated crops of India and have been an integral part of traditional diets, especially in dryland and tribal regions. Crops such as pearl millet, finger millet, foxtail millet, little millet, kodo millet and barnyard millet are now widely recognized as “nutri-cereals” due to their superior nutritional quality and climate resilience. In recent years, millets have gained global recognition for their role in ensuring nutritional security, sustainable agriculture and climate-smart farming.

Despite these advantages, millets were long considered “poor man’s crops” and their cultivation declined due to changing food habits and lack of market demand. Today, the scenario is changing rapidly, mainly due to value addition, which has emerged as a powerful tool to enhance consumption, improve marketability and increase farmers’ income.

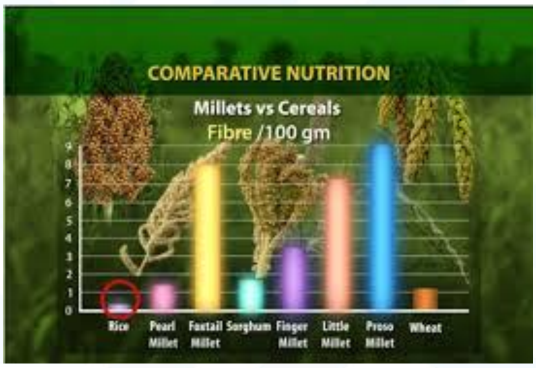

Fig.1 Comparative nutrition availability in different millet

Value Addition in Millets: Transforming Nutri-Cereals into Profitable Agri-Enterprises

Value addition refers to the process of improving the economic and nutritional value of raw millets by processing, packaging, branding and converting them into convenient, ready-to-use or ready-to-eat products. Instead of selling raw grains at low prices, farmers and entrepreneurs can earn significantly higher returns by converting millets into attractive food products.

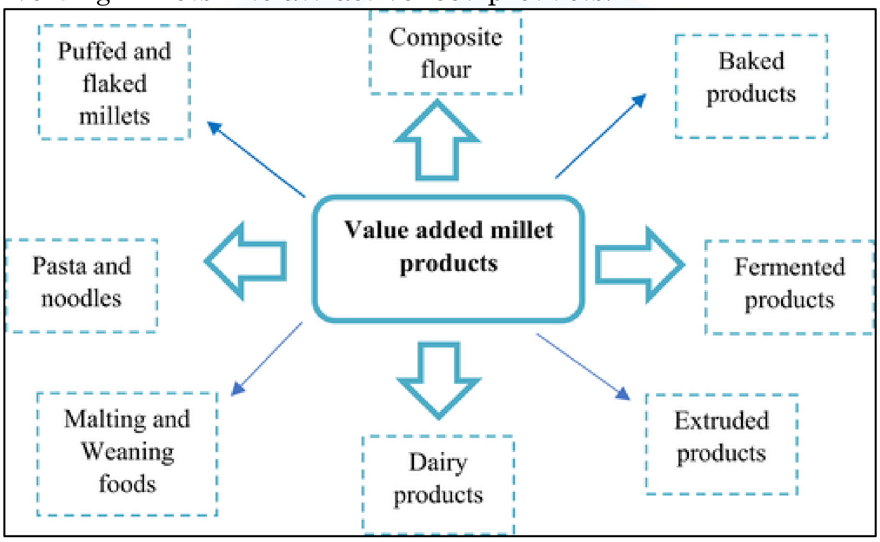

Fig.2 Various value-added millet products

Value addition not only increases income but also improves taste, shelf life, consumer acceptability and nutritional availability of millets.

Why is Value Addition in Millets Important?

Millets are rich in dietary fiber, protein, iron, calcium, zinc and antioxidants. They have a low glycaemic index, making them ideal for diabetic and health-conscious consumers. However, traditional millet processing is labor-intensive and time-consuming, which discourages urban consumers.

Value addition helps to:

a. Increase consumer demand
b. Reduce post-harvest losses
c. Improve shelf life and convenience
d. Enhance market price by 2–4 times
e. Create employment opportunities in rural areas.

General Procedure for Millet Processing

1. Cleaning and Grading: Removal of stones, dust and impurities improves product quality and consumer confidence.

2. Dehusking and Milling: Dehusking removes the hard outer layer, while milling converts grains into flour or semolina.

3. Roasting, Popping and Malting: These processes enhance flavor, digestibility and nutrient availability.

4. Extrusion, Baking and Fermentation: Used for making snacks, bakery products, breakfast cereals and fermented foods.

5. Packaging and Branding: Attractive packaging and labeling increase shelf life and market appeal.

Major Value-Added Millet Products

1. Millet Flours and Mixes
   a. Single millet flour
   b. Multi-millet flour
   c. Ready-to-cook mixes (idli, dosa, dhokla, upma).

2. Bakery Products
   a. Millet biscuits and cookies
   b. Cakes and muffins
   c. Millet bread and rusks

3. Ready-to-Eat and Snack Products
   a. Puffed and popped millets
   b. Extruded snacks and namkeen
   c. Millet flakes and breakfast cereals

4. Malted and Beverage Products
   a. Ragi malt
   b. Multi-millet health drinks
   c. Fermented beverages.

These products are highly popular among urban consumers, children, elderly people and health-conscious groups.

Benefits of Value Addition in Millets

1. Higher Income to Farmers: Value-added millet products fetch 2 to 4 times higher price compared to raw grain sale.

2. Employment Generation: Processing units create jobs for women self-help groups, rural youth and small entrepreneurs.

3. Nutritional Security: Regular consumption of millet products helps in combating malnutrition, anemia and lifestyle diseases.

4. Market Expansion: Value addition opens access to organic, health food and export markets.

5. Sustainable Agriculture: Millets require less water, fewer inputs and tolerate drought, making them ideal for climate-resilient farming.

Role of Women and SHGs in Millet Value Addition

Women self-help groups play a crucial role in millet processing and marketing. Small-scale units for flour milling, snack preparation and packaging can be established at village level with minimal investment. Training and support from government schemes enable women to become successful agri-entrepreneurs.

The Government of India has actively promoted millets through:

a. International Year of Millets (2023)
b. Promotion of millets as "Shree Anna"
c. Support for processing units under PMFME and NRLM schemes
d. ICAR initiatives for millet processing technologies.

Conclusion

Value addition is the key to unlocking the true potential of millets. By linking production with processing and marketing, millets can be transformed from low-value grains into premium health foods. Promotion of millet value addition not only ensures better income for farmers but also contributes to nutritional security, employment generation and sustainable agriculture. With growing health awareness and policy support, value-added millets have a bright future in India and across the globe.

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Intercropping in Chickpea for Increasing Farm Income

Article ID: 72557

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Summary

Chickpea (*Cicer arietinum* L.) is an important pulse crop grown extensively under rainfed and irrigated conditions. Intercropping in chickpea is a viable agronomic practice due to its slow initial growth, wide row spacing and compatibility with several cereals, oilseeds and fodder crops. Chickpea-based intercropping systems enhance land use efficiency, improve soil fertility through biological nitrogen fixation, stabilize yield and provide additional income to farmers under variable climatic conditions.

Introduction

Chickpea (*Cicer arietinum* L.) is one of the most important pulse crops cultivated across the semi-arid and sub-tropical regions of the world, particularly in the South Asia. In India, chickpea occupies a prominent position among grain legumes due to its high nutritional value, adaptability to diverse agro-climatic conditions, and significant contribution to food security and soil health. It is popularly known as "chana" and serves as a major source of plant protein for a large vegetarian population.

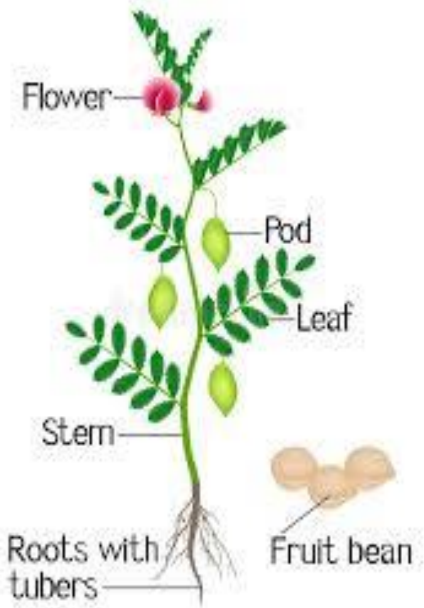

Fig.1 Morphology of chickpea plant

Chickpea seeds are rich in protein, carbohydrates, minerals, and dietary fiber, making them an essential component of balanced human nutrition. Apart from its dietary importance, chickpea plays a vital role in sustainable agriculture through biological nitrogen fixation, thereby improving soil fertility and reducing the dependence on chemical fertilizers. The crop fits well in various cropping systems and is widely grown under rainfed as well as irrigated conditions.

Indian Scenario

Chickpea (*Cicer arietinum* L.) occupies a predominant position among pulse crops grown in India, accounting for nearly 40-45 per cent of the total pulse area and production of the country. India is the largest producer, consumer and importer of chickpea in the world. The crop is mainly cultivated during the rabi season under rainfed as well as limited irrigated conditions.

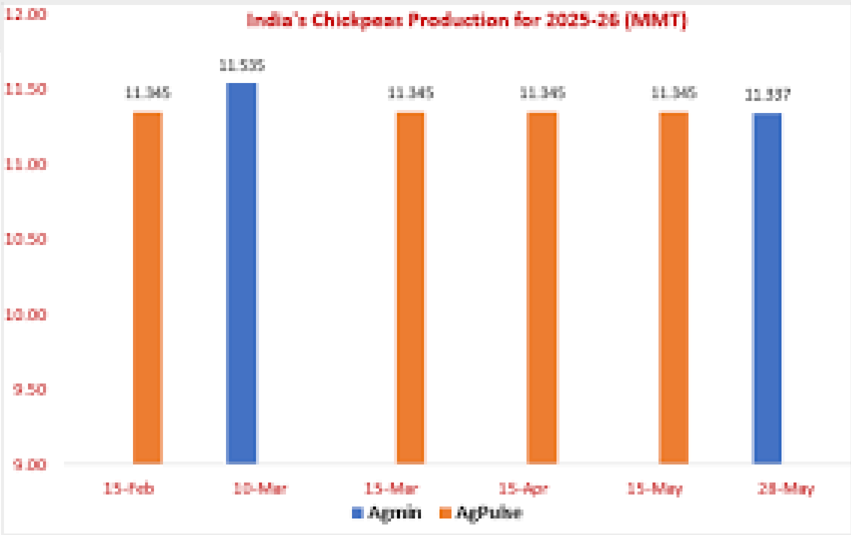

Fig.2 India's chickpea production for 2025-26

During recent years, chickpea is cultivated on an area of about 10-11 million hectares with an annual production of approximately 11-12 million tonnes and an average productivity of 1,050-1,200 kg ha^{-1}. The major chickpea producing states include Madhya Pradesh, which contributes the highest share, followed by Maharashtra, Rajasthan, Uttar Pradesh, Karnaataka and Andhra Pradesh. These states together contribute more than 85 per cent of the total chickpea production in the country.

Why Farmers Prefer Intercropping in Chickpea?

1. Makes better use of empty space between chickpea rows
2. Gives extra income from one field
3. Reduces risk during low or uncertain rainfall
4. Improves soil fertility naturally
5. Helps in better pest and disease control
6. Ensures stable yield and profit

Saves input cost and increases land use efficiency

Important Requirements for Successful Intercropping

1. Choose crop combinations that are compatible with each other
2. Maintain proper spacing and row ratio between crops
3. Select crops with different growth habits to reduce competition
4. Ensure minimum competition for light, water and nutrients
5. Prefer crops with different maturity periods
6. Follow timely sowing and proper nutrient management
7. Adopt efficient irrigation and weed control practices.

Chickpea Based Intercropping Systems

1. Under rain-fed conditions:

a. Chickpea + Mustard (4:1)
b. Chickpea + Linseed (4:1)
c. Chickpea + Safflower (3:1)
d. Chickpea + Barley (4:2).

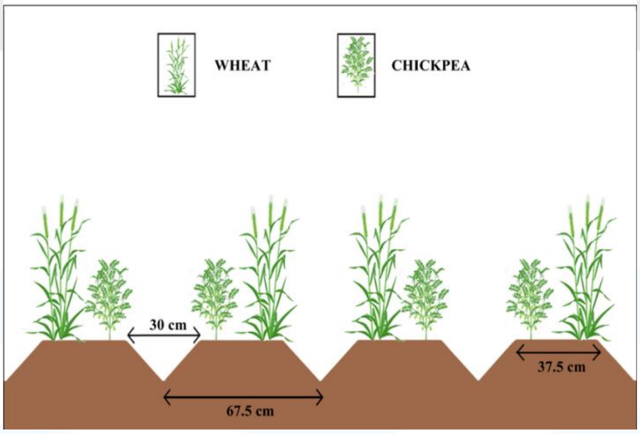

Fig.3 Wheat and Chickpea Intercropping

2. Under irrigated conditions:

a. Chickpea + Wheat (2:1)
b. Chickpea + Coriander (4:1)
c. Chickpea + Fenugreek (4:1)
d. Chickpea + Oat (fodder) (2:1)

Conclusion

Chickpea-based intercropping systems are agronomically feasible and economically profitable under the diverse agro-climatic conditions. Proper selection of intercrops and row proportion helps in maximizing productivity, improving soil fertility and ensuring sustainable income to farmers. Thus, intercropping in chickpea can be recommended as an effective strategy for enhancing farm profitability and resource use efficiency.

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Pseudomonas spp.: as Eco-Friendly Biocontrol Agents in Plant Disease Management

Article ID: 72558

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Summary

Pseudomonas spp., particularly fluorescent *pseudomonads*, are among the most extensively studied and widely used bacterial biocontrol agents in agriculture. These Gram-negative, metabolically versatile bacteria are common inhabitants of soil, rhizosphere, phyllosphere, and plant endosphere. Their success as biocontrol agents is attributed to rapid root colonization, strong competitive ability, and the production of a diverse array of secondary metabolites with antimicrobial properties. *Pseudomonas* spp. suppress a broad spectrum of plant pathogens including fungi, bacteria, and nematodes through multiple direct and indirect mechanisms such as antibiosis, competition for nutrients and niches, siderophore-mediated iron sequestration, production of lytic enzymes, and induction of systemic resistance in plants. In addition to disease suppression, many *Pseudomonas* strains promote plant growth by enhancing nutrient availability, producing phytohormones, and improving stress tolerance. Their ecological adaptability, multiple modes of action, and compatibility with sustainable agricultural practices highlight their importance as effective biocontrol agents in integrated disease management programs.

Introduction

Soil and plant-associated micro-organisms play a crucial role in regulating plant health and productivity. Among these, members of the genus *Pseudomonas* have received a considerable attention due to their abundance in agricultural soils and their strong association with plant roots. The rhizosphere, a narrow zone of soil influenced by root exudates, is particularly rich in *Pseudomonas* spp., which utilize a wide range of organic compounds released by plant roots, including sugars, amino acids, and organic acids.

Plant pathogenic micro-organisms are responsible for significant yield losses worldwide, and the excessive use of chemical pesticides has led to environmental pollution, development of resistant pathogen populations, and adverse effects on non-target organisms. In this context, biological control using beneficial microorganisms such as *Pseudomonas* offers an eco-friendly and sustainable alternative. *Fluorescent Pseudomonas* spp., named for their ability to produce fluorescent pigments under ultraviolet light, are particularly effective biocontrol agents due to their capacity to produce multiple antimicrobial compounds and to adapt to diverse environmental conditions.

Their ability to colonize root surfaces, form biofilms, and persist under fluctuating environmental conditions is critical for effective disease suppression. Moreover, these bacteria interact closely with plants, influencing plant defense responses and overall growth. Although extensive research has been conducted on *Pseudomonas*-mediated biocontrol, the complexity of their interactions with plants, pathogens, and the environment continues to be an active area of investigation.

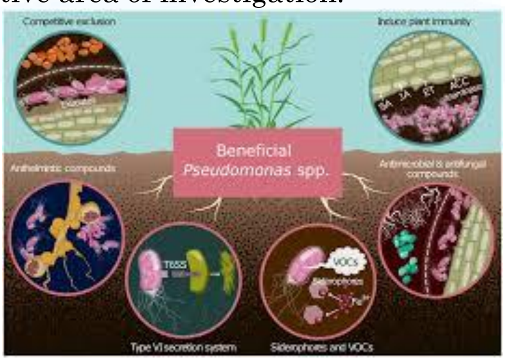

Fig.1. Role of *Pseudomonas* spp. in Suppression of Soil and Seed-Borne Plant Pathogens

Pseudomonas fluorescens are commonly isolated from the rhizosphere of a wide range of crops, with population densities often exceeding 10^6 to 10^8 colony-forming units per gram of root or rhizosphere soil. In many cropping systems, they constitute a dominant fraction of the culturable bacterial community associated with plant roots. Their prevalence is closely linked to their efficient utilization of root exudates and their ability to outcompete pathogenic microorganisms. The production of siderophores, which chelate iron and limit its availability to pathogens, provides a strong competitive advantage in iron-limited soils.

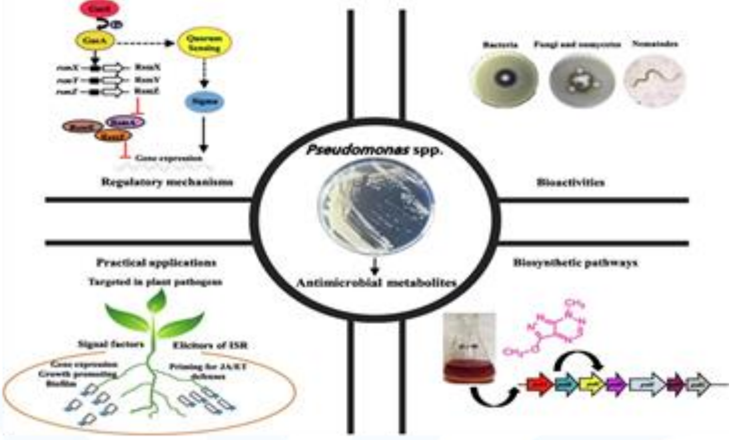

Fig.2 Major Biocontrol Mechanisms of *Pseudomonas* spp.

Despite the wide distribution of *Pseudomonas* spp., significant diversity exists within the genus with respect to biocontrol efficacy and modes of action. Different strains may rely on distinct combinations of antimicrobial metabolites, enzymes, and signaling molecules to suppress pathogens. Understanding strain-specific traits, ecological adaptability, and consistency of performance under field conditions is essential for the successful development and commercialization of *Pseudomonas*-based biocontrol products. Among the well-studied species, *Pseudomonas fluorescens*, *Pseudomonas putida* and *Pseudomonas aeruginosa* have been extensively investigated for their biocontrol and plant growth–promoting properties.

Characteristics of the Genus *Pseudomonas*

1. *Pseudomonas* belongs to the group of Gram-negative, aerobic bacteria.
2. Many strains produce fluorescent pigments such as pyoverdine under iron-limited conditions.
3. They produce a wide range of secondary metabolites including antibiotics, siderophores, hydrogen cyanide, and volatile organic compounds.
4. Members of the genus are capable of utilizing diverse carbon and nitrogen sources.
5. They are commonly found in soil, water, rhizosphere, phyllosphere and plant tissues.
6. Several species exhibit plant growth-promoting traits, including phytohormone production and nutrient solubilization.
7. *Pseudomonas fluorescens* is one of the most widely studied species for biocontrol applications.

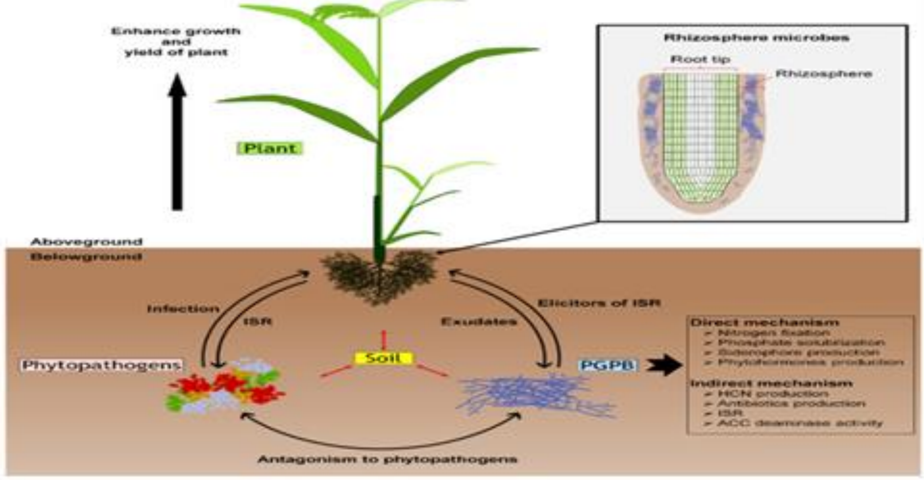

Fig.4. Mechanisms of Disease Suppression and Plant Growth Promotion by *Pseudomonas* spp.

Interaction Between Plant and *Pseudomonas* spp.

1. Suppresses plant pathogens through antibiosis by producing antibiotics such as 2,4-diacetylphloroglucinol, phenazines, pyoluteorin and pyrrolnitrin.
2. Competes effectively with pathogens for nutrients and ecological niches in the rhizosphere.
3. Produces siderophores that sequester iron, limiting pathogen growth.
4. Induces systemic resistance in plants, enhancing their innate defense mechanisms.
5. Improves root growth and architecture, leading to better water and nutrient absorption.
6. Increases plant tolerance to abiotic stresses such as drought and salinity.
7. Contributes to improved crop yield and quality under field conditions.

Methods of Application of *Pseudomonas*

1. **Seed Treatment:** Seeds are coated with *Pseudomonas* formulations before sowing.
2. **Seedling Root Dip:**
    a. Seedlings are dipped in a bacterial suspension prior to transplanting.
    b. Enhances early root colonization and disease protection.
3. **Foliar Spray:** Spray to aerial plant parts to manage foliar pathogens.
4. **Soil Application**:
    a. Applied through soil drenching.
    b. Supports rhizosphere establishment and long-term persistence.
5. **Drip Irrigation / Fertigation:** Applied through irrigation systems for uniform distribution.
6. **Bioformulation-Based Application:** Applied as liquid or carrier-based bio-pesticide formulations.

Conclusion

Pseudomonas spp. represent one of the most promising groups of bacterial biocontrol agents for the sustainable agriculture due to their multifunctional nature and ecological adaptability. Their ability to suppress a wide range of plant pathogens through multiple, complementary mechanisms reduces the risk of resistance development and enhances reliability under field conditions. In addition to disease control, their plant growth–promoting effects contribute to improved crop performance and resilience to environmental stresses. Continued research focusing on strain selection, formulation development, and understanding plant–microbe–pathogen interactions will further enhance the effectiveness of *Pseudomonas*-based biocontrol strategies, supporting reduced reliance on chemical pesticides and promoting environmentally friendly crop production systems.

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Why Agricultural Statistics Matters in Modern Farming?

Article ID: 72559

B. Srikanth, J. Sunil, B. Jagadish

Introduction: Moving from Gut Feelings to Farming Based on Facts

Climate variability, declining resources, shifting markets, and rising needs for food, feed, fibre, and fuel are all factors putting strain on modern agriculture. In this complicated world, relying on intuition or singular "successful" farming experiences is no longer enough. Farmers, scientists, and policymakers may make better decisions by using agricultural statistics, which give them the vocabulary and resources to transform dispersed observations into trustworthy data.

Planning for food security, tracking the Sustainable Development Goals (SDGs), and creating successful interventions increasingly depend heavily on timely, high-quality agricultural statistics, according to organisations such as the Food and Agriculture Organisation (FAO). Using examples from field trials, breeding, climate-smart agriculture, and policy, we examine the importance of agricultural statistics in contemporary farming in this newsletter.

Planning Better Experiments and Obtaining Better Results

At the heart of agricultural research is a basic question: *Does this new approach actually work better than what we are now doing?* Classic works such as Gomez & Gomez's "Statistical Procedures for Agricultural Research" and Cochran & Cox's "Experimental Designs" codified how to organise field trials so that we can answer such issues with certainty.

Key concepts like Randomisation, Replication and Local control are the Basic principles of Design of experiments to differentiate true treatment effects from noise:

1. We can avoid hidden biases by using randomisation (e.g., placing all high-dose fertiliser plots on the most fruitful corner of the field).

2. We can assess variability and compute standard errors, confidence intervals, and significance levels thanks to replication.

3. Blocking and local control increase precision by reducing "background noise" caused by slope or soil heterogeneity.

4. Without adequate experimental design and statistical analysis, we risk suggesting technologies that function simply "by chance" in one region or season and fail elsewhere.

From Yield Tables to Insight: ANOVA, Comparisons and Beyond

Field books and Excel sheets are full of yield numbers, but numbers alone do not tell the story. **Analysis of variance (ANOVA)** is a core statistical framework that partitions total variability into components: treatments, blocks, locations, years, and their interactions. Texts like Gomez & Gomez provide user-friendly procedures for ANOVA, mean comparison tests (LSD, DMRT, Tukey HSD), and diagnostics that are now standard in agronomic research.

In modern farming, ANOVA and related linear models help to:

1. Quantify whether a new variety, fertilizer dose, or management practice is **significantly superior**.

2. Estimate **treatment × environment interactions**, identifying technologies that are stable or specifically adapted.

3. Provide **standard errors and confidence intervals**, giving a realistic picture of uncertainty.

4. This moves recommendations from "looks better" to "statistically proven to be better", which is critical when investing resources at scale.

Powering Plant Breeding and Variety Release

Plant breeding programmes deal with hundreds or thousands of genotypes evaluated across locations and seasons. Statistical tools are essential here, not optional. Methods such as **AMMI (Additive Main effects and Multiplicative Interaction)** and **GGE biplots** help breeders visualise and quantify genotype × environment (G×E) interactions in multi-environment trials (METs). Work by Gauch and others has provided practical protocols for applying AMMI in yield trials.(ACS ESS)

Why does this matter for modern farming?

1. Farmers need varieties that **perform consistently** across years, or that are clearly adapted to specific niches (e.g. drought-prone, saline or high-input environments).

2. Variety release committees require **objective evidence** that a candidate variety is better than checks, not just in one trial but across multiple environments.

3. Advanced models (mixed models, BLUPs, stability parameters) guide breeders in selecting ideotypes that combine high mean performance with stability.

Without robust statistical analysis, breeding becomes a lottery; with it, we can systematically push genetic gain and reduce the risk of releasing poor performers.

Statistics in the Age of Big Data, Sensors and AI

Modern farming is increasingly "data-driven": weather stations, remote sensing platforms, drones, IoT soil sensors, and farm management apps are generating massive streams of data. However, **big data without statistics is just big confusion.**

Agricultural statistics provides the foundation for:

1. Calibrating and validating AI/ML models for yield prediction, disease detection, or irrigation scheduling.

2. Designing **sampling protocols** for ground truth data used to train remote sensing models (e.g. NDVI-yield relationships).

3. Evaluating performance of algorithms using metrics like RMSE, MAE, R^2, accuracy, sensitivity and specificity.

Statistical principles (e.g. training/testing splits, cross-validation, avoiding data leakage, handling imbalance) ensure that AI/ML models genuinely generalise to new farmers, new seasons and new locations.

Farm to Policy: Official Agricultural Statistics

At the national and global levels, agricultural statistics underpin decisions on food imports/exports, buffer stocks, price policies, subsidies and risk-management schemes. FAO's **FAOSTAT** database, for instance, provides harmonised data on crop production, yields and trade for over 245 countries and territories, facilitating global comparisons and trend analysis.(FAOHome)

Some key roles of official agricultural statistics include:

1. Monitoring food security and nutrition indicators to identify vulnerable regions and populations.

2. Supporting early warning systems for droughts, pests and price shocks.

3. Providing input to international outlooks such as the OECD-FAO Agricultural Outlook, which give 10-year projections for commodity markets and help governments plan investments and trade strategies.(OECD)

FAO's methodological standards and quality frameworks guide countries in producing comparable and reliable agricultural statistics, emphasising that decisions must be based on sound evidence, not guesswork.(FAOHome)

Agricultural Censuses and Sample Surveys: Seeing the Whole Picture

Agricultural censuses and large-scale sample surveys provide a "snapshot" of the structure of agriculture: land holdings, cropping patterns, irrigation, livestock, inputs and technology adoption. FAO's guidance on world censuses of agriculture highlights that up-to-date agricultural statistics are essential to monitor production conditions and support short-term policy decisions.(FAOHome)

From a modern farming perspective, these statistical systems help to:

1. Identify technology gaps (e.g. low adoption of improved seed or drip irrigation).
2. Map regional disparities in yields, input use and profitability.
3. Design targeted support programmes (credit, insurance, extension) based on real data rather than anecdote.

Studies on national agricultural statistics strategies similarly underline that such data are crucial for understanding the contribution of agriculture to GDP, employment and rural livelihoods, and for planning long-term sectoral development.(FAOHome)

Managing Climate Risk and Variability

Climate change is introducing greater variability in rainfall, temperature and extreme events. Time-series methods, risk analysis and probabilistic forecasting—core components of agricultural statistics—are now central to climate-smart agriculture:

1. Seasonal yield forecasts combine historical yield data, weather records and remote-sensing indicators using statistical and machine learning models.
2. Risk metrics such as probability of crop failure, downside risk and value-at-risk help farmers and insurers design better crop-insurance products and climate-resilient strategies.
3. Long-term series of production and yield from FAOSTAT and national databases allow us to detect trends and variability, informing adaptation strategies.(FAOHome)

In this way, agricultural statistics directly contribute to building resilience at farm, regional and national levels.

What Does this Mean for Farmers and Stakeholders?

For **farmers**, statistics may not always be visible, but they operate in the background whenever:

1. A recommended variety or practice has been **rigorously tested**.
2. Advisory bulletins mention **“significantly higher yields”** or **“95% confidence”**.
3. Insurance schemes and support prices are designed using **historical yield data**.

For **researchers and students**, a strong foundation in experimental design, data analysis and interpretation is no longer optional—it is part of being a competent agricultural scientist.

For **policy-makers and development agencies**, investing in agricultural statistical systems—surveys, censuses, data management, and analytical capacity—is as important as investing in seeds, fertilizers or irrigation. Without data, we are flying blind; with good statistics, every rupee invested has a higher chance of delivering impact.

Take-Home Messages

1. Agricultural statistics turns raw observations into reliable evidence, guiding decisions from the plot to the parliament.

2. Sound experimental design and analysis are critical to avoid misleading recommendations and wasted investments.

3. Modern breeding, precision agriculture and AI/ML all rest on solid statistical foundations.

4. Official agricultural statistics (censuses, surveys, FAOSTAT) are essential for food security planning, monitoring SDGs and managing climate risk.

Investing in **capacity building in agricultural statistics**—training, software, data systems—is indispensable for truly modern, climate-smart, and farmer-centric agriculture.

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Climate-Smart Extension Strategies for Smallholder Farmers: Pathways toward Resilient and Sustainable Agriculture

Article ID: 72560

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Introduction

Climate change is really changing the way we farm, and it's something we can't just brush off anymore. With rising temperatures, erratic rainfall, new pests showing up, more frequent droughts, and soil getting worn out, crop yields around the globe are taking a hit. The smallholder farmers who make up about 80% of all farmers are hit the hardest because they usually don't have the resources, timely info, or tools to manage risks. Their whole way of making a living hinges on weather and natural resources, making them super vulnerable to climate shocks (FAO, 2021; Morton, 2020).

Just passing on farming techniques isn't cutting it anymore. Farmers really need support that's aligned with climate challenges something that helps them gauge risks, make smart choices, and adopt practices that will hold up against the changing climate. Climate-Smart Agriculture (CSA) is all about boosting productivity, building resilience, and reducing environmental harm (FAO, 2010). For CSA to work well, extension systems need to change, think more data-driven, participatory approaches that can react to current climate situations (Aggarwal *et al.,* 2023).

This article breaks down how climate-smart extension strategies can lend a hand to smallholders and help them achieve more stable farming livelihoods.

What Climate-Smart Agriculture Means?

Climate-Smart Agriculture isn't just about using certain technologies; it's more of a holistic approach that blends agronomy, ecology, climate science, and the knowledge farmers bring to the table. The idea behind CSA is to promote:

1. The smart use of resources.
2. Crop varieties that can withstand stress.
3. Conservation of our soil and water.
4. Strategies to reduce climate-related risks.
5. Advisories based on climate and digital data.

Research indicates that when farmers adopt CSA practices, it can really boost productivity and resilience. But unfortunately, many farmers aren't aware of it, haven't had the training, or struggle with the delivery of information (Raza *et al.,* 2022). This is where climate-smart extension becomes crucial.

Why Climate-Smart Extension Matters?

With climate-smart extension, the role of extension agents shifts from just delivering technology to facilitating knowledge. These workers need to guide farmers on interpreting weather forecasts, understanding climate risks, picking the right crops, and effectively managing their resources. This change involves:

1. Access to real-time climate information.
2. Effective communication about risks.
3. Digital advisory platforms.
4. Community based decision-making.
5. Collaborations with research institutions.
6. Utilizing satellite and weather tools.

This way, farmers aren't just getting advice on what to grow but are also learning the best timing, methods, and suitable climate conditions to work with (Simtowe *et al.,* 2022).

Weather-Based Advisory Services

Weather advisories are fundamental to climate-smart agriculture. They assist farmers in adjusting things like sowing dates, irrigation, fertilizer application, and pest management.

Short-term advisories can alert farmers to rainfall, storms, dry spells, or heatwaves. A simple SMS that says, "Don't spray pesticides tomorrow due to rain" can save a farmer some money and help protect their yields. These advisories can cut production risks by about 15% to 30% (Gadgil *et al.,* 2021).

Agro-meteorological Advisory Services (AAS) unite weather forecasts, crop models, and expert advice. They're shared through WhatsApp, SMS, KVK bulletins, and community radio, which can make a real difference in preparing for droughts, floods, and heat stress.

Water-Smart Extension Strategies

Water scarcity is a major concern for farmers. Climate-smart extension aims to teach them how to save water, use it wisely, and even harvest rainwater.

Efficient irrigation options include techniques like drip irrigation, sprinkler systems, moisture-based scheduling, and Alternate Wetting and Drying (AWD) for rice. Practices that conserve soil moisture, such as mulching and keeping crop residues, help maintain healthy soils. Also, rainwater harvesting methods like farm ponds and contour bunds really enhance resilience.

Climate-Resilient Crop and Variety Options

To adapt to changing conditions, diversifying crops and using stress-tolerant varieties is key. Research groups like ICAR, ICRISAT, CIMMYT, and IRRI have worked on developing varieties that can handle drought, heat, and flooding. Climate-smart practices such as intercropping, crop rotation, and using millet-based systems can stabilize income even when climate shocks occur (Dharmaraju *et al.,* 2023).

Climate-Informed Pest and Disease Management

Pests are responding to climate change, and we need forecasting models for things like fall armyworm, pink bollworm, and wheat rust to help extension workers give farmers timely warnings.

Using Integrated Pest Management (IPM) techniques that include biological control, pheromone traps, resistant varieties, and weather-adapted pesticide applications can help reduce costs and enable sustainable pest control.

Strengthening Farmer Capacity and Community Adaptation

Climate change isn't just an individual farmer's problem; it's a community issue. Farmer Field Schools (FFS) provide hands-on learning opportunities. Community climate champions play a big part in sharing advisories and promoting tech use. Community seed banks help maintain local varieties and ensure they're available after climate shocks. Women farmers are vital in seed preservation, water management, and livestock care, making gender-inclusive extension practices really important (FAO, 2022).

ICT, Drones, and Remote Sensing

Digital agriculture is changing the game for extension work. Mobile apps are useful for things like fertilizer scheduling, diagnosing pests, and tracking market prices. Drones can create NDVI-based health maps and help with precision spraying. And satellite monitoring is great for analyzing droughts, floods, and plant stress (Kogo *et al.,* 2021).

Policy and Institutional Support

Farmer Producer Organizations (FPOs) help improve collective marketing and encourage the adoption of climate-smart practices. Public-Private Partnerships (PPP) enable access to digital advisory services and insurance. National initiatives like PMKSY, PM-KUSUM, NMSA, and the Digital Agriculture Mission are in line with CSA objectives.

Challenges

Some major challenges still exist, includes:

1. Shortage of extension workers,

2. Low digital literacy,
3. Fragmented farms,
4. Financial issues, and
5. Reluctance to adopt new technologies.

We need to invest in building capacity and improving ICT infrastructure.

Conclusion

Climate-smart extension is vital for smallholder farmers who are navigating climate uncertainties. By combining research, digital tools, local knowledge, and community action, we can strengthen resilience and promote sustainable agricultural growth.

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Role of Vegetable Legumes in Climate-Smart Agriculture

Article ID: 72561

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Abstract
Leguminous vegetables such as beans and peas play a crucial role in ensuring sustainable agriculture, improving soil health, and enhancing human nutrition. These crops are rich in protein, dietary fiber, vitamins, and essential minerals while being low in fat and cholesterol. Their unique ability to fix atmospheric nitrogen through symbiotic association with *Rhizobium* bacteria improves soil fertility and reduces dependence on chemical fertilizers. In addition to their nutritional benefits, leguminous vegetables contribute to climate-smart agriculture by lowering greenhouse gas emissions, improving carbon sequestration, and enhancing crop productivity when used in crop rotations or intercropping systems. Promoting leguminous vegetables can therefore address soil degradation, malnutrition, and environmental challenges simultaneously.

Introduction
Leguminous vegetables have been cultivated for more than 6,000 years across different regions of the world and continue to play a vital role in agricultural sustainability and food security. Although legumes grown for human consumption account for only about 5% of cultivated crops globally, their importance in maintaining soil health and nutritional balance is immense. Leguminous vegetables include crops such as cowpea, cluster bean, French bean, garden pea, dolichos bean, broad bean, and winged bean, all of which are valued for their edible pods, seeds, or tender plant parts.

In India, where a large proportion of the population follows a vegetarian diet, leguminous vegetables serve as a primary source of dietary protein. In many developing and third-world countries, especially among economically weaker sections, vegetable legumes form the backbone of daily protein intake. Their dual role in improving soil fertility and providing high-quality nutrition makes them indispensable in modern farming systems.

Nutritional Importance of Leguminous Vegetables
Leguminous vegetables are nutritionally dense and are recognized as one of the healthiest plant-based food groups. They are typically low in fat, contain no cholesterol, and are rich in folate, potassium, iron, magnesium, and calcium. In addition, legumes provide both soluble and insoluble dietary fiber, which plays a vital role in improving digestion and reducing lifestyle-related disorders.

Legumes are an excellent source of plant protein and can effectively substitute animal-based protein, which is often associated with higher fat and cholesterol content. Although legumes are relatively deficient in sulfur-containing amino acids such as methionine and cysteine, this limitation is easily overcome when they are consumed along with cereals. This complementary protein relationship has been traditionally followed in Indian diets through combinations such as dal–rice and dal–roti.

According to the World Health Organization (WHO), nearly 80% of heart disease, stroke, and type 2 diabetes, and over one-third of cancers could be prevented by addressing major risk factors, including unhealthy diets. Pulses and legumes are therefore included in dietary guidelines worldwide. The World Food Programme (WFP) recommends inclusion of 60 g of pulses in its standard food basket, highlighting their importance in achieving nutritional security.

Role in Soil Health and Fertility
One of the most remarkable characteristics of leguminous vegetables is their ability to fix atmospheric nitrogen through root nodules formed by *Rhizobium* bacteria. This biological nitrogen fixation reduces the

need for synthetic nitrogen fertilizers such as urea and ammonium nitrate, thereby lowering production costs and minimizing environmental pollution.

Legume crops contribute significantly to soil fertility by:

a. Increasing available nitrogen content
b. Improving soil organic matter through residue incorporation
c. Enhancing soil microbial activity
d. Improving soil structure and water-holding capacity.

Studies conducted at the Indian Institute of Horticultural Research (IIHR), Bengaluru, have demonstrated that cultivation of leguminous vegetables can enhance soil fertility and subsequently increase the yield of succeeding crops by 10–15%. Similar studies have reported yield increases of over 10% in rice grown after legumes and 10–12% higher sugarcane yield when legumes are used as intercrops.

Legumes in Sustainable and Climate-Smart Agriculture

Leguminous vegetables play a vital role in sustainable farming systems. They are integral components of crop rotations and intercropping systems and help maintain long-term soil productivity. Compared to non-leguminous crops, legumes require lower external inputs and are considered a low-carbon source of protein.

Leguminous vegetables contribute to climate change mitigation through:

a. Reduction in greenhouse gas emissions (CO_2 and N_2O)
b. Lower fossil fuel uses due to reduced fertilizer requirement
c. Carbon sequestration in soil
d. Biomass generation for biofuel production.

The residues of legume crops differ biochemically from cereal residues and decompose faster, enriching soil organic matter and nutrient cycling. Their ability to support diverse soil microorganisms further enhances soil health and ecosystem resilience.

Economic and Cropping System Benefits

Leguminous vegetables are mostly short-duration crops, completing their life cycle within 70–75 days. They start yielding within 45–50 days of sowing, making them suitable for inclusion in multiple cropping systems. These crops can be grown as:

1. Rotational crops
2. Intercrops with cereals and commercial crops
3. Catch crops during fallow periods.

The short duration and low input requirement make leguminous vegetables economically attractive. Farmers benefit from reduced expenditure on fertilizers, pesticides, and fungicides, especially when disease-resistant varieties are adopted. The development of high-yielding and disease-resistant legume varieties has further enhanced their profitability and acceptance among farmers.

Important Varieties of Leguminous Vegetable Crops

Crop	Botanical name	Important varieties	Salient features / remarks
Garden pea	*Pisum sativum*	Pusa Shree, Arkel, Arka Ajit, Kashi Kanak, Kashi Samridhi, Kashi Uday, Arka Apoorva	High yield; Arka Apoorva is whole-pod edible, suitable for fresh salad and cooking
Cowpea	*Vigna unguiculata*	Arka Garima, Kashi Shyamal, Kashi Unnati, Kashi Kanchan, Pusa Komal, Pusa Barsati, Pant Lobia-1	Dual purpose (vegetable and pulse), tolerant to abiotic stress
French bean	*Phaseolus vulgaris*	Arka Komal, Arka Sharath, Kashi Param, Arka Suvidha, Arka Anoop, Pant Anupama, Pusa Parvathi	Tender pods, good market preference, suitable for fresh consumption

Dolichos bean (Field bean)	*Lablab purpureus*	Arka Amogh, Arka Jay, Kashi Haritima, Arka Sambhram, Arka Soumya, Arka Vijay, Pusa Sem-1, Pusa Sem-2	Long harvesting duration, suitable for kitchen gardens and commercial farming
Cluster bean (Guar)	*Cyamopsis tetragonoloba*	Pusa Navbahar, Goma Manjari, Pusa Mausami, Pusa Sadabahar, Durga Bahar	Drought tolerant, suitable for arid and semi-arid regions
Broad bean	*Vicia faba*	Pusa Udit, Arka Bold	Large seeded, suitable for hill and temperate regions
Yard-long bean	*Vigna unguiculata* ssp. *sesquipedalis*	Arka Mangala, Arka Mangala-2, Kashi Gauri, Kashi Unnati-2	Extra-long pods (up to 75–80 cm), popular in niche and urban markets

Conclusion

Leguminous vegetables offer a unique solution to multiple challenges faced by modern agriculture, including soil degradation, nutritional insecurity, and climate change. Their ability to improve soil fertility, enhance crop productivity, and provide high-quality nutrition makes them indispensable in sustainable farming systems. Incorporating leguminous vegetables at least once in a cropping season can significantly improve soil health and farm profitability while contributing to better human health.

Thus, promoting leguminous vegetables is not only an agronomic necessity but also a strategic intervention for ensuring food, nutritional, and environmental security.

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Sea Buckthorn (*Hippophae rhamnoides*): From Climate-Resilient Crop to Evidence-Based Functional Food

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Abstract
Sea buckthorn (*Hippophae rhamnoides* L.) has emerged from relative agronomic obscurity to become a high-value functional crop with growing relevance in nutrition, medicine, and sustainable agriculture. Native to cold arid and semi-arid regions of Europe and Asia, the plant exhibits exceptional environmental resilience and an unusually dense nutrient and bioactive profile. In recent years, well-designed randomized controlled trials and mechanistic studies have strengthened the evidence for its cardiometabolic, anti-inflammatory, dermatological, and hepatoprotective effects. Concurrently, advances in cultivation practices and processing technologies have expanded its commercial viability, particularly in nutraceutical and functional food markets. This article critically examines sea buckthorn from field to physiology—covering cultivation ecology, nutrient composition, disease-specific evidence, and current market availability—positioning it as a “need-of-the-hour” crop for nutrition-sensitive agriculture and evidence-based dietary interventions.

Introduction
The global burden of diet-related non-communicable diseases (NCDs), combined with climate instability and food system stress, has intensified the search for crops that are both nutritionally potent and environmentally resilient. Sea buckthorn (*Hippophae rhamnoides* L.) exemplifies this dual potential. Traditionally used in Tibetan, Mongolian, and Ayurvedic systems of medicine, sea buckthorn has transitioned from ethnobotanical relevance to scientific credibility as controlled human studies increasingly support its physiological benefits.

Unlike many functional foods promoted on the basis of in vitro or observational data alone, sea buckthorn has been evaluated in randomized controlled trials (RCTs) and meta-analyses, particularly in relation to lipid metabolism, inflammation, skin integrity, and oxidative stress. This convergence of agronomic, nutritional, and clinical evidence makes sea buckthorn a compelling subject for contemporary nutrition science.

Botanical Characteristics and Cultivation Potential
Sea buckthorn is a deciduous, dioecious shrub belonging to the family *Elaeagnaceae*. It thrives in marginal soils, tolerating salinity, drought, and extreme temperatures (−40°C to +40°C). The plant forms a symbiotic association with nitrogen-fixing *Frankia* bacteria, improving soil fertility and making it suitable for land reclamation and erosion control (Wang *et al.,* 2022).

1. Cultivation and Sustainability: Sea buckthorn is cultivated extensively in China, Mongolia, Russia, and parts of Europe, with emerging interest in Himalayan regions of India. Its low water requirement and minimal dependence on chemical inputs align well with sustainable agriculture goals. Breeding programs have focused on higher berry yield, reduced thorn density, and improved harvest efficiency, addressing earlier constraints to commercialization.

Table 1: Key Nutritional and Bioactive Components of Sea Buckthorn (Wang *et al.,* 2022) (Chen *et al.,* 2023):

Component Group	Major Constituents	Key Functional Significance
Vitamins & Antioxidants	Vitamin C, β-carotene, lycopene, zeaxanthin, tocopherols	Strong antioxidant defence, immune support, collagen synthesis, skin and endothelial health
Fatty Acids	Omega-3, omega-6, omega-9, omega-7 (palmitoleic acid)	Lipid regulation, insulin sensitivity, epithelial and mucosal integrity
Polyphenols	Isorhamnetin, quercetin derivatives	Anti-inflammatory, Vaso protective, antioxidant effects
Phytosterols	β-sitosterol, campeterol	Reduced intestinal cholesterol absorption, LDL lowering
Dietary Fiber	Pectin's, cellulose	Improved gut health, glycaemic control
Organic Acids	Malic, citric acids	Enhanced mineral absorption, digestive and antimicrobial effects

Evidence-Based Health Benefits

1. Cardiometabolic Health: A systematic review and meta-analysis of 11 randomized controlled trials demonstrated that sea buckthorn supplementation significantly reduced total cholesterol, LDL-cholesterol, and triglycerides while modestly increasing HDL levels, particularly in individuals with elevated baseline cardiovascular risk (Guo *et al.,* 2017).

In a double-blind, placebo-controlled trial, hypertensive and hypercholesterolemic subjects receiving sea buckthorn seed oil (0.75 mL/day for 30 days) exhibited reductions in blood pressure, oxidized LDL, and triglycerides, alongside improvements in antioxidant status compared with placebo (Vashishtha *et al.,* 2017).

2. Glycaemic Control and Metabolic Syndrome: Controlled feeding trials suggest that sea buckthorn berry products attenuate postprandial glucose and insulin responses when consumed with carbohydrate-rich meals. These effects are attributed to delayed glucose absorption, improved insulin sensitivity, and modulation of low-grade inflammation (Chen *et al.,* 2023).

3. Skin, Mucosal, and Epithelial Health: One of the most consistent clinical applications of sea buckthorn oil is in dermatological health. Randomized trials have reported improvements in skin hydration, elasticity, and symptom severity in individuals with dry skin and atopic dermatitis following oral or topical sea buckthorn oil supplementation (Wang *et al.,* 2022).

Omega-7 fatty acids are believed to support epithelial regeneration and barrier function, explaining the observed benefits in skin, ocular, and gastrointestinal mucosa.

4. Liver and Inflammatory Conditions: Emerging clinical and experimental evidence suggests hepatoprotective effects, including reductions in liver enzyme levels and oxidative stress markers in individuals at risk of non-alcoholic fatty liver disease (Chen et al., 2023). Anti-inflammatory effects, reflected in reduced C-reactive protein and improved antioxidant enzyme activity, further support its role in chronic disease prevention.

Scientifically Proven Consumption Forms and Doses

1. Sea Buckthorn Seed or Pulp Oil: Sea buckthorn seed and pulp oils are the most extensively studied consumption forms, with evidence derived from multiple randomized controlled trials. Clinical studies indicate that daily supplementation in the range of 0.5–1.0 mL, administered either as capsules or liquid oil, leads to significant improvements in lipid profiles, including reductions in total cholesterol, triglycerides, and oxidized LDL. In addition to cardiometabolic benefits, consistent improvements in skin hydration and mucosal integrity have been reported, attributed primarily to the high omega-7 and antioxidant content. Consequently, sea buckthorn oil is best suited for individuals with elevated cardiometabolic risk and for dietary support in dermatological and mucosal disorders *(Vashishtha et al., 2017; Geng et al., 2022).*

2. Sea Buckthorn Juice and Juice Concentrates: Sea buckthorn juice and concentrated juice preparations have been evaluated mainly through controlled feeding and short-term human intervention studies. A daily intake of approximately 30–50 mL, typically diluted with water, has been shown to enhance systemic antioxidant status and attenuate postprandial glucose and insulin responses when consumed with meals. These effects are largely attributed to the synergistic action of vitamin C, polyphenols, and organic acids present in the berries. However, due to its high acidity and astringency, juice consumption is best recommended alongside meals to improve tolerability and minimize gastrointestinal discomfort *(Chen et al., 2023).*

3. Powdered Berry Extracts: Powdered Sea buckthorn berry extracts represent a practical and increasingly popular form for dietary incorporation, supported by human studies and translational research. These powders are commonly used in functional foods, smoothies, and fortified products, allowing for flexible dosing and easy integration into habitual diets. One of the major advantages of powdered extracts is their longer shelf life and the possibility of standardizing polyphenol and carotenoid content, which enhances reproducibility of health effects. Although clinical dose-response data remain limited, existing evidence supports their role in antioxidant defense and metabolic health support.

4. Topical Sea Buckthorn Preparations: Topical formulations containing sea buckthorn oil have been investigated in clinical dermatological trials, particularly for wound healing, burns, dry skin, and atopic conditions. These preparations have demonstrated efficacy in improving epithelial regeneration, reducing inflammation, and enhancing skin barrier function.

The beneficial effects are primarily mediated through omega-7 fatty acids, tocopherols, and carotenoids, which collectively promote tissue repair and protect against oxidative damage. As a result, topical sea buckthorn applications are widely used in medical-grade cosmeceuticals and adjunct dermatological therapies *(Wang et al., 2022).*

Sea buckthorn is currently available in global markets as nutraceutical capsules, cold-pressed oils, juices, cosmetic formulations, and functional beverages. China dominates production, while Europe emphasizes standardized extracts. In India, commercialization is emerging through Himalayan agricultural initiatives, though consumer awareness remains limited.

Sea buckthorn represents a rare convergence of environmental resilience, nutritional richness, and clinical relevance. Supported by randomized controlled trials and systematic reviews, it has moved beyond traditional use to evidence-based functionality. With appropriate standardization and policy support, sea buckthorn has the potential to contribute meaningfully to sustainable diets, chronic disease prevention, and nutrition-sensitive agriculture.

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Flowering and Fruiting in Phalsa

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Phalsa, a fruit of Indian origin, commonly known as Indian Sherbet fruit. In Telugu it is called as Phutiki. Fruit is mentioned in Vedic literature as having certain medicinal properties. It is commercially cultivated in limited areas around big cities of Punjab Hariyana Gujarat, Maharashtra and Bihar for ready quick sale in cities owing to its poor keeping quality. Phalsa is a flowering plant with small berry fruit conventionally blooms in summer and quiescent in winter. Primarily phalsa is cultivated for its nutritious and therapeutic fruits. It is also grown as intercrop in aonla Mango, ber and bael. Pleasant acid flavoured ripe berries of phalsa contain a high amount of vitamins A, and C approximately (16.11, and 4.38 mg respectively), minerals (Calcium 820.32 mg/100 g, Phosphorous 814.5 mg/100 g and iron 27.10 mg/100 g), and fibre but low in calories, fat and glycaemic index. Fruits that are highly perishable need to be processed immediately after harvest. The pigment responsible for the colour of Phalsa fruit is Anthocyann, viz. Delphinidin-3-glucoside and Cyanidin-3- glucoside. Both seed coats and kernels are rich in linoleic acid. Many studies revealed that fruit is good for wound healing, anaemia, diabetes control, controlling urinary tract infections.

It is a short scraggly shrub of 4 m height, yields small purplish-red, soft, tender round drupaceous fruits with soft, fibrous greenish white with purple stained pulp. Fruits have different intensity of coloration at successive stages. Ripe phalsa fruits are purplish black in colour, subacidic in flavor.

Canopy Management and Pruning

Phalsa is a bushy plant that grows into a tree if left unpruned. Since Phalsa bear fruits on current season growth, regular and severe annual pruning is needed before the on-set of spring. Yearly pruning encourages new shoots from the base at ground level and higher yield of marketable fruit than those of more drastic trimming. The Phalsa plant may be easily reproduced by rooting hardwood cuttings or layering.

Flowering and Fruiting in Phalsa

Phalsa flowers in late winter/early spring (Feb-April), producing small, yellow flowers in leaf axils, leading to fruit set from March to May, peaking in mid-April, with fruits maturing 40-55 days post-flowering into small, dark purple berries that ripen gradually, requiring multiple pickings through April and May in North India for a summer harvest.

Reference

An indigenous value fruit of Indian drylands: Phalsa by Rani B Thallapally, Purnima Mishra and Rajashekhar B.

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Physiological Consequences of Dietary Intake of Heavy Metal-Contaminated Fish in Humans

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Introduction

Fish is an essential component of the human diet due to its high-quality protein, omega-3 fatty acids, vitamins, and minerals. However, rapid industrialization and environmental degradation have led to increased levels of heavy metals such as mercury (Hg), lead (Pb), cadmium (Cd), arsenic (As), and chromium (Cr) in aquatic ecosystems, which bioaccumulate in fish tissues and enter the human food chain. These metals are persistent, non-biodegradable, and toxic even at low concentrations (FAO/WHO, 2011). The consumption of fish contaminated with such metals can disrupt physiological functions by interfering with enzyme activities, inducing oxidative stress, damaging organs, and altering metabolic pathways (Järup, 2003). Thus, understanding the physiological effects of heavy-metal-contaminated fish on humans is essential for public health protection.

Heavy Metals Present in Contaminated Fish

Heavy metals enter aquatic environments through industrial discharge, mining effluents, agricultural runoff, sewage sludge, and atmospheric deposition. Mercury, particularly methylmercury, is one of the most toxic metals and accumulates in fish muscle tissue, posing severe neurotoxic risks (Clarkson & Magos, 2006). Lead contamination originates from industrial waste, paints, and batteries, and interferes with neurological and hematopoietic processes (Needleman, 2004). Cadmium from fertilizers, electroplating, and mining activities accumulates in fish kidneys and liver and is known for its nephrotoxicity (WHO, 2010). Arsenic, especially in its inorganic form, affects metabolic functions and increases cancer risk (Smith et al., 2002). Although trace metals such as chromium, copper, nickel, and zinc are essential in small amounts, they become toxic in higher concentrations, disrupting cellular metabolism (Tchounwou et al., 2012).

Physiological Effects on Human Organ Systems

Heavy metal exposure from contaminated fish affects multiple organ systems. The nervous system is highly sensitive to mercury and lead due to their ability to cross the blood–brain barrier. Methylmercury causes cognitive impairment, memory loss, and motor dysfunction (Grandjean et al., 2010), while lead exposure leads to neurobehavioral deficits and developmental disorders in children (Needleman, 2004). The renal system is another key target; cadmium causes proximal tubular damage, proteinuria, and reduced glomerular filtration rate, whereas lead and mercury contribute to chronic kidney disease and hypertension (Järup & Akesson, 2009). The cardiovascular system is affected through oxidative stress and endothelial damage. Cadmium and lead increase blood pressure, while mercury stimulates reactive oxygen species that impair cardiac function (Houston, 2011). The gastrointestinal system experiences inflammation, abdominal pain, vomiting, and impaired nutrient absorption due to direct mucosal damage caused by arsenic and cadmium (Tchounwou et al., 2012). The reproductive system suffers from heavy metal-induced endocrine disruption; cadmium and lead reduce sperm quality, mercury affects ovarian function, and arsenic increases the risk of miscarriage and low birth weight (Nordberg et al., 2014). The immune system becomes suppressed due to decreased antibody production and enhanced oxidative stress, increasing susceptibility to infections (Silbergeld, 2003). Skeletal effects include bone demineralization and weakened structure because lead and cadmium interfere with calcium metabolism (Alvarez & Mathee, 2003). Heavy metals also disrupt endocrine and metabolic processes, contributing to thyroid dysfunction, insulin resistance, and hormonal imbalance (Patrick, 2006).

Table:1. Major heavy metals found in contaminated fish and their physiological effects on humans:

Heavy Metal	Major Sources in Aquatic Environment	Primary Target Organs/Systems	Key Physiological Effects in Humans
Mercury (Hg)	Industrial discharge, coal combustion, chlor-alkali plants; methylation in sediments	Nervous system, kidneys, cardiovascular system	Neurotoxicity, memory loss, tremors, impaired motor function, developmental defects in children, oxidative stress; kidney damage
Lead (Pb)	Battery industries, paints, pipelines, smelting, wastewater	Nervous system, hematopoietic system, kidneys, bones	Learning disabilities, reduced IQ, anemia, hypertension, nephropathy, bone demineralization
Cadmium (Cd)	Mining, electroplating, phosphate fertilizers, sewage sludge	Kidneys, bones, reproductive system	Renal tubular dysfunction, proteinuria, osteoporosis, reduced sperm quality, endocrine disruption
Arsenic (As)	Groundwater contamination, pesticides, industrial waste	Skin, liver, cardiovascular system, nervous system	Skin lesions, cancer risk, abdominal pain, neuropathy, metabolic disruption, hypertension
Chromium (Cr)	Leather tanning, metal plating, textile effluents	Liver, kidneys, respiratory system	DNA damage, oxidative stress, renal toxicity, possible carcinogenic effects
Nickel (Ni)	Electroplating, metal processing, industrial effluents	Skin, respiratory system, immune system	Dermatitis, respiratory irritation, allergic reactions, immune suppression
Copper (Cu)	Mining runoff, pesticides, industrial effluents	Liver, gastrointestinal system	Nausea, vomiting, abdominal cramps, liver damage at high levels
Zinc (Zn)	Industrial discharge, metal corrosion, fertilizers	Gastrointestinal tract, immune system	V omiting, diarrhea, stomach pain; toxic in high doses despite being essential

Cellular and Molecular Mechanisms of Toxicity

Heavy metals exert toxicity at the molecular level by generating reactive oxygen species (ROS), causing oxidative stress, DNA damage, and lipid peroxidation (Stohs & Bagchi, 1995). They bind to enzyme sulfhydryl groups, inhibiting key metabolic processes and interfering with mitochondrial function (Patrick, 2003). Arsenic and cadmium induce epigenetic modifications that contribute to carcinogenesis (Arita & Costa, 2009). The long biological half-life of metals like cadmium and lead leads to their accumulation in bones and soft tissues, resulting in prolonged toxicity even after exposure stops (Nordberg et al., 2014).

Long-Term Health Risks

Chronic exposure to heavy-metal-contaminated fish is associated with several long-term diseases. Cadmium and arsenic increase the risk of cancers of the lungs, skin, liver, and bladder (IARC, 2012). Mercury and lead exposure contribute to neurodegenerative diseases such as Alzheimer's and Parkinson's (Caito & Aschner, 2017). Children exposed prenatally or through breast milk suffer developmental delays, reduced IQ, and motor deficits (Grandjean et al., 2010). Long-term exposure also leads to hypertension, metabolic syndrome, immune suppression, and chronic kidney disease (Houston, 2011).

Prevention and Public Health Considerations

Reducing heavy metal exposure requires regular monitoring of fish, strict pollution control policies, and improved wastewater treatment. Public health agencies recommend limiting consumption of high-trophic-level fish such as tuna and swordfish, which accumulate larger quantities of methylmercury (FAO/WHO, 2011). Aquaculture practices should emphasize clean water, controlled feed quality, and routine metal testing. Consumers can reduce risk by selecting small, low-trophic fish and maintaining antioxidant-rich diets, which help reduce oxidative damage induced by heavy metals (Stohs & Bagchi, 1995). Strong regulatory enforcement and public awareness programs are essential for minimizing health risks.

Conclusion

The consumption of heavy metal-contaminated fish poses significant physiological risks to humans, affecting major organ systems including the nervous, renal, cardiovascular, reproductive, immune, skeletal, and endocrine systems. Heavy metals cause cellular toxicity through oxidative stress, enzyme inhibition, and genetic damage, leading to long-term chronic diseases. Preventive strategies such as environmental monitoring, safe fish consumption guidelines, pollution reduction, and public education are crucial for safeguarding human health and ensuring sustainable aquatic ecosystems.

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Soil–Plant–Water Dynamics under Saline Conditions in Vegetable Crops: A Review

Article ID: 72565

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Abstract
Soil salinity is a major abiotic stress limiting vegetable crop productivity, particularly in arid, semi-arid and intensively irrigated agro-ecosystems. Excess accumulation of soluble salts in the root zone disrupts soil physical, chemical and biological properties, thereby altering soil–plant–water relationships. Salinity induces osmotic stress, ion toxicity and nutrient imbalance, resulting in reduced water uptake, impaired physiological processes and significant yield and quality losses in salt-sensitive vegetable crops. However, vegetables employ adaptive mechanisms such as osmotic adjustment, selective ion regulation, antioxidant defence and morphological modifications to tolerate saline conditions. This review summarizes the causes and classification of soil salinity, its effects on soil and plant water relations and physiological responses of vegetable crops and highlights integrated management practices to sustain vegetable production under increasing salinization pressure.

Keywords: Soil salinity, vegetable crops, plant–water relations, osmotic stress, saline irrigation, salinity management.

Introduction
Soil salinization refers to the accumulation of water-soluble salts in the soil profile at levels that adversely affect crop growth and productivity. It is one of the most widespread forms of land degradation, particularly in irrigated agriculture. Globally, a substantial proportion of cultivated land is affected by salinity, with vegetable-growing regions being especially vulnerable due to frequent irrigation, shallow root systems and high sensitivity of vegetable crops to salts. Salinity poses a serious challenge to sustainable vegetable production by altering soil properties and disrupting soil–plant–water relationships.

Vegetable crops require a continuous and adequate supply of water for optimal growth and yield. However, under saline conditions, the availability of water to plants is reduced despite sufficient soil moisture, resulting in physiological drought. High salt concentrations lower the soil water potential, restrict water uptake by roots and cause ionic and nutritional imbalances within plant tissues. As a result, plant growth, photosynthesis, nutrient acquisition and yield formation are severely affected.

Understanding the complex interactions among soil, plant and water under saline conditions is critical for designing effective management strategies. This review focuses on soil–plant–water dynamics in saline environments, emphasizing their impact on vegetable crops and discussing agronomic, biological and preventive approaches to mitigate salinity stress.

Soil Salinity: Causes and Classification
Causes of Soil Salinization: Soil salinization may occur naturally or as a result of human activities. Natural or primary salinity develops due to weathering of parent materials, deposition of marine salts, capillary rise of saline groundwater and climatic conditions characterized by low rainfall and high evaporation. Coastal regions are particularly prone to salinity due to seawater intrusion and salt-laden winds.

Secondary salinity arises mainly from anthropogenic activities such as excessive irrigation with saline or poor-quality water, inadequate drainage, overuse of fertilizers and improper land-use practices. In irrigated vegetable production systems, repeated application of saline irrigation water coupled with insufficient leaching leads to salt accumulation in the root zone. Replacement of deep-rooted native vegetation with shallow-rooted crops may also raise the water table, enhancing salt movement toward the soil surface.

Classification of Salt-Affected Soils: Salt-affected soils are broadly classified into saline, sodic and saline–sodic soils based on electrical conductivity (EC), pH and exchangeable sodium percentage (ESP). Saline soils are characterized by high EC (>4 dS m^{-1}), low ESP (<15) and near-neutral pH (<8.5). These soils often exhibit white or brown salt crusts on the surface. Sodic soils have high ESP (>15) and alkaline pH (>8.5), leading to poor soil structure and reduced infiltration. Saline–sodic soils possess both high salinity and sodicity, making reclamation more challenging.

Effects of Salinity on Soil–Water Relations: Salinity profoundly influences soil physical and hydraulic properties. High concentrations of soluble salts increase soil osmotic potential, thereby reducing the availability of water to plants. In sodic conditions, excess sodium disperses soil particles, causing poor aggregation, surface crusting, reduced porosity and low infiltration rates. These changes restrict root penetration and water movement within the soil profile.

Saline soils often exhibit poor aeration and waterlogging due to reduced permeability. The accumulation of salts near the soil surface, driven by evaporation and capillary rise, further exacerbates water stress in vegetable crops. Consequently, even when soil moisture appears adequate, plants experience difficulty in absorbing water, leading to physiological drought conditions.

Plant–Water Relations under Salinity Stress: Salinity-induced water stress is primarily osmotic in nature. Elevated salt concentrations in the soil solution lower the external water potential, reducing the gradient required for water uptake by roots. As a result, plants exhibit decreased leaf water potential, relative water content and transpiration rates.

Stomatal closure is a common response to salinity, aimed at reducing water loss. However, this also limits carbon dioxide diffusion into leaves, leading to reduced photosynthetic rates. Salinity-induced reduction in root hydraulic conductivity further restricts water transport from soil to shoots. In vegetable crops, these effects are particularly severe due to their high-water demand and sensitivity to stress.

Physiological and Biochemical Responses of Vegetable Crops: Vegetable crops respond to salinity through a range of physiological, biochemical and morphological adaptations. One of the key mechanisms is osmotic adjustment, achieved by the accumulation of compatible solutes such as proline, glycine betaine, sugars and organic acids. These osmolytes help maintain cell turgor and protect cellular structures.

Salinity also induces oxidative stress through the overproduction of reactive oxygen species (ROS). To counteract this, plants activate antioxidant defense systems involving enzymes such as superoxide dismutase, catalase and peroxidase. Hormonal changes, particularly increased abscisic acid levels, play a crucial role in regulating stomatal behavior and stress signaling.

Ion toxicity, mainly due to sodium (Na^+) and chloride (Cl^-), disrupts cellular metabolism and enzyme activities. Selective ion uptake and compartmentalization of toxic ions into vacuoles are important tolerance mechanisms observed in relatively salt-tolerant vegetable species.

Effects of Salinity on Growth, Yield and Quality of Vegetables: Salinity stress adversely affects germination, seedling establishment, vegetative growth and reproductive development of vegetable crops. Typical visual symptoms include wilting, chlorosis, leaf tip burning, necrosis and stunted growth. Root growth is often more severely affected than shoot growth, limiting water and nutrient uptake.

Yield reductions under salinity are common due to decreased photosynthesis, reduced leaf area and impaired assimilate partitioning. Salinity also increases the incidence of physiological disorders such as blossom-end rot in tomato, pepper and eggplant, primarily due to calcium imbalance.

Interestingly, moderate salinity has been reported to enhance certain quality attributes in vegetables. Increased total soluble solids, sugars, organic acids, carotenoids and antioxidant compounds have been observed in crops such as tomato, melon, spinach, lettuce and broccoli. However, these quality improvements often occur at the expense of yield, highlighting the need for careful management.

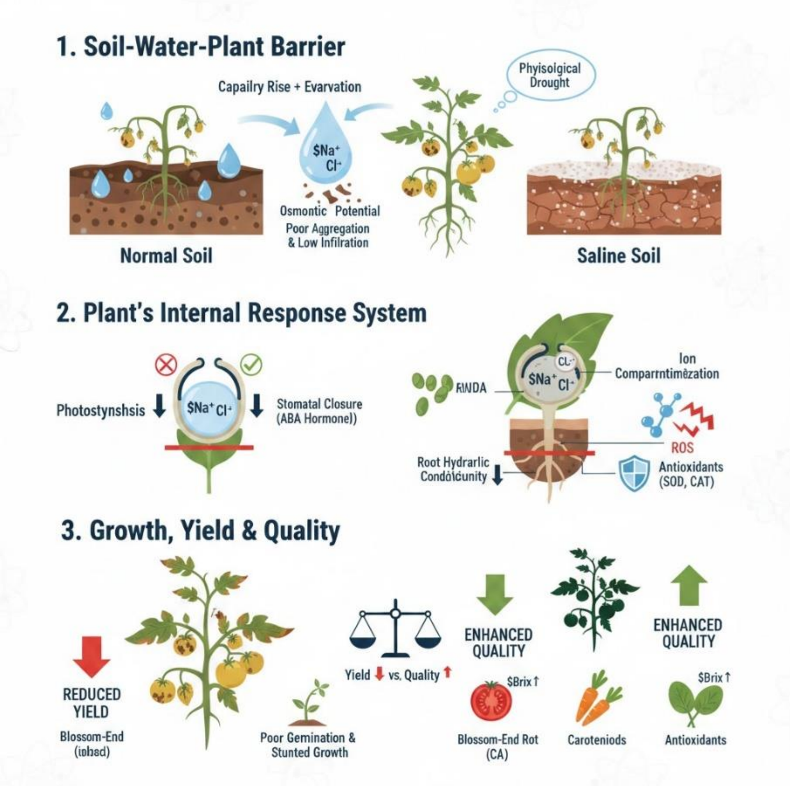

Fig.1. Salinity stress effects

Irrigation Water Quality and Salinity Management: Irrigation water quality plays a pivotal role in salinity development and management. The use of saline or marginal-quality water requires appropriate strategies to minimize salt accumulation. Drip and micro-irrigation systems are effective in maintaining favorable soil moisture conditions and reducing salt buildup in the root zone.

Leaching of excess salts beyond the root zone through periodic application of additional irrigation water is a common practice. Blended irrigation, cyclic use of saline and non-saline water and deficit irrigation strategies may also help manage salinity while conserving water resources.

Soil and Crop Management Practices: Effective salinity management requires an integrated approach combining mechanical, cultural and biological methods. Mechanical practices include surface scraping and leaching to remove accumulated salts. Cultural practices involve proper land levelling, provision of adequate drainage, use of salt-free or low-salinity irrigation water and application of acidic fertilizers.

Organic amendments such as farmyard manure, compost, green manures and crop residues improve soil structure, water-holding capacity and microbial activity, thereby enhancing salt tolerance. Mulching and raised-bed cultivation help reduce evaporation and salt accumulation at the soil surface.

Biological Approaches and Preventive Measures: Biological interventions, particularly the use of plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi, have shown promise in alleviating salinity stress. These beneficial microorganisms enhance nutrient availability, produce phytohormones and improve root growth and water uptake.

Preventing soil salinization is more cost-effective than reclamation. Optimizing irrigation practices, avoiding over-irrigation, maintaining proper drainage, using cover crops and regular monitoring of soil salinity are essential preventive measures.

Conclusion

Soil salinity poses a significant threat to vegetable production by disrupting soil–plant–water dynamics and inducing physiological, biochemical and nutritional stresses. Salinity reduces water availability, impairs plant water relations and limits growth and yield of vegetable crops. Although plants exhibit adaptive mechanisms to cope with salinity stress, their effectiveness is often insufficient under high or prolonged salt exposure.

Integrated management strategies that combine improved irrigation practices, soil amendments, organic and biological approaches and preventive measures are essential for mitigating salinity stress. Sustainable soil–water–crop management, supported by continuous monitoring and site-specific interventions, will play a crucial role in maintaining vegetable productivity under increasing salinization pressures. Future research should focus on developing salt-tolerant vegetable cultivars and refining precision-based management practices to ensure resilient and sustainable vegetable production systems.

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Trends in Transgenic Vegetable Breeding

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Abstract

Vegetable crops are vital for human nutrition and health but are highly vulnerable to biotic and abiotic stresses, leading to considerable yield losses and intensive pesticide use. Transgenic vegetable breeding has emerged as a precise and effective approach to introduce desirable traits that are difficult or time-consuming to achieve through conventional breeding. Over the past three decades, significant progress has been made in developing transgenic vegetables with resistance to insects, viruses and herbicides, as well as improved quality, nutritional value and shelf life. Commercial successes such as virus-resistant squash, Bt-sweet corn and Bt-eggplant highlight the potential of this technology. This review discusses major trends, targeted traits, notable case studies, regulatory and societal challenges and future prospects of transgenic vegetable breeding for sustainable and climate-resilient vegetable production systems.

Keywords: Transgenic vegetables, genetic engineering, Bt crops, virus resistance, vegetable improvement.

Introduction

Vegetables constitute an indispensable component of balanced human diets, supplying essential vitamins, minerals, dietary fibre and bioactive compounds that contribute to overall health and disease prevention. With rising population pressure, urbanization and increased awareness of nutritional security, global demand for vegetables continues to increase. However, vegetable production faces serious challenges due to high susceptibility to pests, diseases, weeds and environmental stresses.

Compared to field crops, vegetables often receive higher pesticide inputs per unit area because of their tender tissues, continuous harvest and strict quality standards. Excessive pesticide use has raised concerns regarding environmental pollution, pesticide resistance, food safety and human health. Although conventional breeding has contributed to improved varieties, its effectiveness in vegetables is often limited by narrow genetic diversity, sexual incompatibility, long breeding cycles and complex inheritance of key traits.

Transgenic vegetable breeding offers a complementary and powerful alternative by enabling the direct introduction of specific genes into elite cultivars. This technology allows breeders to overcome species barriers, accelerate varietal development and precisely target desirable traits. Over the years, advances in molecular biology, gene cloning and plant transformation techniques have expanded the scope of transgenic vegetable improvement.

Concept and Development of Transgenic Vegetable Breeding

Transgenic breeding involves the stable integration of foreign or modified genes into the plant genome using genetic engineering techniques such as *Agrobacterium tumefaciens*-mediated transformation or particle bombardment. Unlike conventional breeding, which relies on recombination within sexually compatible species, transgenics enable gene transfer across taxonomic boundaries.

The development of transgenic vegetables typically includes identification of target genes, construction of expression vectors, plant transformation, selection of transformed plants, molecular characterization and evaluation under confined and field conditions. Early successes in plant biotechnology during the 1980s and 1990s laid the foundation for transgenic crop development, with vegetables playing a pioneering role through the commercialization of transgenic tomato.

The scope of transgenic vegetable breeding extends beyond yield improvement to include reduction in chemical inputs, enhancement of nutritional quality, improved postharvest characteristics and tolerance to abiotic stresses. These traits are particularly relevant in the context of sustainable and climate-smart agriculture.

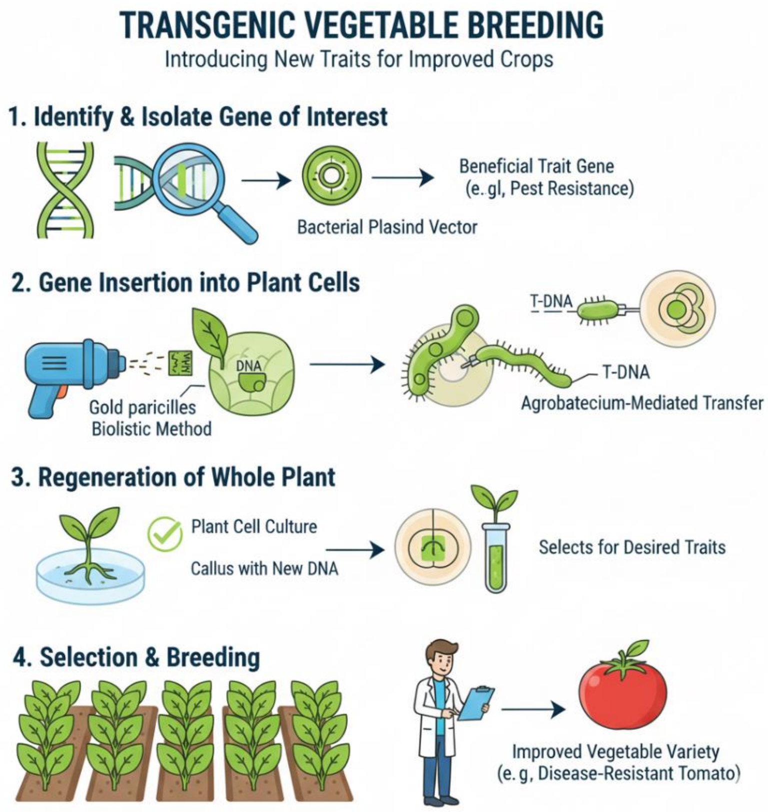

Fig. 1. Transgenic breeding concept

Major Traits Targeted in Transgenic Vegetables

1. Insect Resistance: Insect resistance is the most widely targeted and successful trait in transgenic vegetables. Genes derived from *Bacillus thuringiensis* (Bt) encode crystal (Cry) proteins that are toxic to specific insect pests but safe to humans and non-target organisms. Bt technology has been effectively used to control major lepidopteran pests in vegetables.

Bt-eggplant (brinjal) expressing Cry1Ac protein provides resistance against the fruit and shoot borer (*Leucinodes orbonalis*), a devastating pest in South Asia. Bt-sweet corn offers protection against European corn borer and corn earworm, resulting in improved yield and reduced insecticide use. These transgenic vegetables have demonstrated economic and environmental benefits through reduced pesticide applications and improved farmer profitability.

2. Virus Resistance: Viral diseases are among the most difficult to manage in vegetable crops due to the lack of effective chemical controls. Transgenic approaches have successfully conferred virus resistance using coat protein-mediated resistance, antisense RNA and RNA interference (RNAi) strategies.

Virus-resistant summer squash was one of the earliest commercialized transgenic vegetables, providing resistance against Zucchini yellow mosaic virus, Watermelon mosaic virus and Cucumber mosaic virus. These transgenic varieties showed stable resistance, improved yield and reduced crop losses in virus-prone regions.

3. Herbicide Tolerance: Herbicide-tolerant transgenic vegetables enable effective weed control with broad-spectrum herbicides, reducing labor costs and improving production efficiency. Although this trait is more prevalent in field crops, its application in vegetables is gaining interest, particularly for crops where weed management is labor-intensive.

Herbicide tolerance can also facilitate conservation agriculture practices such as reduced tillage, which improves soil health and reduces erosion. However, careful management is required to prevent herbicide overuse and resistance development.

4. Quality and Shelf-Life Improvement: Postharvest losses are a major concern in vegetable supply chains, especially in developing countries. Transgenic approaches targeting ethylene biosynthesis, cell wall-modifying enzymes and respiration pathways have been explored to delay ripening and senescence.

The Flavr Savr™ tomato, the first commercially released transgenic crop, was developed by suppressing polygalacturonase activity to delay fruit softening. Although it was not commercially successful, it marked a milestone in transgenic crop development. Subsequent research has focused on improving firmness, flavor retention and shelf life in tomato and other vegetables.

5. Nutritional Enhancement: Transgenic vegetable breeding has been used to enhance nutritional quality by increasing vitamins, antioxidants and health-promoting compounds. Examples include increasing carotenoids, anthocyanins and folates in tomato, potato and leafy vegetables.

Biofortified transgenic vegetables have the potential to address micronutrient deficiencies, particularly in developing countries where vegetables form a major component of daily diets. Such functional foods contribute to both nutritional security and public health.

Case Studies of Transgenic Vegetables

1. Tomato: Tomato has served as a model crop for transgenic research due to its well-characterized genome and ease of transformation. In addition to delayed ripening, transgenic tomatoes have been developed with improved nutritional content, enhanced stress tolerance and resistance to pathogens. Research on metabolic engineering in tomato continues to provide insights into fruit development and quality improvement.

2. Potato: Transgenic potato varieties have been developed for resistance to insects such as Colorado potato beetle and viral diseases like potato virus Y. Bt-potato demonstrated substantial reductions in insecticide use and yield stability. However, market rejection and regulatory challenges limited its widespread adoption, highlighting the importance of consumer acceptance in transgenic vegetables.

3. Eggplant (Bt Brinjal): Bt-eggplant is one of the most significant examples of transgenic vegetable success in developing countries. In Bangladesh, Bt-brinjal adoption has resulted in higher yields, reduced pesticide sprays and increased farmer income. The experience demonstrates the potential of transgenic vegetables to benefit smallholder farmers when supported by appropriate regulatory frameworks.

4. Sweet Corn: Bt-sweet corn has been successfully adopted in several countries, particularly for fresh market consumption. It provides effective control of lepidopteran pests, improved cob quality and reduced pesticide residues. Recent developments include stacked traits combining insect resistance and herbicide tolerance.

Transgenic Vegetables in Integrated Pest Management

Transgenic vegetables play a valuable role in integrated pest management (IPM) by reducing dependence on chemical pesticides and enhancing ecological sustainability. Insect-resistant and virus-resistant transgenic crops help maintain pest populations below economic threshold levels, conserve natural enemies and reduce environmental contamination.

However, resistance management strategies such as refuge planting, gene stacking and monitoring of pest populations are essential to delay resistance evolution. Integration of transgenic crops with cultural, biological and mechanical control measures ensures long-term effectiveness.

Regulatory, Ethical and Societal Challenges

Despite proven benefits, transgenic vegetables face significant regulatory and societal challenges. Regulatory approval processes are often lengthy, expensive and complex, limiting participation by public-sector institutions. Vegetables face additional scrutiny because they are consumed fresh and directly.

Public perception, misinformation and lack of awareness have influenced consumer acceptance. Ethical concerns regarding gene transfer, biodiversity and corporate control of seeds also affect adoption. Transparent biosafety assessments, science-based regulations and effective public communication are crucial for wider acceptance.

Emerging Trends and Future Directions

Recent trends in transgenic vegetable breeding include the development of cisgenic crops, intragenic approaches and precision-based genetic modification. Advances in genomics, transcriptomics and functional gene analysis are accelerating trait discovery.

There is increasing emphasis on developing region-specific transgenic vegetables targeting local pest complexes, climatic stresses and nutritional needs. Public–private partnerships and international collaborations are expected to play a key role in translating research into farmer-ready technologies.

Conclusion

Transgenic vegetable breeding has made significant contributions to improving pest resistance, reducing pesticide use, enhancing quality and promoting sustainable vegetable production. While technical achievements are substantial, adoption remains constrained by regulatory, economic and societal factors. Integrating transgenic approaches with conventional breeding, IPM strategies and emerging biotechnological tools offers a promising pathway for addressing future challenges in vegetable agriculture. With supportive policies, public awareness and science-based regulation, transgenic vegetables can play a vital role in ensuring food and nutritional security under changing climatic and production scenarios.

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Cultivating Resilience: Breeding Vegetables to Thrive in a Drier World

Article ID: 72567

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Abstract
As climate change intensifies drought conditions globally, securing our food supply requires vegetables that can do more with less water. This article explores the frontline battle to develop drought-resilient crops through advanced breeding. We journey from the sun-baked fields where plants first show signs of stress, down to their roots and into their very DNA, to uncover how scientists are decoding nature's survival strategies. By harnessing both traditional wisdom and cutting-edge genetic tools from grafting hardy rootstocks to precise gene editing researchers are creating the next generation of super-vegetables. These crops are designed not just to survive dry spells, but to produce abundant, nutritious food in the face of growing environmental uncertainty, offering a tangible solution for farmers and consumers in a warming world.

Keywords: Drought, Climate-smart crops, breeding, Sustainable agriculture.

Introduction
Imagine a vegetable garden under a relentless summer sun. The tomato leaves begin to curl and wilt, the vibrant green of cucumber vines fades and promising bean pods wither before they can be picked. This isn't just a gardener's disappointment; it's a microcosm of one of the most pressing challenges in global agriculture: drought.

With shifting climate patterns leading to more frequent and severe dry spells, the need for vegetables that can withstand water scarcity has never been more urgent. Unlike many field crops, most vegetables are inherently sensitive to drought. Their high-water content and often shallow roots make them vulnerable and water stress at critical moments like flowering can devastate yields and quality.

But within this challenge lies a remarkable story of scientific innovation. Around the world, plant breeders, geneticists and farmers are collaborating on a crucial mission: to unlock the genetic secrets of drought tolerance and cultivate a new generation of resilient crops. This is not simply about survival; it's about ensuring food security, protecting farmers' livelihoods and maintaining the diversity of nutritious foods on our plates in an increasingly unpredictable climate.

How Drought "Stresses" a Plant: More Than Just Thirst
When we think of a plant suffering from drought, we picture dry soil and wilted leaves. However, the reality inside the plant is a complex cascade of physiological crises. It begins with the roots sensing drier soil and sending chemical alarms, primarily a stress hormone called abscisic acid (ABA), up to the leaves.

The plant's first emergency response is to close tiny pores on its leaves called stomata. This conserves precious water but comes at a heavy cost: with the stomata shut, the plant can no longer take in carbon dioxide. Photosynthesis the very engine of plant growth grinds to a halt, starving the plant of energy and the sugars needed to produce fruits and vegetables.

Simultaneously, as water becomes scarce inside plant cells, their internal machinery starts to malfunction. Proteins can unfold and membranes can rupture. To prevent this, plants accumulate special protective compounds like proline and betaine, which act like molecular antifreeze, stabilizing cell structures. This process, called osmotic adjustment, is a key survival tactic.

Perhaps most insidiously, drought leads to a buildup of toxic molecules known as reactive oxygen species (ROS). These can damage DNA, proteins and fats. In response, plants ramp up their internal antioxidant systems, producing enzymes to mop up these dangerous compounds. A plant's ability to manage this "oxidative stress" is a major determinant of its drought tolerance.

The Hidden Key: Roots and the Struggle for Nutrients

The battle for survival is won or lost underground. A plant's root system is its lifeline and under drought, its architecture becomes paramount. Breeders seek plants that develop deeper, more extensive and denser root systems to scavenge water from a larger soil volume.

For example, research shows that cauliflower, when stressed by drought, can send roots down to 90 cm, significantly deeper than when well-watered. In contrast, tomatoes and peppers, with their naturally shallower roots, are more vulnerable to surface drying. Selecting for better roots is a cornerstone of traditional drought breeding.

However, drought creates a double jeopardy: it doesn't just limit water; it also starves the plant of nutrients. Nutrients move through soil water to the roots. When the soil dries, this delivery system breaks down. Furthermore, the plant's own ability to actively take up nutrients is impaired. The energy-intensive pumps that pull in nutrients like nitrogen and phosphorus require water. A drought-stressed plant may be sitting in soil with adequate fertility but is unable to access it, leading to hidden hunger that further stunts growth and yield.

Nature's Blueprint: Hunting for Drought-Tolerant Genes

Long before modern science, nature was conducting its own breeding experiments. In the wild relatives of our domesticated vegetables, scientists find a treasure trove of drought-survival blueprints.

Consider the humble tomato. Its wild cousin, *Solanum pennellii*, from the arid coasts of Peru, has evolved succulent leaves that store water. Another, *Solanum chilense* from the Atacama Desert, boasts an incredibly deep and robust root system. Researchers have successfully crossed these wild species with commercial tomatoes, transferring valuable traits like improved water-use efficiency and stronger roots into high-yielding varieties.

This pattern repeats across the vegetable kingdom:

1. **Eggplant/Aubergine:** Wild species like *Solanum macrocarpon* offer natural resilience.

2. **Potato:** Wild relatives such as *Solanum acaule* from the high Andes show exceptional drought tolerance.

3. **Legumes:** The tepary bean (*Phaseolus acutifolius*), native to the southwestern US and Mexico, is a champion of dry-land farming.

The goal of breeders is to carefully cross these hardy wild plants with our favourite eating varieties, selecting offspring that combine the best of both worlds: the toughness of their ancestors and the taste and yield of modern crops.

The Breeder's Toolbox: From Field Selection to Gene Editing

Developing a new drought-tolerant variety is a multi-faceted endeavour, employing tools ranging from the simple to the sophisticated.

1. **Conventional & Phenotypic Breeding:** This is the time-tested foundation. Breeders cross promising parent plants and then grow thousands of offspring in "stress nurseries" fields where water is deliberately limited. They meticulously observe and measure which plants perform best, selecting for traits like:
    a. **Yield Stability:** Consistent production under stress.
    b. **Water Use Efficiency (WUE):** More biomass per drop of water.
    c. **Canopy Temperature:** Cooler leaves can indicate better water circulation. This method is effective but can be slow, taking up to a decade to develop a new variety.

2. **Marker-Assisted Selection (MAS):** This is like giving breeders a genetic GPS. Scientists first identify specific stretches of DNA (molecular markers) that are physically located near genes controlling drought tolerance. Instead of waiting for a plant to mature in a drought field, breeders can test a seedling's DNA in a lab. If it has the right markers, it likely carries the desired trait, dramatically speeding up the selection process.

3. **Genetic Engineering and Gene Editing:** These are the precision tools of modern biology.

a. Genetic Engineering involves adding a useful gene from another organism. For example, a gene for producing a protective osmolyte (like betaine from bacteria) can be inserted into a tomato plant to help its cells retain water.

b. Gene Editing (e.g., CRISPR-Cas9) is even more revolutionary. Instead of adding foreign genes, it allows scientists to make precise edits to the plant's own existing genome. They can **"turn up"** the expression of a beneficial drought-response gene or **"turn off"** a gene that makes the plant overly sensitive to stress. This approach is accelerating the development of resilient crops with minimal changes to their genetic background.

Beyond Breeding: Grafting and Smart Management

Sometimes, the fastest solution isn't a new seed, but a new combination of plant parts. Grafting is a ancient horticultural technique undergoing a modern renaissance, especially for high-value vegetables like tomatoes, watermelons and eggplants.

The process involves surgically attaching the shoot of a delicious, high-yielding variety (the scion) onto the root system of a hardy, drought-tolerant wild relative or selected rootstock (the rootstock). The result is a "super-plant": it produces the tomatoes we love to eat, but draws water and nutrients with the rugged, deep roots of its resilient base.

Studies show grafted watermelon plants can produce over 60% higher yields under water deficit than ungrafted ones. This method provides an almost immediate boost to drought resilience without the wait of a full breeding cycle.

Breeding must also be paired with smart agronomy. The most drought-tolerant gene will fail if the plant is not properly cared for. Strategies like mulching (to reduce soil evaporation), drip irrigation (to deliver water directly to roots efficiently) and conservation tillage (to improve soil water retention) are essential partners to genetic gains, creating a holistic system of resilience.

Fig. 1. Integrated Strategies for Drought-Tolerant Crop Development

Conclusion

The journey to develop drought-resilient vegetables represents a profound convergence of science and necessity. By translating intricate plant stress signals from root-level water sensing to cellular antioxidant responses into targeted breeding strategies, we are fundamentally reimagining agriculture for a changing climate. The most promising path forward integrates ancient agricultural wisdom with cutting-edge genetic technologies, combining hardy wild crop relatives, precision gene editing and sustainable practices like grafting. This multidisciplinary approach moves us beyond merely helping plants survive drought toward enabling them to thrive despite it.

Ultimately, this work cultivates more than hardier vegetables it nurtures the foundation of future food security. Each deeper root system and each more efficient leaf represent a step toward abundance in an uncertain climate. By investing in these biological solutions today, we harvest not just better crops, but greater hope for resilient food systems that can sustain generations to come, even as our world grows drier.

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Assessing the impact of Capacity Building Programme on Administrative & Financial Management for the Personnel of KVKs of ATARI, Umiam

Article ID: 72568

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Abstract

A three-day Capacity Building Programme on *"Efficient Administrative and Financial Management"* was successfully organized by ICAR–Agricultural Technology Application Research Institute (ATARI), Umiam, from 1st to 3rd November 2023. Designed specifically for junior-level officers of Krishi Vigyan Kendras (KVKs) and ATARI, the programme aimed to strengthen their administrative and financial competencies through an integrated and practical learning approach. The training focused on enhancing understanding of ICAR rules, procurement procedures, financial management, service matters, and digital governance tools such as PFMS, TSA, and GeM. Participants actively engaged in interactive sessions, case discussions, and experiential learning exercises led by expert trainers. The programme not only improved their technical knowledge and administrative acumen but also fostered teamwork, accountability, and confidence-key attributes for effective governance and resource utilization in the ICAR system.

Introduction

Human resources are the backbone of any organization, and their development plays a crucial role in achieving institutional efficiency and sustainability. Within the ICAR system, administrative and finance personnel form the core of institutional operations, ensuring smooth functioning, transparency, and compliance with established norms. However, many newly recruited officers begin their careers with limited exposure to the intricate procedures, rules, and financial systems that govern institutional administration.

Recognizing this need, ICAR-ATARI, Umiam, took the initiative to design and conduct a specialized Capacity Building Programme on "Efficient Administrative and Financial Management" exclusively for junior-level officers of KVKs and ATARI. The objective was to empower participants with updated knowledge, practical skills, and problem-solving capabilities essential for handling administrative and financial responsibilities effectively. The three-day programme was meticulously planned based on Training Needs Assessment (TNA), ensuring relevance to the day-to-day challenges faced by officers in areas such as procurement, budgeting, pension processing, taxation, and service matters. Topics covered included procurement procedures under GFR, office management, budgeting and expenditure control, GeM purchases, PFMS and TSA systems, pension and service book maintenance, and GST compliance. The sessions were delivered by experienced officers and subject matter experts from ICAR and other government organizations, making the training rich in practical insights and institutional applicability. The programme also emphasized interactive learning, encouraging participants to engage in open discussions, case-based learning, and peer-to-peer exchanges. This approach helped transform theoretical understanding into actionable knowledge, aligning with ICAR's vision of developing a competent, efficient, and confident workforce.

Assessment Criteria

To evaluate the effectiveness of the Capacity Building Programme, a quantitative assessment approach was employed through structured pre- and post-training quiz tests. A total of 26 participants took part in both assessments, which were designed to measure their conceptual understanding and practical knowledge across key topics covered during the training sessions. The pre-training assessment served as a baseline to gauge the participants' initial level of understanding of administrative and financial procedures. After the completion of the training, the post-training test was administered to assess the extent of learning and conceptual improvement achieved. The difference between the pre- and post-test scores provided an objective measure of the learning gain resulting from the programme. To further analyze the outcomes, statistical evaluations and visualizations-including histograms, and box plots-were used to compare score distributions and illustrate the overall learning shift. A *paired t-test* was applied to determine whether the improvement in scores was statistically significant.

Results & Discussions

The analysis of pre- and post-training scores of 26 participants revealed a marked improvement in their understanding and application of concepts related to administrative and financial management. As shown in Figure 1, the pre-training scores (green) were largely concentrated in the 10-18 range, reflecting limited prior familiarity with the subject matter. In contrast, the post-training scores (dark orange) shifted noticeably toward the 25-30 range, indicating substantial learning gains. This rightward shift signifies that the Capacity Building Programme on Administrative and Financial Management for Junior Officers of KVKs and ATARI effectively enhanced participants' competencies, equipping them with improved knowledge and practical skills essential for efficient organizational functioning.

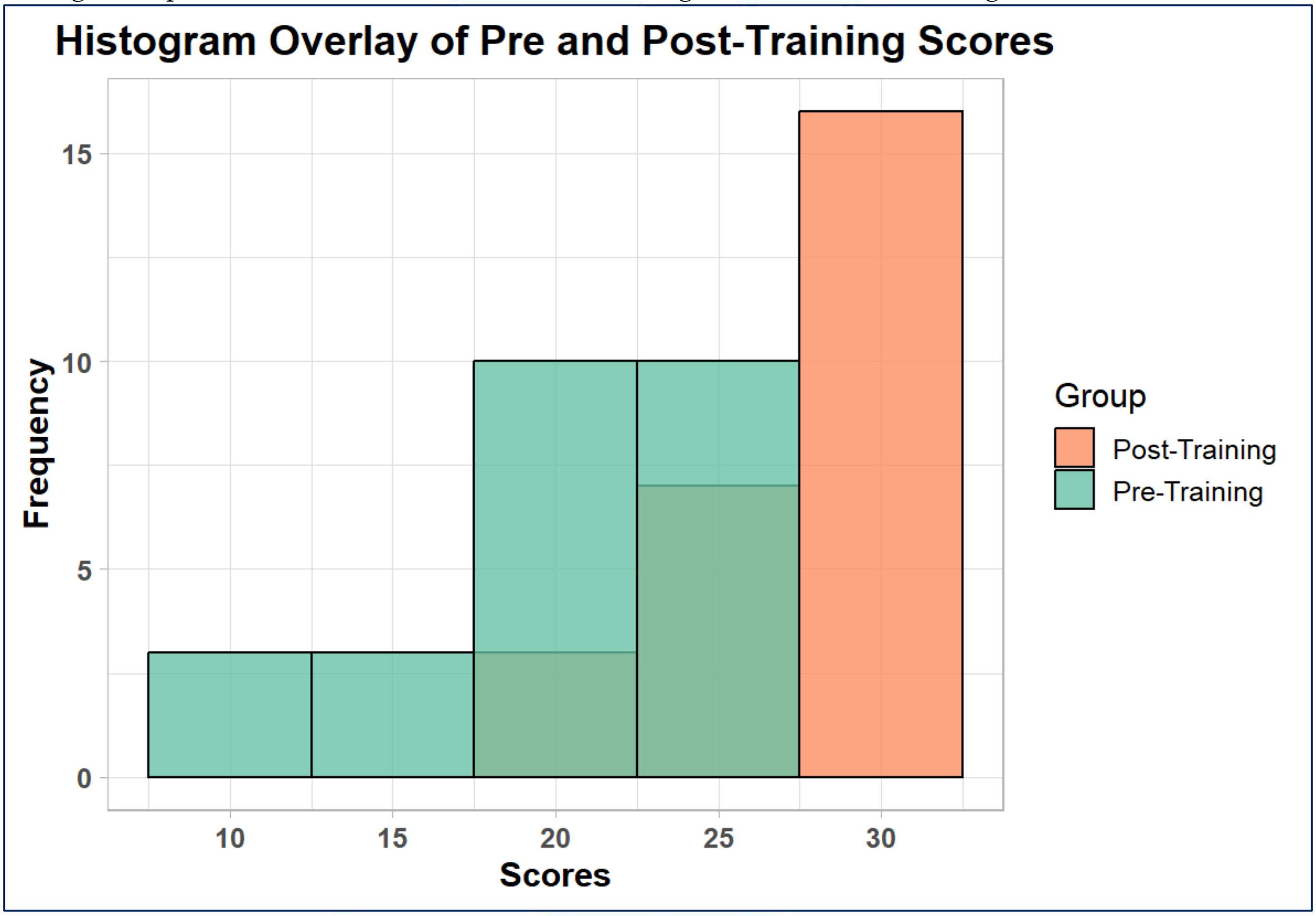

Figure 1: Histogram overlay plot

Figure 2 depicts the distribution of candidates across different score ranges before and after training. It is evident that before the training, a majority of participants scored within the lower and middle ranges, indicating limited prior understanding of the examination content. In contrast, after the training, the distribution shifted markedly toward higher score ranges- with around 17 participants achieving scores between 26-30, a range where no participants were present in the pre-training phase. This clear upward shift in performance highlights the positive impact of the pre-examination training in enhancing participants' knowledge and preparedness for the examination. Figure 3 illustrates the gain percentages of individual participants in the Capacity Building Programme on Administrative and Financial Management for Junior Officers of KVKs and ATARI. The majority of participants demonstrated positive gains, with several achieving improvements exceeding 20%, indicating substantial learning progress. A few participants exhibited exceptionally high gains, reflecting strong responsiveness to the training, while some showed modest improvements, likely influenced by differences in prior knowledge or individual learning pace.

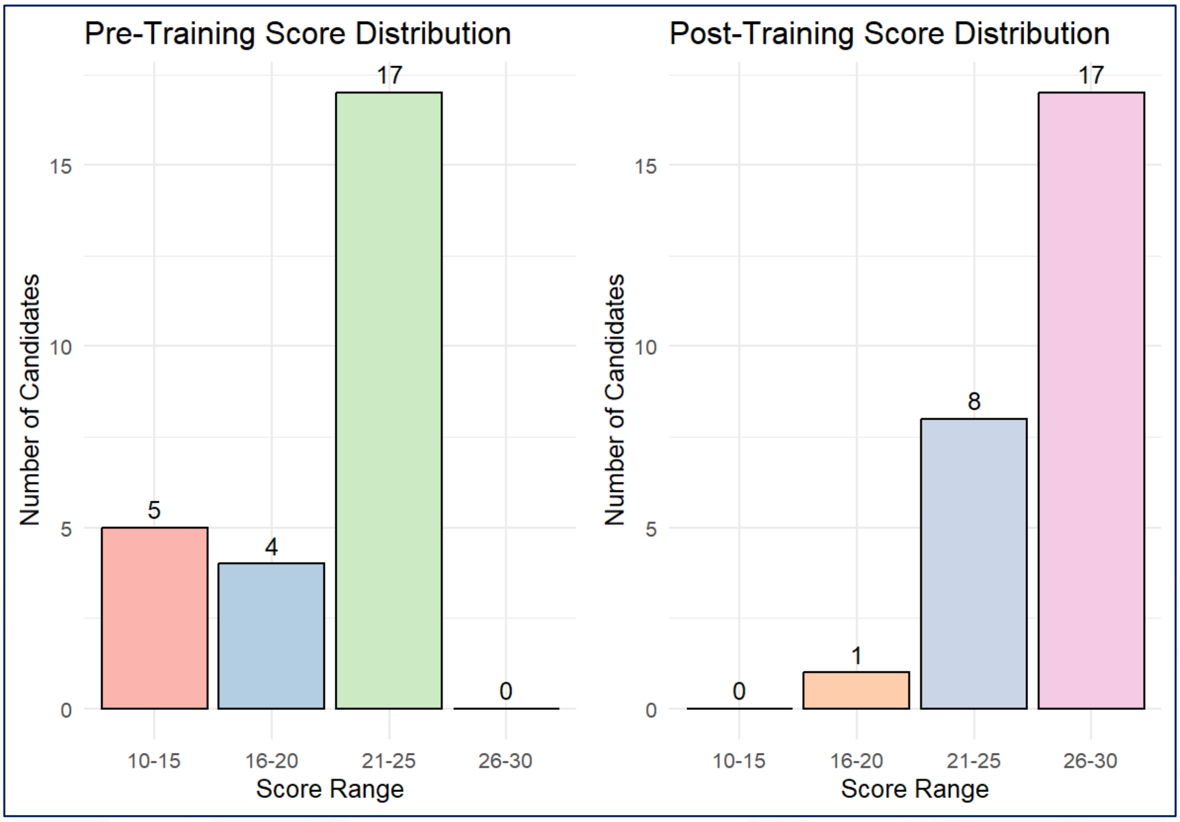

Figure 2: Distribution of candidates across different score ranges before and after the training

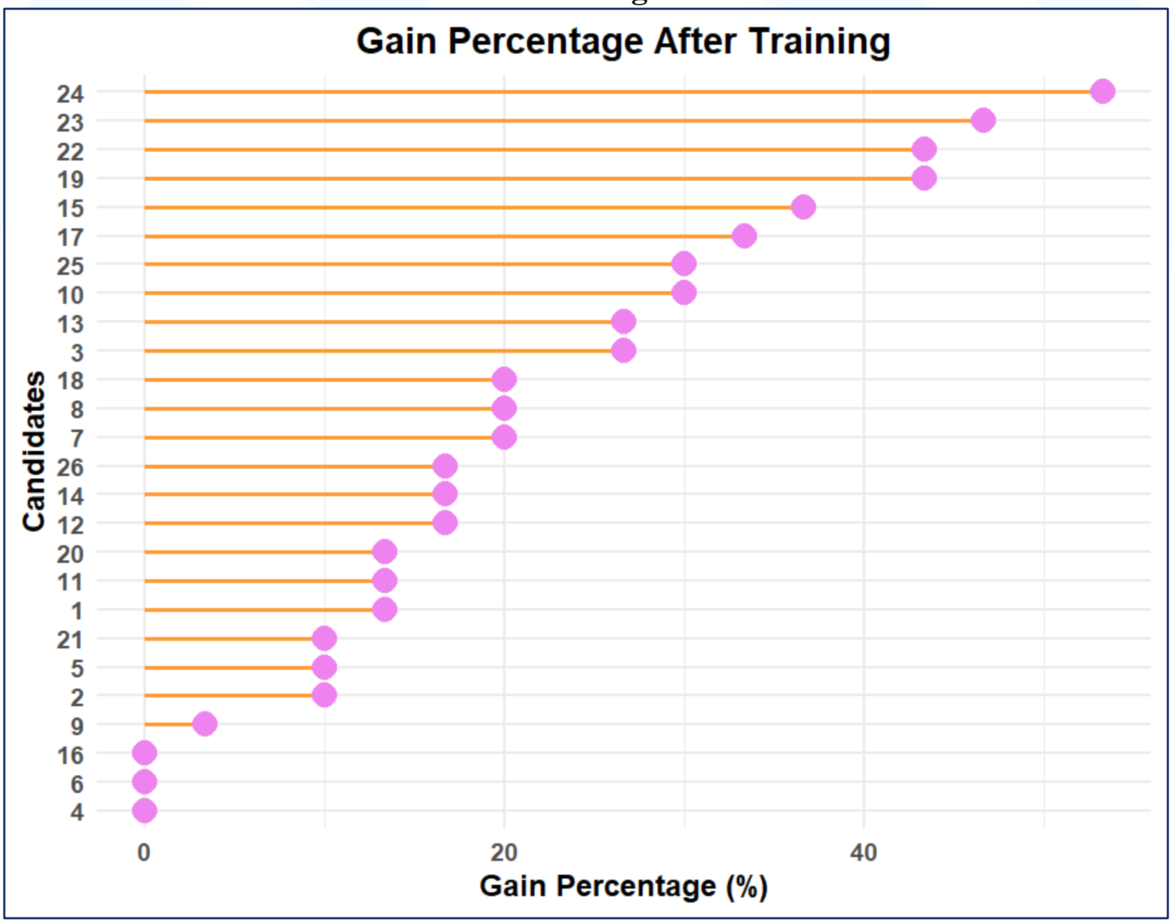

Figure 3: Gain percentage plot of candidates

The box plot and summary statistics (Figure 3) further highlight the impact of the training. The mean score rose from 20.3 to 26.7, and the median increased from 22 to 28. While the majority of participants showed improvement, the magnitude of progress varied, indicating that some benefited more from the training than others.

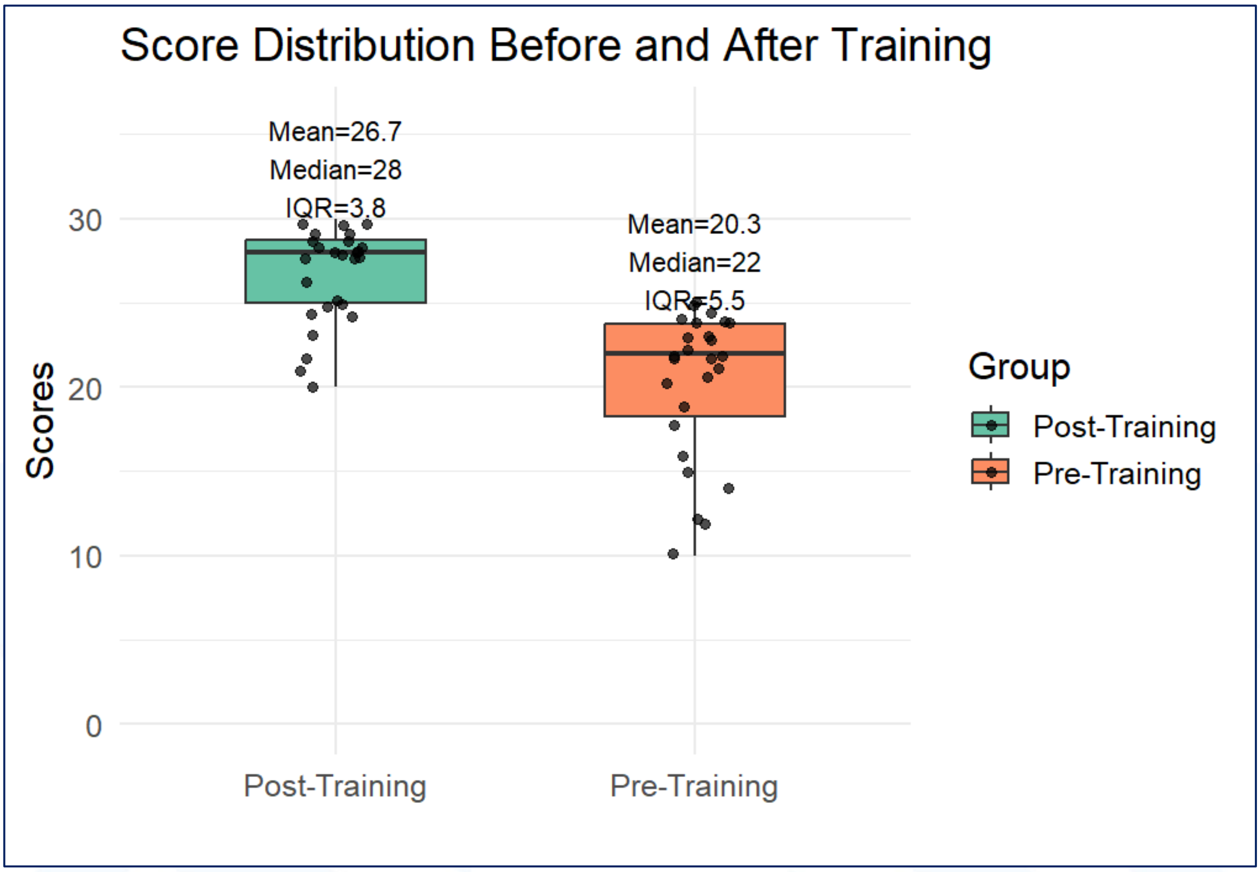

Figure 3: Box plot of distribution of scores before and after the training

A *paired t-test* confirmed a statistically significant improvement in participants' scores ($t = -7.27$, $df = 25$, $p < 0.05$), demonstrating the effectiveness of the training. Overall, the results indicate that structured, interactive capacity-building programmes can substantially enhance the administrative and financial management skills of Junior Officers of KVKs and ATARI, supporting ICAR's objective of developing a competent and confident workforce. The analysis clearly revealed a substantial increase in post-training scores, demonstrating that the capacity building programme effectively enhanced participants' knowledge, confidence, and readiness to apply improved administrative and financial management practices in their respective institutions.

Conclusion

The Capacity Building Programme on *"Efficient Administrative and Financial Management"* proved to be a valuable initiative for enhancing the professional competence of junior officers in KVKs and ATARI. The interactive and practical approach not only improved their understanding of administrative and financial regulations but also instilled confidence in executing their roles more effectively. The success of this programme reinforces the importance of continuous learning and capacity building in strengthening ICAR's administrative and financial governance framework.

Reference

Capacity Building Programme on Efficient Administrative and Financial Management for Junior level officers of KVKs and ATARI Organized by ICAR-Agricultural Technology Application Research Institute, ICAR-Zone VII, Umiam-793103, Ri Bhoi, Meghalaya on 1-3 November, 2023.

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Empowering Aspirants for Success in the Limited Departmental Audit & Accounts Examination in ICAR System

Article ID: 72569

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Abstract

The Indian Council of Agricultural Research (ICAR) has always been at the forefront of promoting excellence and professionalism among its workforces. In line with this vision, The ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati, in collaboration with certified master trainers and subject matter experts from ICAR and other government departments, led the initiative to strengthen participants' understanding of financial, administrative, and auditing concepts. The training combined theoretical and practical sessions conducted through online platforms, ensuring nationwide accessibility. To evaluate its effectiveness, structured pre-training and post-training assessments were administered, which revealed a significant improvement in participants' conceptual clarity, analytical skills, and problem-solving abilities. The initiative not only contributed to enhancing professional competence but also reflected ICAR's commitment to promoting continuous learning and career advancement within its system.

Introduction

Capacity building remains an essential pillar of organizational development, particularly in administrative and financial domains where precision, compliance, and analytical understanding are paramount. Recognizing the importance of developing competent internal talent, the ICAR-NIASM launched a Pre-Examination Training Programme for the Limited Departmental Audit & Accounts Examination (LDA&A Exam.). This examination is a crucial gateway for ICAR employees aspiring to advance to the position of Assistant Finance & Accounts Officer, a role that demands in-depth knowledge of rules, regulations, and accounting procedures. The training was organized by the ICAR–NIASM, Baramati, from 20th July 2023 to 6th October 2023, targeting Assistants, Personal Assistants (PAs), Upper Division Clerks (UDCs), Stenographers, and Lower Division Clerks (LDCs) serving in ICAR institutes and regional stations who had applied for or were eligible to appear for the examination. The course was meticulously designed to provide an all-encompassing learning experience, focusing equally on theoretical understanding and practical applications.

Delivered through the Zoom platform, the programme included around 50 interactive sessions, each of 60 minutes duration, led by master trainers from ICAR and senior officers from various government organizations. The major topics covered in the training included Financial Rules, Budgeting, Payment and Accounting Procedures, Principles of Commercial Accounting, Service Rules (both theory and practical), and Auditing. The sessions were designed using PowerPoint presentations, real-life case studies, and self-exploration exercises, ensuring participant engagement and conceptual clarity. The training's primary objective was to help participants gain confidence in tackling the examination through improved understanding of core financial principles and government accounting systems. Moreover, it aimed to enhance participants' time management, analytical thinking, and decision-making skills-essential competencies for future administrative leaders in ICAR.

Assessment Criteria

To ensure the effectiveness of the training and measure learning outcomes, pre-training and post-training assessments were systematically implemented. These assessments served as a quantitative tool to evaluate participants' knowledge acquisition and conceptual improvement throughout the course. Before the commencement of lectures, participants were asked to complete a pre-training multiple-choice questionnaire (MCQ) designed to assess their baseline understanding of topics such as financial rules, service regulations, and auditing practices. Upon completion of the training sessions, the same set of questions was administered as a post-training assessment. The responses were collected digitally through Google Forms, ensuring efficiency and accuracy in data collection. The analysis of assessment data involved the use of statistical methods to determine the extent of improvement in participants' scores. Techniques such as the paired t-test were applied to evaluate the significance of the difference between pre-training and post-training results. In addition, box plots and histograms were used to visualize the distribution of scores, highlighting individual and group-level progress. The gain percentage was computed to quantify the overall increase in knowledge levels among participants.

Results & Discussions

The analysis of pre- and post-training data from 58 participants indicated a clear enhancement in knowledge and skills related to administrative and financial management. As shown in Figure 1, the histogram overlay illustrates the distribution of scores before and after the training. Pre-training scores, represented in violet, were mostly concentrated between 60 and 100, while post-training scores, shown in dark orange, shifted noticeably toward the 100-120 range. This rightward shift reflects a marked improvement in performance, with fewer participants scoring in lower ranges and more achieving higher scores. The overlapping region around 80-100 highlights partial continuity, but the overall movement toward higher scores confirms the effectiveness of the training intervention.

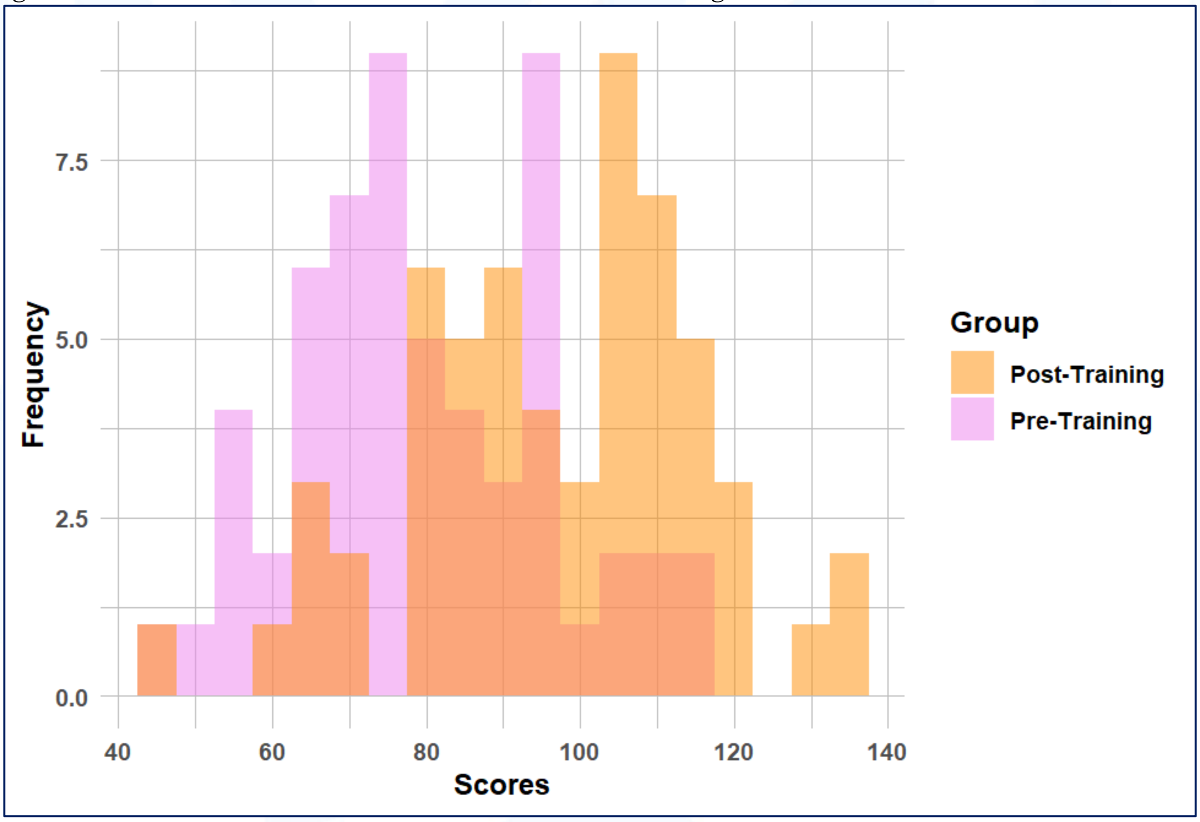

Figure 1: Histogram overlay plot

The bar plot of gain percentages (Figure 2) illustrates the individual improvements of 58 participants following the training. The gain percentage-calculated as the difference between post- and pre-training scores relative to total marks-shows considerable variation across candidates. Most participants recorded positive gains, with several achieving improvements exceeding 30%, reflecting substantial learning progress. A few individuals displayed exceptionally high gains, indicating strong responsiveness to the training, while others showed modest improvement. This variation suggests that the training's impact differed among participants, likely due to differences in prior knowledge and learning pace. Overall, the plot clearly demonstrates the training's positive effect, with the majority of candidates showing meaningful score enhancement.

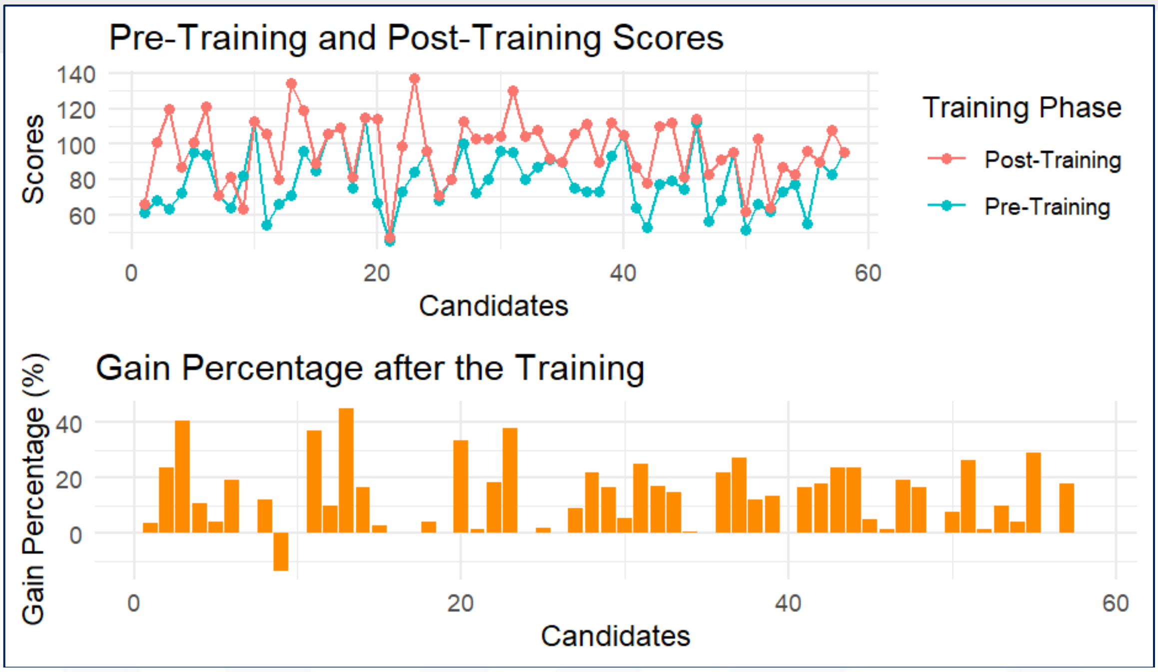

Figure 2: Pre- and post-training scores & gain percentage plot

The box plot and statistical results (Figure 3) indicate a clear improvement in participant scores after the training. The mean score increased from 79 to 96, and the median from 77 to 100, reflecting a strong positive impact of the program. Interestingly, the interquartile range (IQR) remained unchanged at 25.75 for both pre- and post-training scores, suggesting that while overall performance improved, the variation among the middle 50% of participants remained stable. This consistency implies that the training elevated scores uniformly across the group, effectively enhancing overall performance without widening disparities.

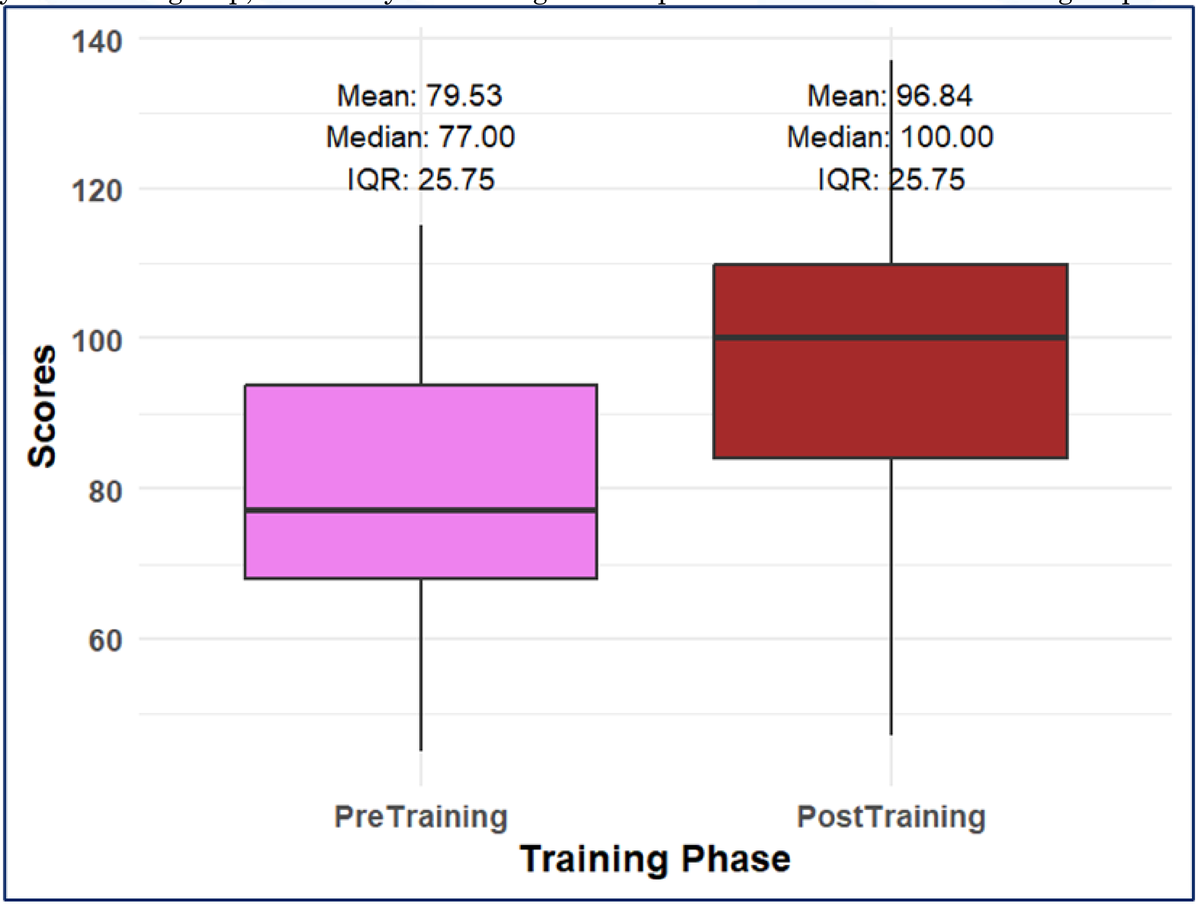

Figure 3: Box plot showing the distribution of participants' scores before and after the training

A *paired t-test* was conducted to evaluate the difference between pre-training and post-training scores. The results indicated a significant improvement, with a t-statistic of -7.52 and 57 degrees of freedom. The *p-value* (< 4.179e-16) was far below the standard alpha level of 0.05, leading to the rejection of the null hypothesis and confirming a statistically significant difference between the two sets of scores. These findings affirm that the pre-examination training effectively achieved its objective of enhancing preparedness for the LDA&A Examination. Overall, the initiative highlights the impact of well-structured and interactive training programmes in fostering professional growth, in alignment with ICAR's vision of developing a competent, knowledgeable, and confident administrative workforce.

Conclusion

This Pre-Examination Training Programme proved to be a valuable initiative in strengthening the professional competence of ICAR personnel. The interactive sessions, expert guidance, and structured assessments significantly enhanced participants' understanding and confidence. Overall, the programme effectively prepared aspirants for the examination while promoting continuous learning and professional growth within the ICAR system.

Reference

Capacity Building Programme on Limited Departmental Audit & Accounts Examination: Empowering Aspirants for Success in the LDA&A Examination to be organized by ICAR-NIASM, Baramati, Pune, Maharashtra. (http://niam.res.in/training).

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Measuring the Effectiveness of Capacity Building Programme on Pension & Retirement Benefits, & NPS for the Administrative Personnel of ICAR Institutes

Article ID: 72570

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Abstract

The Government of India provides a range of benefits to ensure the financial security and well-being of retired employees. With the increasing importance of retirement planning due to rising living costs and longevity, understanding pension systems is crucial for administrative and finance officers. This article evaluates the effectiveness of a three-day Capacity Building Programme on Pension, Retirement Benefits, and the National Pension System (NPS) organized by ICAR-National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Nagpur. Using pre- and post-training quiz assessments, the study measured knowledge gains among 13 participants. Results indicate a significant improvement in participants' understanding of key concepts, highlighting the value of structured training in strengthening administrative and financial capacity in ICAR institutes.

Introduction

Retirement planning has become an essential aspect of financial security due to factors such as inflation, increasing cost of living, and longer life expectancy. The Government of India plays a pivotal role in ensuring the well-being of retired employees by providing pension, gratuity, dearness relief, leave encashment, and other benefits. The Defined Benefit Pension System (DBPS) and the National Pension System (NPS)-a Defined Contribution Pension System (DCPS)-represent two approaches to retirement planning for central government employees, regulated by the Pension Fund Regulatory & Development Authority (PFRDA). Recognizing the need to enhance the understanding of these systems among administrative and finance officers, ICAR-NBSS&LUP conducted a Capacity Building Programme. The training aimed to equip participants with knowledge of both theory and practice of pension administration, retirement benefits, and NPS rules, facilitating effective financial management within ICAR institutes.

Programme Overview

The programme was conducted offline over three days (15-17 November 2023) at ICAR-NBSS&LUP, Nagpur. Eleven interactive sessions of 75 minutes each combined lectures, self-exploration exercises, and case analyses. Pre- and post-training quizzes were used to assess learning outcomes. Senior officers from ICAR and other institutions acted as resource persons. The target audience comprised administrative and finance staff from ICAR institutes across India, with a focus on the western region.

Assessment Criteria

The evaluation employed a quantitative approach using structured pre- and post-training quizzes to measure conceptual understanding and practical knowledge. Key aspects of the assessment included:

1. **Participants:** 13 administrative and finance officers.
2. **Pre-Training Quiz:** Established baseline knowledge on pension, retirement benefits, and NPS procedures.
3. **Post-Training Quiz:** Measured learning outcomes following the programme.
4. **Analysis:** Differences between pre- and post-test scores quantified learning gains. Statistical tools such as paired t-tests were applied to determine the significance of improvement. Visualizations, including histograms and violin plots illustrated the overall shift in understanding.

Results & Discussion

The evaluation of pre- and post-training quiz scores for the 13 administrative and finance officers demonstrated a significant enhancement in their understanding of pension administration, retirement benefits, and the National Pension System. The pre-training scores (depicted in purple in Figure 1) were mostly clustered between 25 and 35, indicating a moderate initial familiarity with the topics. Following the three-day Capacity Building Programme, the post-training scores (shown in yellow) shifted predominantly to the 40-50 range, reflecting considerable improvement in both conceptual knowledge and practical application. This positive shift highlights the effectiveness of the programme in strengthening participants' competencies, enabling them to manage administrative and financial responsibilities more efficiently and with greater confidence.

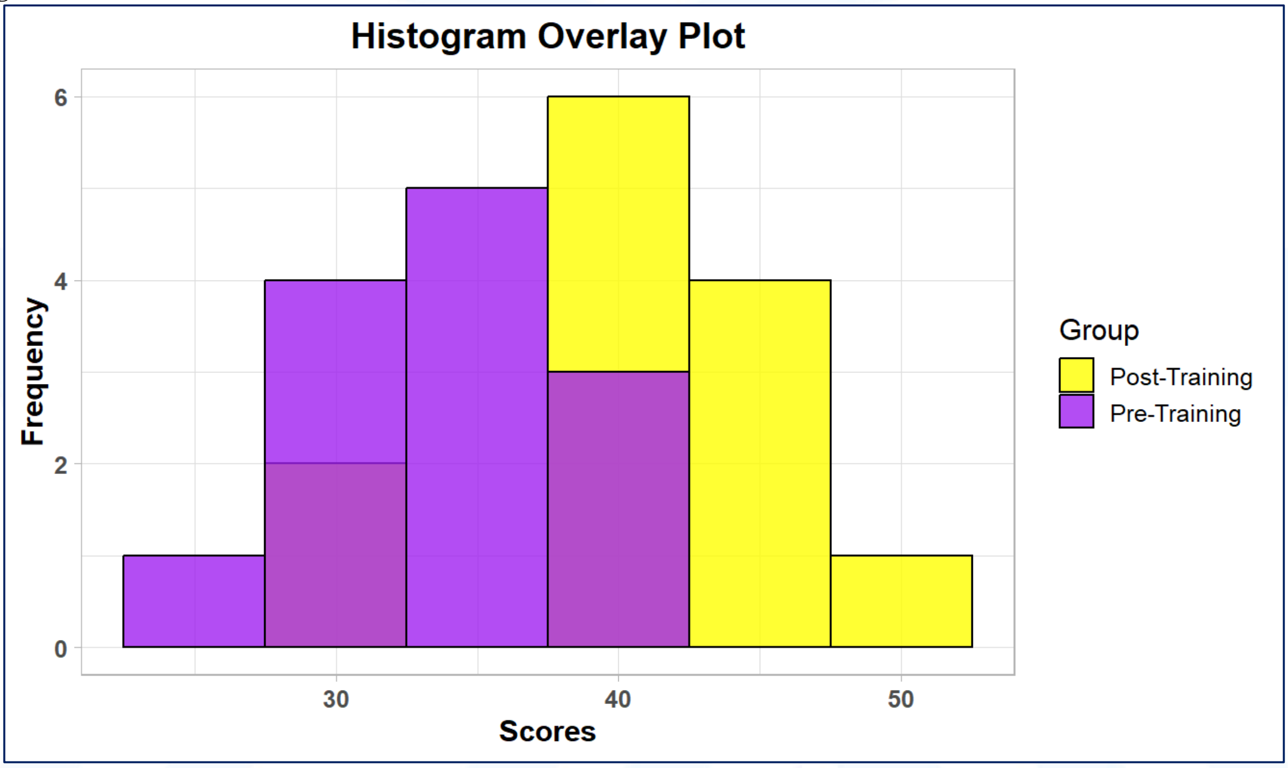

Figure 1: Histogram overlay plot

Figure 2 shows the distribution of the 13 participants across different score ranges before and after the training. Prior to the programme, most participants scored in the lower to middle ranges, suggesting limited initial familiarity with the content related to pension, retirement benefits, and the National Pension System.

Following the training, the distribution shifted noticeably toward higher scores, with approximately 9 participants achieving scores between 41 and 45-a range that had no representation in the pre-training assessment. This upward shift clearly demonstrates the positive effect of the training in enhancing participants' knowledge and readiness.

Figure 3 presents the percentages of gain for each participant in the Capacity Building Programme. Most participants showed meaningful improvements, with several registering gains exceeding 15%, reflecting substantial learning. A few participants achieved particularly high gains, indicating strong engagement and responsiveness, whereas some showed moderate improvements, likely due to differences in prior knowledge or individual learning pace.

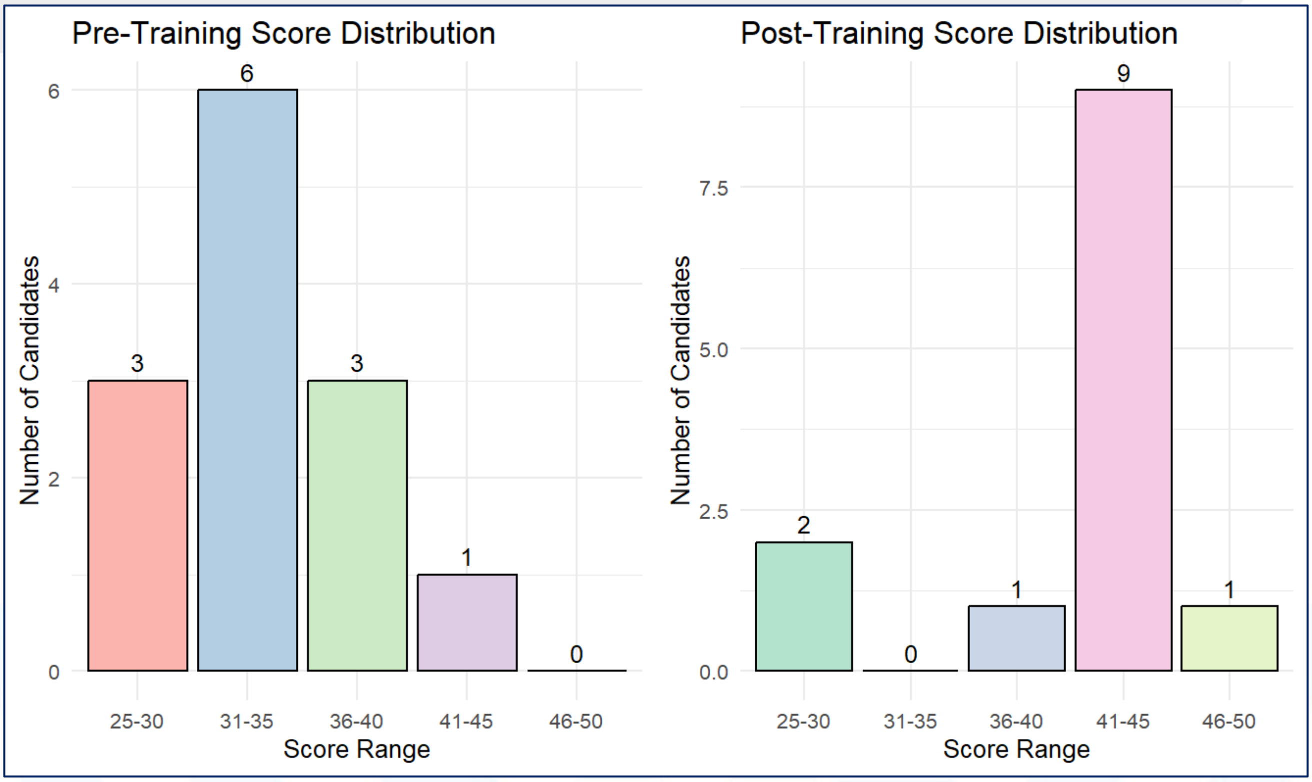

Figure 2: Distribution of the 13 participants across score ranges before and after the training program

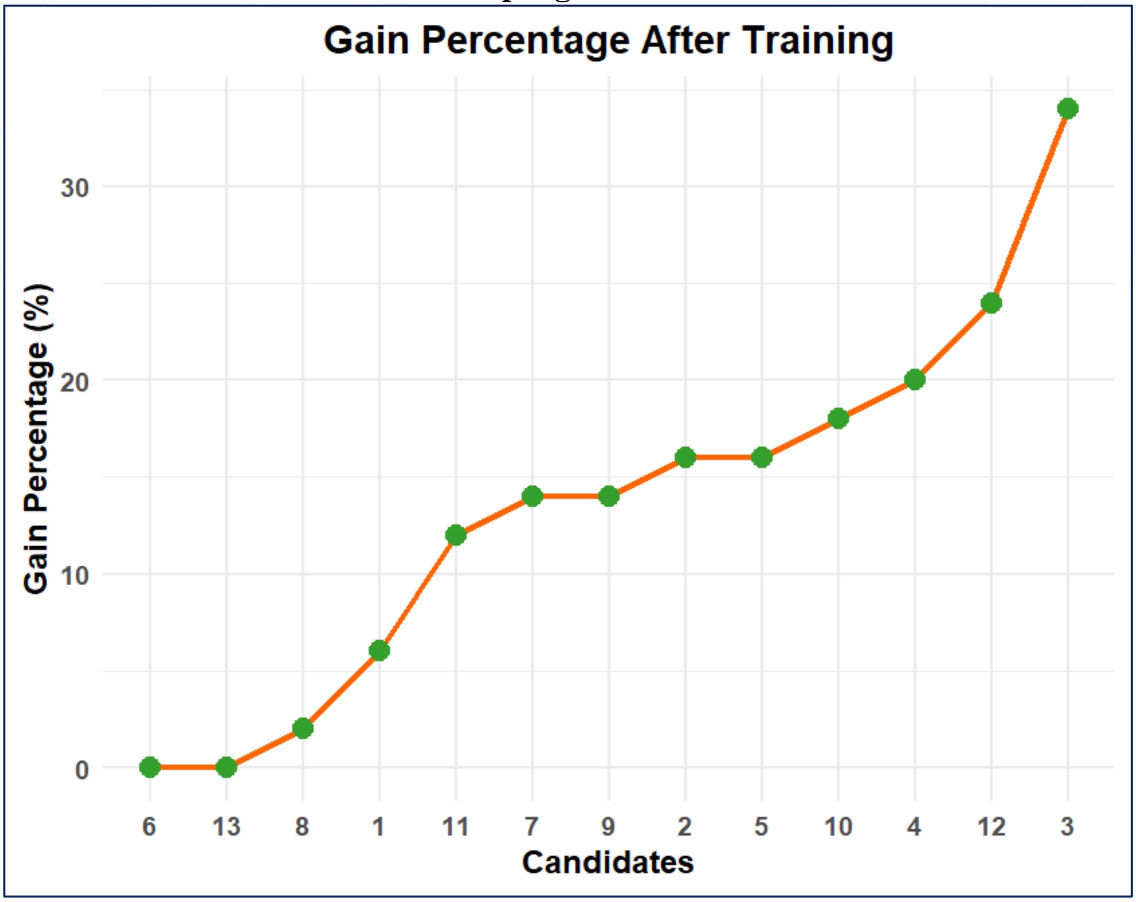

Figure 3: Candidates gain percentage plot

The violin plot and summary statistics (Figure 3) further illustrate the effect of the training. The mean score increased from 34.1 to 40.8, while the median rose from 34 to 42. Although most participants demonstrated improvement, the extent of gain varied, suggesting that some participants benefited more substantially from the training than others.

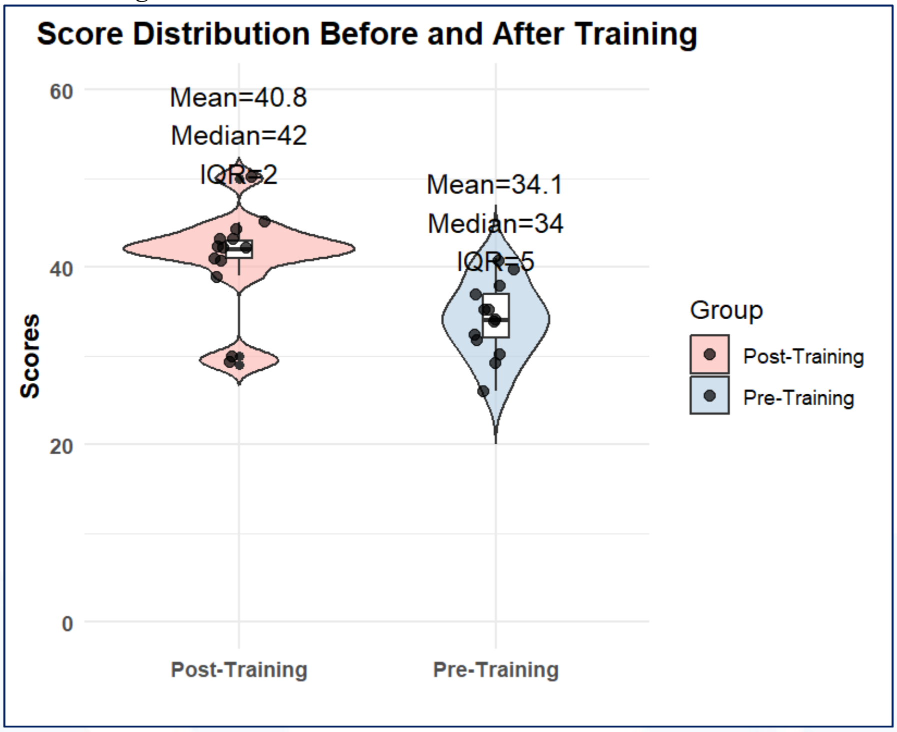

Figure 3: Box plot of distribution of scores before and after the training

A *paired t-test* confirmed a statistically significant improvement in the scores of the 13 administrative and finance officers *($t = -4.96$, $df = 12$, $p < 0.05$)*, demonstrating that the training effectively enhanced their understanding of pension administration, retirement benefits, and the National Pension System. Overall, the programme strengthened participants' knowledge, confidence, and readiness to apply improved administrative and financial practices in their roles.

Conclusion

The training programme significantly enhanced participants' knowledge of pension administration, retirement benefits, and the NPS. Paired t-test analysis confirmed a statistically significant improvement in scores, validating the effectiveness of the structured, interactive training. These findings underscore the importance of capacity-building initiatives in strengthening administrative and financial competency among ICAR personnel. The programme demonstrates that targeted training interventions can effectively prepare officers for accurate and efficient management of pension-related responsibilities, contributing to better service delivery for retired employees.

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Kokum: The Hidden Treasure of the Western Ghats

Article ID: 72571

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Introduction

Kokum (*Garcinia indica*) is an indigenous evergreen tree belonging to the family Clusiaceae, endemic to the Western Ghats of India and widely associated with the Konkan belt and adjoining humid regions. It is one of the important tree spices cultivated predominantly in the South Konkan region of Maharashtra, Western Ghats, Coorg, Wayanad, Gujarat, Goa, evergreen forests of Assam, Khasi and Jaintia hills. The crop is traditionally valued for the sun-dried rind of its fruit, locally known as 'amsul', its seed fat (kokum butter) and a range of bioactive compounds that support culinary, medicinal, nutraceutical and industrial applications (Baliga *et al*., 2011). Despite its long history of traditional use, kokum remains commercially underexploited due to limitations in systematic cultivation, availability of quality planting material, standardization and processing infrastructure. In recent years, increasing demand for natural acidulants, stable natural pigments, plant-based fats and functional bioactives has renewed scientific and commercial interest in kokum.

Botany

Kokum is a slender, medium-sized evergreen tree with drooping branches that gradually attain a pyramidal canopy at maturity. The species is predominantly dioecious, bearing male and female flowers on separate trees, though bisexual flowers may occasionally occur. Flowers are axillary or terminal, solitary or fascicled and are tetramerous and hypogynous. The calyx consists of four sepals, while the corolla has four petals that are yellow to pink on the dorsal surface and dark pink on the ventral surface. Male flowers possess long pedicels and numerous stamens forming a short capitate column, with oblong, sessile anthers that are usually four-celled. The pistil in male flowers is rudimentary, resulting in no fruit set. Female flowers have short pedicels, with staminodes arranged in four tufts around the pistil. The stigma is sessile and radiate, with each ray bearing two lines of tubercles, while the ovary is two to eight-celled with axile placentation. Bisexual flowers, when present, bear underdeveloped seeds. Anthesis in kokum occurs between 6:00 and 8:00 a.m., with anthers dehiscing just before anthesis. The stigma attains maturity one day prior to anthesis and receptivity reaches its peak of about 80 per cent on the day of anthesis. Natural open pollination results in approximately 68 per cent fruit set, whereas hand pollination enhances fruit set to nearly 78 per cent. Fruits are globose, dark red to purple when ripe and generally contain five to eight seeds embedded in the pulp.

Distribution, Ecology and Crop Significance

Kokum is closely associated with the Western Ghats biodiversity hotspot and adjacent humid tracts, where it grows in forest margins, home gardens and traditional agroforestry systems. The species is well adapted to high rainfall environments and performs well on lateritic and marginal soils, provided drainage is adequate. These characteristics make kokum a promising diversification crop for rainfed horticulture and climate-resilient farming systems (Desai *et al.*, 2022). Traditionally, its value chain has been centered on dried rind used as a souring agent, but emerging markets now include pigment-rich extracts and functional food ingredients.

Chemical Composition and Uses

The fruit rind of kokum contains substantial amounts of malic acid, along with smaller quantities of tartaric and citric acids, which impart the characteristic sour taste and preservative properties. Due to its acidity, kokum rind is widely used as a natural flavouring substitute and is traditionally employed as a fish preservative. The ripened rind and juice are commonly used in culinary preparations, especially for making Solkadi, a traditional digestive beverage consumed after meals in the Konkan region. Kokum syrup, popularly known as “Amrit Kokum”, is prepared from ripe fruits and has high market demand owing to its refreshing taste, cooling effect and digestive benefits. The deep red to purple colour of kokum rind is primarily due to anthocyanin pigments, particularly cyanidin-3-glucoside and cyanidin-3-sambubioside. These water-soluble pigments accumulate during fruit ripening and contribute significantly to the antioxidant capacity of kokum products (Nayak *et al.*, 2010). Owing to their stability under acidic conditions, kokum anthocyanins are considered promising natural food colourants, with reported pigment recovery of about 2-3 per cent from the fruit rind. Their potential applications include beverages, confectionery, dairy products and nutraceutical formulations. Kokum rind also contains hydroxycitric acid (HCA), an organic acid structurally related to citric acid. HCA is known to inhibit ATP-citrate lyase, an enzyme involved in fatty acid synthesis, thereby reducing lipid accumulation and supporting weight-management functions (Lim *et al.*, 2021). In addition, kokum rind contains garcinol, a fat-soluble yellow pigment with strong antioxidant and anti-inflammatory properties (Patra *et al.*, 2025). The combined presence of anthocyanins, HCA, garcinol and polyphenols contributes to kokum’s functional and nutraceutical potential. Seeds contain 32-35 per cent fat, commonly known as kokum butter. This fat is edible, nutritive, demulcent, astringent and emollient in nature (Nayak and Rastogi, 2010). Traditionally, kokum butter has been used for local application in ulcerations and fissures of the lips and hands. Owing to its excellent oxidative stability and favourable melting characteristics, it is widely used in pharmaceutical and cosmetic products, including creams, ointments, lip balms and soaps.

Varieties

Among the improved cultivars, Konkan Amritha, developed through clonal selection, is the most prominent variety of kokum recommended for commercial cultivation. It is an early-bearing variety with a short harvesting period of about 78 days, requiring only a few pluckings. The fruits are medium-sized with an average weight of 34.45 g and rind weight of 17.55 g. The variety yields about 138.28 kg of fruits per tree and is a pure female type, making it highly suitable for orchard cultivation when adequate male trees are maintained.

Climate and Soil Requirements

Kokum grows well on a wide range of soils, from marginal to deep alluvial soils, provided they are well drained. Lateritic soils of the Konkan belt are particularly suitable. The crop prefers a warm and moderately humid climate, with temperatures ranging from 20 to 35°C, relative humidity of 60-80 per cent and well-distributed annual rainfall of 2500-4000 mm.

Propagation and Inter-Cultural Operations

Propagation through seeds is the prevailing practice in kokum. Fresh, bold seeds collected from high-yielding and regular-bearing trees are cleaned and sown in polythene bags containing potting mixture.

Soaking seeds in water for two days prior to sowing improves germination up to 90 per cent. One-year-old seedlings are used for field planting. Vegetative propagation through softwood grafting has also been found successful, particularly during October, using 5-6 month old scion sticks and rootstocks older than 22 weeks. Grafting performed *in situ* results in higher survival and establishment. Planting is done at the onset of the monsoon with a spacing of 6 × 5 m, accommodating about 333 plants per hectare. Pits of 60 × 60 × 60 cm are dug and filled with well-decomposed farmyard manure and soil. Staking is provided immediately after planting. Young plants require partial shade during summer and winter months and irrigation once in a fortnight during dry periods for better establishment. Orchards should be kept clean through regular weeding. Kokum trees are generally not manured, which results in low productivity; however, recommended fertilization includes 5 kg FYM and 50:25:25 g $N:P_2O_5:K_2O$ in the first year, gradually increasing to 500:250:250 g $N:P_2O_5:K_2O$ by the tenth year. Fertilizers are applied in August in circular trenches below the canopy. Rainfed crops such as cucurbits, okra, and sweet potato can be grown as intercrops. Since kokum is dioecious, about 10 per cent male trees are retained for effective pollination, and excess male plants can be converted into female plants through top working.

Pests and Diseases

Kokum is relatively free from serious pests and diseases. Among pests, leaf miner is the most important, causing damage to tender leaves. Spraying 0.03 per cent phosphamidon or dimethoate has been found effective in controlling the infestation.

Harvesting and Yield

Seedling-raised trees commence bearing in 7-8 years, while grafted trees bear earlier, in 5-6 years. Flowering starts from October-November and continues upto February. Fruit harvesting begins in March and continues until the first fortnight of June, with peak harvest during April-May. Maturity is indicated by colour change from green to red or purple. Yield varies from 30 to 175 kg per tree, with productivity ranging from 10 to 52 tonnes per hectare.

Processing and Utilization

Kokum is processed into a wide range of value-added products. Dried green kokum rind is prepared by cutting immature fruits longitudinally and sun-drying them. Kokum syrup is prepared from ripe rind by adding cane sugar in a 1:2 ratio, straining and storing under hygienic conditions, often with sodium benzoate as a preservative. Dried ripe kokum rind is produced by repeated treatment with brined kokum juice followed by drying and is used as a substitute for tamarind in curries. Kokum agal, a brined juice prepared using fruit pulp or rind with common salt, is widely used for making Solkadi (Deore *et al*., 2011). Other products include anthocyanin pigments used as natural colourants and organic acids with potential medicinal applications.

Conclusion

Kokum is a high-value, climate-resilient indigenous tree spice with immense potential in culinary, medicinal, nutraceutical, pharmaceutical and cosmetic industries. The presence of anthocyanin pigments, hydroxycitric acid, garcinol, and kokum butter significantly enhances its functional importance. With scientific cultivation, improved propagation techniques, standardized processing and value addition, kokum can transition from a regionally important tree spice to a nationally and globally relevant functional crop.

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Comparison of Area of Different Food Grain Decade Wise of Maharashtra

Article ID: 72572
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Introduction

The area under food grain cultivation in Maharashtra has generally shown a **declining trend** over the past few decades, primarily due to shifts in cropping patterns towards commercial crops like sugarcane, cotton, fruits, and vegetables. Cereals like jowar and bajra have seen a significant decrease in area, while pulses and some oilseeds expanded during the 1990s and early 2000s.

Specific data points and trends are available from various government reports:

1. Dominance and Decline of Foodgrains: Food grain crops historically occupied more than 50% of the gross cropped area in Maharashtra. However, this share has consistently declined over time.

2. Shift from Cereals to Other Crops: The reduction in food grain area is largely attributed to the decrease in area under major cereals such as sorghum (jowar), bajra, and ragi. Jowar, once a dominating crop, has seen a significant decrease in consumption and area after 1983.

3. Increase in Commercial Crops: Areas under cash crops such as sugarcane and cotton, as well as fruits and vegetables, have registered an increase in share in the gross cropped area. The area under sugarcane, for instance, nearly tripled from 3.19 lakh hectares in 1980-81 to 10.22 lakh hectares in 2012-13, though it fluctuates annually.

4. Pulses and Oilseeds Trends: The area under pulses and oilseeds expanded in the 1990s and early 2000s, with soybean becoming prominent in oilseeds.

Table no -1 Decade wise Area of Kharif Cereals (Area in '000 ha) of Maharashtra:

Sr no	Crop	1960-61	1970-71	1980-81	1990-91	2000-01	2010-11	2020-21
1	Paddy	1299.60	1362.40	1458.60	1597.30	1486.40	1486.21	1472.68
2	Jowar	2548.60	2537.00	2970.70	2768.50	1910.00	1031.70	378.74
3	Bajra	1636.10	2038.70	1534.00	1940.40	1800.00	1034.60	687.50
	Maharashtra	**10604.00**	**10320.00**	**10975.80**	**11136.80**	**9824.30**	**8985.40**	**7079.34**

From the above table one can conclude that the area under cereal crop is continuously increasing trend from the year 1960-61 till 1990-92 and again declining stage from the year 2000-01 till the year 2020-21.

For paddy the area has shown increasing trend in area till 1990-91 and shown somewhat constant trend in year 2000-01 to 2010-11and again decreasing trend in 2020-21,

For Jowar area is somewhat decreasing from the year 1960-61 to 1970-71 again increasing trend in 1980-81 and then continuously decreasing trend form the year 2000-01 till 2020-21.

For Bajra area increased in 1970-71 as compared to 1960-61 again decreased in 1980-81 and again increased in the year 1990-91, again decreased continuously from 2000-01 till 2020-21.

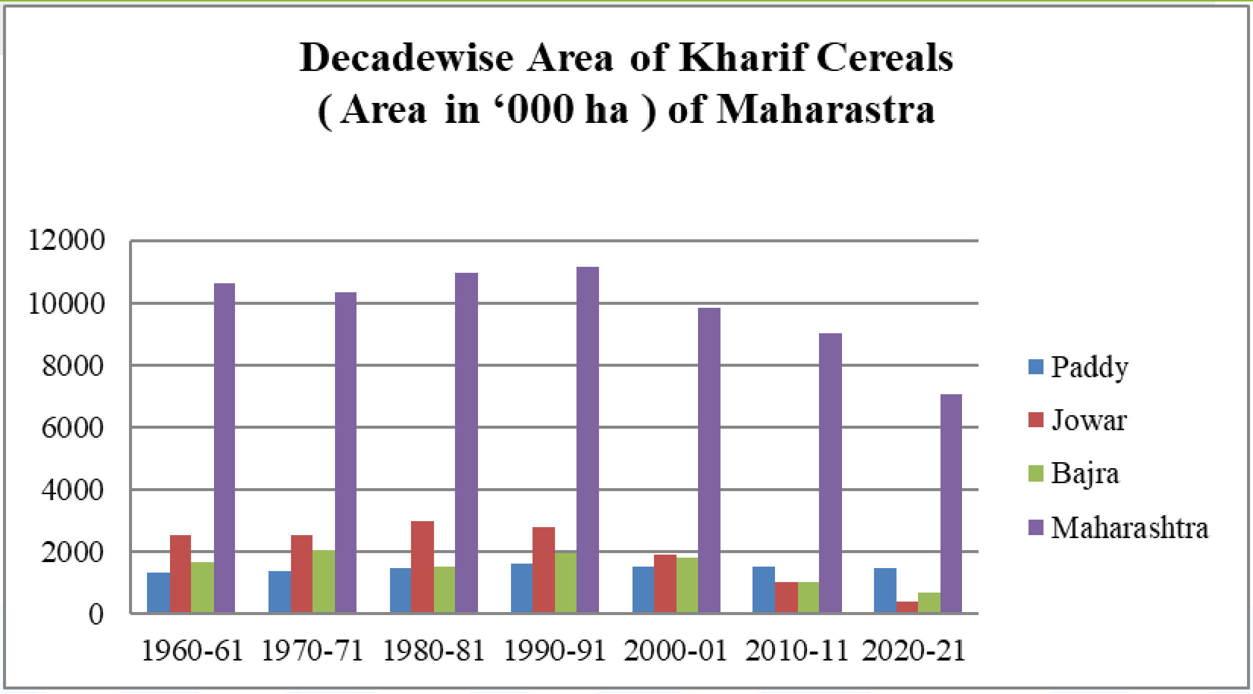


Table no -2 Decade wise Area of Pulses (Area in '000 ha) of Maharashtra:

Sr no	Area of Pulses	1960-61	1970-71	1980-81	1990-91	2000-01	2010-11	2020-21
	Maharashtra	2361.30	2566.30	2716.30	3257.30	3557.20	4037.66	4594.58

From the above table one can conclude that the area under Pulse l crop is continuously increasing trend from the year 1960-61 till the year 2020-21.

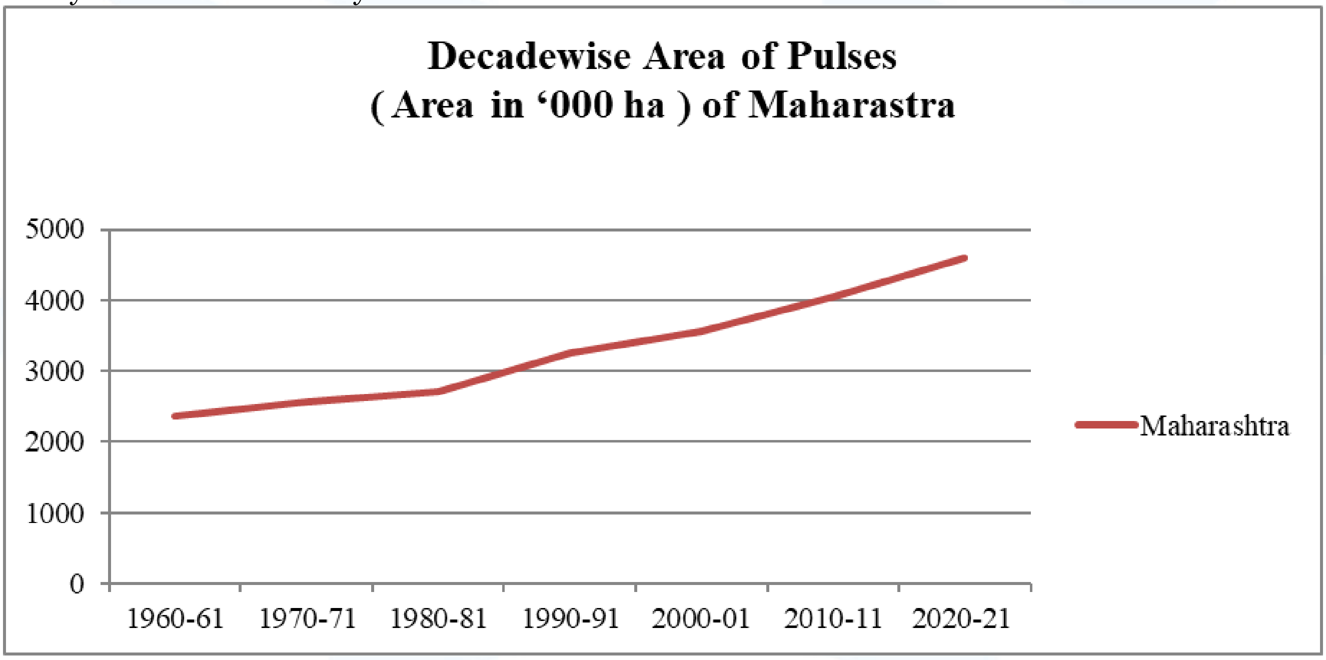
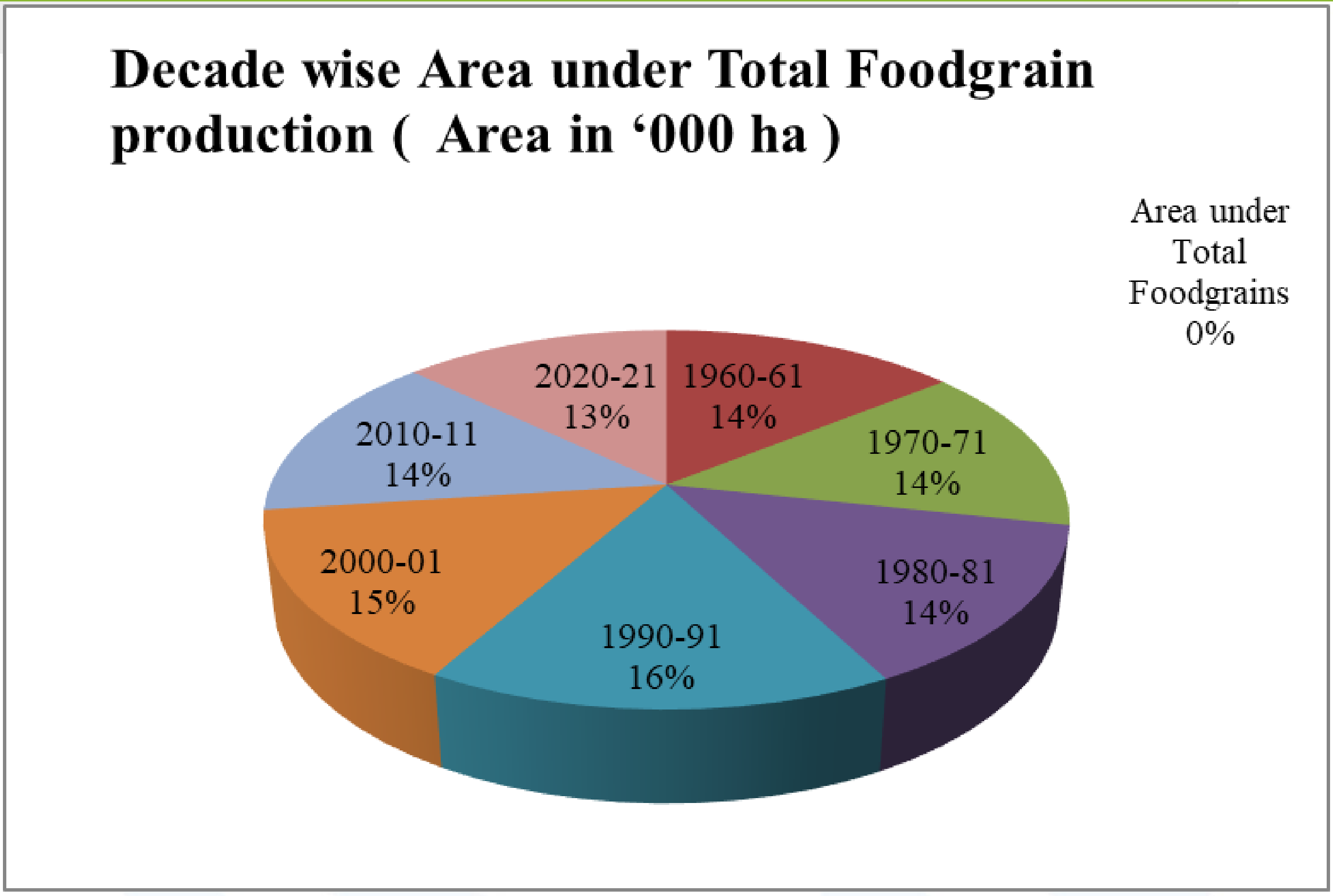


Table no -3 Decade wise Area under Total Foodgrain production (Area in '000 ha):

Sr no	Area under Total Foodgrains	1960-61	1970-71	1980-81	1990-91	2000-01	2010-11	2020-21
	Maharashtra	12955.30	12886.30	12691.10	14393.10	13381.50	13023.06	11673.92

From the above table one can conclude that the area under total food grain crop is continuously increasing trend from the year 1960-61 till 1990-92 and again declining stage from the year 2000-01 till the year 2020-21.



Conclusion

The primary conclusion regarding the area of different food grains in Maharashtra over recent decades is a **shift in cropping patterns away from traditional food grains (especially coarse cereals like jowar and bajra) towards commercial cash crops** such as sugarcane, fruits, vegetables, and oilseeds like soybean. While the overall production of food grains has increased due to improved productivity (yield per hectare), the total area dedicated to them has largely stagnated or declined.

1. Overall Food Grain Area Decline/Stagnation: The total area under food grains in Maharashtra has generally decreased or shown only a slow, fluctuating growth rate over several decades, such as from 1980-81 to 2011-12.

2. Shift from Coarse Cereals: A significant trend has been the sharp decline in the area used for coarse cereals (jowar, bajra) since the 1970s and 1980s. For example, the area under rabi sorghum (jowar) showed a notable decreasing trend into the late 2010s.

3. Increase in Commercial Crops: The land area previously used for food grains has been increasingly diverted to commercial and horticultural crops due to factors like increased irrigation facilities, market demand, and government programs.

- **a. Sugarcane** has seen a tremendous and significant increase in area, especially where irrigation is available.
- **b. Oilseeds, particularly soybean**, have also seen a massive increase in cultivated area in recent decades, replacing some traditional crops like groundnut and jowar.

4. Pulses Area Fluctuations: The area under total pulses has varied, with some crops like chickpea and pigeon pea (tur) showing an increase in area and production in recent decades, while others have declined.

5. Productivity Improvements: Despite a declining or static area, the total production of food grains has often increased due to the adoption of high-yielding varieties, better inputs (fertilizers, pesticides), and improved technology (part of the Green Revolution effect), which increased the yield per hectare.

Maharashtra's agricultural land use has commercialized over the decades, prioritizing high-value and cash crops over traditional food grains, while relying on yield improvements to maintain food production levels.

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Cold Weather Impact on Vegetable Crops: Rising Pest and Disease Challenges for Farmers

Article ID: 72573

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Introduction

The winter season is generally considered favourable for many vegetable crops in India, particularly in states such as Telangana, Andhra Pradesh, Karnataka, and Maharashtra. Low temperatures during winter typically enhance crop quality, improve pigment formation, and increase the shelf life of produce. However, in recent years, farmers have been reporting an unusual trend a rise in pest and disease outbreaks despite the otherwise favourable cool-season conditions. These unexpected infestations are contributing to significant economic losses and threatening vegetable productivity across the region.

Vegetable crops play a vital role in global nutrition, rural employment, and farm income. Yet, they are highly susceptible to climatic fluctuations. Among the various environmental stresses, cold weather comprising chilling, near-freezing temperatures, fog, and prolonged dew periods exerts profound impacts not only on plant physiology but also on pest and pathogen behaviour. These interactions often create microclimates that favour disease development and pest survival, ultimately increasing the vulnerability of crops to biotic pressures. Cold weather stress is therefore not just about reduced plant growth. It fundamentally alters the ecology of pathogens and insects. Sudden cold waves extended foggy mornings, and high relative humidity during early hours create ideal conditions for rapid spread of fungal and bacterial diseases. Simultaneously, low temperatures slow down the plant's immune response, weaken cell walls, and suppress natural defence mechanisms, making crops more susceptible to infections.

This article synthesizes scientific literature on the effects of cold weather on major vegetable diseases powdery mildew (PM), downy mildew (DM), late blight, and wilt diseases. It also examines the behaviour of South American tomato pinworm (Tuta absoluta) under low-temperature conditions and explains why chemical control measures are becoming increasingly ineffective under modern climatic variability.

Cold Weather and Vegetable Physiological Stress

Vegetable crops perceive low temperature through molecular and physiological signalling pathways that regulate membrane stability, enzyme function, and immune activation. Chilling or freezing stress causes: Membrane rigidification and electrolyte leakage, making tissues more prone to pathogen entry. Suppressed photosynthesis due to inhibited chloroplast activity. Accumulation of reactive oxygen species (ROS), weakening natural defense mechanisms. Reduced synthesis of defense molecules such as phenolics, phytoalexins, and antioxidant enzymes. Cold stress delays flowering, slows cell division, prolongs leaf wetness due to dew or frost, and alters canopy moisture dynamics. These plant-level disruptions provide ideal conditions for diseases to establish more aggressively than under moderate temperatures. In species like tomato, brinjal, chilli, cucurbits, and leafy vegetables many of which are inherently sensitive to chilling cold stress becomes the foundation for enhanced infection risk.

Disease Dynamics Under Cold Weather

Cold weather does not merely increase disease incidence; it fundamentally reshapes pathogen biology, survival, and host pathogen interactions.

Powdery Mildew and Downy Mildew: PM fungi (Erysiphe, Podosphaera, Leveillula) and DM oomycetes (*Pseudoperonospora, Peronospora spp.*) exploit cool, humid environments. Winter conditions increase disease pressure by: Extending leaf wetness duration due to long dew/frost deposition. Increasing relative humidity around plant surfaces, enhancing spore germination. Reducing host tissue immunity, enabling faster colonization. Prolonging spore viability, allowing rapid secondary spread. In cucurbits, tomato, onion, and leafy vegetables, cool nights (<15 °C) followed by mild days frequently trigger early and severe PM and DM outbreaks.

Late Blight (*Phytophthora infestans*): Late blight thrives under cool (12–18 °C), moist conditions and remains one of the most destructive diseases of potato and tomato. Cold spells contribute by: Enhancing sporulation and sporangia release under high humidity. Increasing leaf wetness from fog and dew, facilitating infection. Weakening leaf tissues through cold-induced injury, making them more susceptible. A single cold, humid night can initiate explosive late blight development, leading to rapid field collapse.

Wilt Diseases: Although wilt pathogens such as *Fusarium oxysporum, Verticillium dahliae*, and *Ralstonia solanacearum* prefer warm soils, cold weather creates indirect pathways for infection: Chilled soils weaken roots and slow nutrient uptake. Cold-induced micro-cracks facilitate pathogen entry. Waterlogging from winter irrigation increases root stress. Cold-tolerant strains like *Ralstonia solanacearum* race 3 biovar 2 can persist even in low-temperature conditions. Thus, winter can inadvertently increase wilt incidence once temperatures rise.

Tuta absoluta and Cold Weather Adaptation

The South American tomato pinworm, *Tuta absoluta*, is capable of causing up to 100% yield loss if unmanaged. Cold temperatures influence its biology in several ways: Larvae survive cold by entering a quiescent or slow-metabolism state. Pupae in soil or plant debris are insulated and capable of overwintering. Adults seek protected microhabitats (greenhouses, residues, volunteer plants). Cold slows its development but does not prevent survival, enabling rapid population resurgence when temperatures rise. Cold seasons often weaken natural enemies more than the pest itself, contributing to winter and early-spring flare-ups.

Why Chemical Controls Fail Under Cold Stress?

Farmers often report that pesticides are not working during winter. Multiple scientific factors contribute to this declining efficacy:

Temperature-Dependent Chemical Activity: Systemic fungicides move poorly through cold plant tissues. Insecticides show reduced penetration when pest metabolism is slow. Low temperatures extend dew duration, diluting spray deposits.

Increased resistance development: Repeated use of similar chemical groups particularly in *T. absoluta* and PM/DM pathogens selects for resistant strains. Cold stress further accelerates resistance by reducing natural enemies and enabling survival of resistant individuals during overwintering.

Misapplication under cold conditions: Spraying during fog or dew leads to poor adhesion. Cold-stressed crops absorb chemicals inefficiently. Morning and evening sprays often fail due to high humidity and slow drying.

Ecological disruption and pest resurgence: Broad-spectrum pesticides destroy parasitoids and predators (Trichogramma, Chrysoperla, ladybird beetles), while cold weather suppresses beneficial insects even further, enabling pest resurgence.

Environmental effects: Cold soils alter chemical breakdown, mobility, and runoff patterns, reducing effective dose availability.

Integrated Perspectives and Future Directions

Given the complexity of cold-induced pest–disease interactions, climate-smart plant protection is essential.

Resistant and Cold-Tolerant Varieties: Breeding programs must integrate low-temperature tolerance with disease resistance.

Microclimate Management: Mulching, row covers, windbreaks, and protected cultivation reduce chilling injury and humidity accumulation.

Need-Based Chemical Use: Rotate FRAC and IRAC-classified molecules, prefer mid-day spraying during winter months, avoid chemical use during dew, fog, or freezing conditions.

Biological Control and Soil Health: Use of Trichoderma, Bacillus, Pseudomonas, parasitoids, and predatory insects supports ecological resistance.

Weather-Based Forecasting: Late blight and DM forecasting models, pheromone traps, and disease monitoring systems enhance decision-making.

Conclusion

Cold weather significantly alters the physiology of vegetable crops, reshapes pathogen ecology, and enhances the survival and adaptability of pests like Tuta absoluta. Diseases such as powdery mildew, downy mildew, late blight, and wilt show increased intensity under cool, humid microclimates created by fog, dew, and temperature fluctuations. Simultaneously, pesticide failures are becoming common due to resistance development, poor absorption in cold-stressed plants, unfavorable weather conditions during application, and ecological imbalance. A holistic, research-driven, climate-adaptive strategy combining resistant varieties, microclimate management, biological control, forecasting tools, and precise chemical interventions is now essential for sustainable vegetable production under increasingly unpredictable winter conditions.

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Climate Smart Vegetable Production: Strategies for Sustainable Yield, Nutritional Security and Resilience

Article ID: 72574

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Vegetable production plays a crucial role in fulfilling nutritional needs, enhancing rural incomes and supporting sustainable food systems globally. However, climate change through drought, heat, erratic rainfall and increased pest as well as disease pressure poses significant threats to vegetable productivity and quality. Climate Smart Vegetable Production (CSVP) integrates resilient cultivars, efficient water and nutrient management, protected cultivation systems, smart technologies and adaptive agronomy to sustain yields under climate risk. This article synthesizes key CSVP approaches, focusing on recent scientific advances in stress mitigation, resource efficiency and resilience building. Emphasis is placed on physiological, agronomic and technological strategies that can enhance vegetable production for nutritional security and climate resilience.

Introduction

Vegetable crops contribute essential vitamins, minerals, antioxidants and fiber to human diets, supporting both nutrition security and economic livelihoods. Yet, these crops are highly sensitive to climate variability because they depend on stable agro-climatic conditions for flowering, fruiting and yield formation. Rising temperatures, increased drought frequency and unpredictable rainfall disrupt plant physiological processes, leading to yield loss and quality deterioration. With global climate trends showing increased frequency of stress events, sustainable vegetable production systems require strategic interventions that go beyond traditional agronomy. Climate Smart Vegetable Production seeks to simultaneously improve productivity, enhance system resilience and optimize resource use efficiency.

Impact of Climate Change on Vegetable Crops

Climate change affects vegetables in multiple ways:

Temperature and Drought Stress: Drought and heat stress are major constraints; they disrupt photosynthesis, nutrient uptake and reproductive development. Recent scientific reviews highlight the increasing impact of drought stress on physiological and biochemical processes in vegetables, showing how water deficits impair growth and yield formation under warming climates.

Water Stress and Resource Constraint: Water scarcity influences both root function and canopy development, leading to lower water use efficiency and higher vulnerability to heat and oxidative stress. Integrating efficient irrigation with stress adaptive practices is critical for stable production.

Core Climate-Smart Strategies in Vegetable Production

Climate Responsive Agronomic Practices: Smart irrigation scheduling and protected cultivation have emerged as essential tools for managing moisture stress and microclimate conditions. Research on high-value vegetable production demonstrates how optimized irrigation regimes under protected structures improve water use efficiency and yield stability in challenging environments like hot arid regions. Protected cultivation (e.g., greenhouse, polyhouse) creates a controlled microclimate that protects crops from extreme temperatures and rainfall variability, enabling off-season production and improved produce quality.

Smart and Precision Water Management: Smart irrigation systems that use soil moisture sensors and precision scheduling reduce drought impacts and optimize water application. Precision watering aligns crop demand with irrigation closely, limiting waste and improving physiological responses. Notably, irrigation system optimization under controlled environments has shown tangible benefits in vegetable production under water stress scenarios.

Integrated Stress Mitigation Techniques

Abiotic stress mitigation requires a combination of genetic, cultural and technological innovations:

1. Physiological and biochemical tolerance mechanisms: Understanding plant stress responses, such as antioxidant enzyme activation and signal transduction networks, provides a basis for selecting climate-adaptive strategies.

2. Biostimulants and smart inputs: Applications of biostimulants, plant growth regulators and microbial products can improve stress tolerance and nutrient uptake efficiency.

Grafting and Innovative Cultivation Methods

Recent research and institutional studies highlight grafting as a potent climate-smart tool to improve resilience and productivity. When grafted onto tolerant rootstocks and grown under protected cultivation systems, vegetable plants exhibit improved vigor, enhanced resistance to climate stressors and significant yield gains. This integration of grafting with protected microclimates represents a scalable innovation for smallholder and commercial systems alike.

Adoption of Smart Technologies

Digital and precision tools such as real-time climate monitoring, decision support systems, and automated irrigation help producers anticipate stress events and manage crops proactively. These systems enhance decision accuracy and resource use.

Climate Smart Vegetable Production and Nutritional Security

Vegetables are critical sources of micronutrients essential for human health. Climate-induced yield and quality declines can exacerbate micronutrient deficiencies globally. CSVP approaches that stabilize yields and maintain quality under climatic stress therefore play a direct role in improving dietary diversity and nutritional outcomes.

Challenges and Future Prospects

Despite clear benefits, CSVP adoption faces barriers such as high initial investment, technical complexity and limited access to knowledge in resource-constrained regions. Policy incentives, farmer training and research focus on cost-effective technologies are necessary to expand uptake. Future research priorities include:

1. Development of heat- and drought-tolerant cultivars
2. Optimization of protected cultivation designs for diverse climates
3. Integration of IoT and AI for real-time stress prediction
4. Evaluation of combined strategies under field conditions.

Conclusion

Climate-Smart Vegetable Production offers a pathway to achieve sustainable yields, improved resource efficiency and enhanced resilience to climatic challenges. By combining agronomic innovation, resource optimization, technological adoption and stress mitigation strategies, vegetable production systems can sustain productivity and contribute to nutritional security in a changing climate. Strengthening research collaborations and extension networks will be essential for scaling and adoption across diverse agro-ecosystems.

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The Rise of Millets After the International Year of Millets (2023)

Article ID: 72575

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Abstract

Millets, once marginalized by the dominance of rice and wheat, are regaining prominence in India as nutritious, climate-resilient grains. Following the United Nations' declaration of 2023 as the International Year of Millets, India has strengthened its leadership as the world's largest producer and exporter. The domestic market, valued at 17.25 million metric tons in 2023, is projected to grow at a CAGR of 6.5% during 2025–2031, driven by rising health awareness, demand for plant-based proteins, and gluten-free alternatives. Government initiatives, industry innovation, and cultural revival have expanded millet consumption across urban households, schools, restaurants, and global markets. Despite challenges in processing, infrastructure, and pricing, millets are increasingly recognized as the grains of the future, offering sustainable solutions for nutrition, rural livelihoods, and food security.

Introduction

Millets, once dismissed as "poor man's food," are making a strong comeback as key components of sustainable and healthy diets. For centuries, they sustained Indian civilizations by thriving in harsh soils, feeding millions, and shaping diverse regional cuisines. However, the Green Revolution and the dominance of polished rice and wheat gradually pushed millets out of the mainstream, confining their consumption by the 1990s mainly to drought-prone rural areas. This trend has reversed dramatically in recent years, particularly after the United Nations declared 2023 as the International Year of Millets (IYoM), an initiative led by India, the world's largest millet producer. The global spotlight, coupled with growing awareness of their nutritional richness, climate resilience, and policy support, has reintroduced millets into urban diets, school meal programmes, restaurants, and export markets. No longer relics of the past, millets are now being recognized as vital foods for the future of sustainable and resilient food systems.

India's Millet Leadership

India is the world's largest producer of millets, contributing over 38.4% of global production. The country grows a diverse range of millets- from the widely consumed bajra, jowar, and ragi to the nutritionally rich foxtail, barnyard, kodo, proso, and little millets.

Table1. Top Producing Countries:

Market	% of Global Production	Total Production (2024/2025, Metric Tons)
India	38.4%	11.57 million
Niger	13%	3.84 million
China	9%	2.7 million
Mali	7%	1.99 million
Nigeria	5%	1.55 million
Ethiopia	4%	1.13 million
Senegal	4%	1.1 million
Burkina Faso	3%	800,000
Sudan	3%	793,000
Chad	2%	619,000

USDAFAS-2025

Table 2. Major Producing States:

State	Share of National Production (%)	Key Notes
Rajasthan	27	India's millet powerhouse; major producer of pearl millet (bajra) and sorghum (jowar)
Karnataka	18	Leading state in finger millet (ragi) cultivation
Maharashtra	14	Strong in sorghum (jowar) and finger millet production
Uttar Pradesh	12	Focused largely on pearl millet (bajra) and sorghum (jowar)
Gujarat	7	Primarily cultivates pearl millet (bajra) and sorghum (jowar)

Millets Go Global: India's Export Boom

India has emerged as the largest exporter of millets, with shipments rising sharply after IYoM 2023. Key destinations include the USA, Japan, UAE, Nepal, and Europe. Global demand is driven by interest in ancient grains, sustainable agriculture, and gluten-free diets. Millets have become a symbol of India's soft power in food diplomacy.

Table 3. Millet Consumption Trends in India (2015–2025):

Year	Average Per Capita Consumption (kg/year)	Key Drivers
2015	~2.5	Decline due to preference for rice/wheat under PDS subsidies
2016–2018	~2.6–2.8	Slight stabilization; niche rural consumption
2019	~3.0	Early awareness campaigns by NGOs and state governments
2020	~3.2	COVID-19 boosted demand for immunity-enhancing foods
2021	~3.5	Rising urban health consciousness; packaged millet products
2022	~3.8	Government schemes promoting millets in midday meals and PDS
2023	~4.1	*International Year of Millets* declared by UN; major awareness push
2024	~4.2	Expansion of millet exports and processed food industry
2025	~4.3	Sustained demand in urban households; growing global recognition

India Millets Market Overview

According to 6Wresearch internal database and industry insights, the India Millet Market is expected to grow at a CAGR of 6.5% during 2025-2031. The key factors driving this growth are the increase in awareness about the health benefits of millets, the rising demand for plant-based protein sources, and the growing trend of millets as a gluten-free alternative to wheat and rice.

Growth Factors for India Millet Industry

1. Growing awareness of the nutritional benefits of millets as a healthy grain alternative.
2. Growing demand for plant-based protein sources due to changing dietary habits.
3. Expansion of the organic millet segment as a result of the demand for pesticide-free products.
4. The growing popularity of millets in processed product segments, such as snacks and breakfast cereals.

India Millet Market Trends

The India Millet Market is experiencing several emerging trends, such as the use of millets in ready-to-eat and processed foods. Consumers are switching to gluten-free alternatives, and millets appeal to a healthier diet that emphasises cutting down on wheat. Another evolving trend is for more organic and sustainable millet farming, with government initiatives focusing on health benefits and its adaptive use as a cooking ingredient.

Emerging Developments in the India Millet Market

The India Millet Market is witnessing a rise in the production of ready-to-eat millet-based snacks, with companies exploring new product lines like millet-based breakfast cereals and flour. The demand for organic millets is also increasing due to their nutritional benefits and minimal pesticide usage.

Additionally, government programs are enhancing millet production and distribution, further boosting market growth. The expansion of millet products into international markets is expected to drive additional opportunities.

India's millets market has witnessed remarkable growth, reaching 17.25 million metric tons in 2023, driven by rising awareness of their health benefits, diversification of millet-based products, and increasing adoption in urban diets. Prominent players such as Sresta Natural Bioproducts Pvt. Ltd. (24 Mantra Organic), Organic Tattva, Sri Lakshmi Venkatramana (SLV) Industries, Earthon Products Pvt. Ltd., and Patanjali Ayurved Ltd. have expanded their distribution networks, invested in brand-building, and introduced innovative products to capture market share. In April 2023, Britannia became the first company in the organized segment to launch millet bread, aligning with the government's push during the United Nations-declared International Year of Millets. The government has allocated substantial funds to strengthen the sector, with Odisha alone investing over INR 2,500 crores to support farmers, while the Ministry of Agriculture and Farmers Welfare promotes sustainable practices, awareness campaigns, and value chain development. This revival has boosted rural incomes, spurred culinary innovations, and diversified consumer diets. Karnataka, benefiting from favourable climatic conditions, strong traditions of millet cultivation, and schemes such as "Raitha Siri," continues to dominate national production (Ken Research, 2024).

Why Millets are Making a Comeback?

1. A Nutritional Powerhouse: Millets are packed with dietary fiber, iron, calcium, magnesium, antioxidants, and plant-based protein. Their low glycemic index makes them ideal for managing diabetes, obesity, and hypertension—lifestyle diseases that are rising sharply in India. Unlike refined cereals such as polished rice and wheat, millets provide slow-release energy and essential micronutrients, making them a wholesome alternative for health-conscious consumers. Nutritionists increasingly recommend millets as part of balanced diets, and urban households are rediscovering their value in everyday meals.

2. Climate-Smart Crops: Beyond nutrition, millets are climate-resilient crops that require 70% less water than rice, thrive in drought and heat, grow in poor soils, and mature quickly within 60–90 days. As climate change intensifies and water scarcity threatens food security, millets offer a sustainable solution for both farmers and consumers. Their adaptability makes them vital for semi-arid regions, ensuring livelihoods while reducing dependence on resource-intensive crops.

3. Government Push: India has taken strong steps to revive millets. They are now included in the Mid-Day Meal Scheme and Integrated Child Development Services (ICDS), ensuring children benefit from their nutrition. Minimum Support Prices (MSP) for major millets provide farmers with income security, while millet-based startups are supported through Farmer Producer Organizations (FPOs). Promotion through G20 events, global exhibitions, and branding campaigns during the United Nations-declared *International Year of Millets (2023)* has boosted both production and consumption. States like Odisha have invested over INR 2,500 crores in millet missions, while Karnataka's "Raitha Siri" scheme has strengthened farmer participation.

4. Market Expansion & Food Industry Innovation: The food industry has embraced millets with enthusiasm. From noodles, pasta, cookies, and snacks to ready-to-eat mixes, millet beverages, flour blends, and restaurant menus, innovation is reshaping how millets are consumed. Startups and FPOs are building vibrant value chains, while established FMCG companies like ITC and Britannia have launched millet-based products, including millet bread in 2023. Export demand is also rising, with India emerging as a global leader in millet trade.

5. Changing Consumer Preferences: Post-COVID, consumers are seeking immunity-boosting foods, sustainable diets, and local traditional grains. Millets fit perfectly into this shift, offering both health and heritage. Urban millennials and Gen Z are increasingly experimenting with millet-based recipes, while fitness enthusiasts embrace them as part of high-protein diets.

6. Millets in Indian Kitchens: A Cultural Revival: Millets have always been part of India's culinary heritage—ragi mudde in Karnataka, bajra roti in Rajasthan, and jowar bhakri in Maharashtra are iconic dishes. Today, chefs are reinventing these grains in modern forms: millet pizza bases, millet dosa, laddoos,

biryani, and breakfast cereals. This blend of tradition and innovation is making millets appealing to younger generations, bridging the gap between heritage and modern lifestyles.
Climate-Smart

Challenges Ahead

Despite the momentum, challenges remain. Processing infrastructure is limited, consumer awareness is uneven across regions, and value-added millet products often cost more than subsidized rice and wheat. Storage and supply chains need strengthening to prevent post-harvest losses. Addressing these gaps will be crucial to sustain the millet revolution and ensure equitable access.

The Road Ahead

The comeback of millets is more than a dietary trend- it is a movement toward healthier lives, resilient farming, and sustainable food systems. With government support, industry innovation, and consumer acceptance, millets are poised to become central to India's food security strategy and a global model for climate-smart nutrition.

Conclusions

Millets are making a strong comeback because they are healthy to eat, easy to grow, and good for the planet. They help fight lifestyle diseases, support farmers in dry regions, and fit well with modern food trends. With government support, new products from food companies, and growing interest from consumers, millets are set to play a big role in India's diet and economy. These ancient grains are truly the grains of the future bringing better health, stronger rural incomes, and more sustainable food systems.

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AI (Artificial Intelligence) in Plant Breeding

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Abstract

Artificial Intelligence (AI) is increasingly being integrated into plant breeding to overcome the limitations of conventional breeding approaches, which are often time-consuming and resource-intensive. Advances in high-throughput genotyping, phenotyping, and environmental data collection have generated large and complex datasets that are difficult to analyze using traditional statistical methods alone. AI techniques, including machine learning and deep learning, enable efficient integration and analysis of these datasets to predict plant performance, identify superior genotypes, and accelerate breeding decisions. Applications of AI in plant breeding include genomic selection, automated phenotyping, gene–trait association analysis, and support for gene-editing strategies. By improving prediction accuracy and reducing breeding cycles, AI enhances the efficiency, precision, and scalability of crop improvement programs. As global agriculture faces challenges from climate change, population growth, and resource constraints, AI-driven plant breeding offers a promising pathway toward developing high-yielding, resilient, and sustainable crop varieties.

Introduction

Plant breeding plays a crucial role in improving crop productivity, quality, and resilience to biotic and abiotic stresses. However, conventional breeding approaches are often slow and require extensive field trials over multiple years. The increasing availability of large-scale genomic, phenotypic, and environmental data has created new opportunities for advanced data-driven breeding strategies. In this context, Artificial Intelligence (AI) has emerged as a transformative tool that enhances the efficiency and precision of modern plant breeding programs.AI refers to computational techniques such as machine learning (ML) and deep learning (DL) that enable systems to learn from data and make predictions.

Key Roles of AI in Plant Breeding

1. Genomic Selection and Prediction:

a. AI models (e.g., deep learning, random forests, support (vector machines) analyze massive genomic datasets to predict how genetic variations affect traits.
b. Helps breeders select superior genotypes without lengthy field trials.
c. Example: Predicting yield or drought resistance from genomic markers.

2. Phenotyping (Trait Measurement):

a. Computer vision and machine learning enable automated analysis of plant images (from drones, satellites, or lab imaging).
b. Can assess traits like plant height, leaf area, color, or disease symptoms rapidly and accurately.
c. Reduces manual scoring errors and speeds up large-scale screening.

3. Genotype-to-Phenotype Modeling:

a. Deep neural networks model complex, non-linear relationships between genotype, environment, and phenotype.
b. Helps in understanding gene-environmental interactions and predicting performance under climate change.

4. Accelerating Hybrid Development:

a. AI optimizes parental selection by predicting hybrid performance before crossbreeding.
b. Facilitates heterosis prediction and genomic-assisted mating designs.

5. Precision Agriculture Integration:

a. AI combines field sensor data (soil moisture, nutrient levels) with plant genomics to fine-tune breeding targets.
b. Links breeding programs with on-farm performance data for real-world adaptability.

Technologies Involved

Area	AI/ML Technique	Application
Genomic Prediction	Deep learning, Random forest, Bayesian models	Trait prediction from SNPs
Image Analysis	CNNs (Convolution Neural Networks	Disease detection, growth monitoring
Environment Modeling	Reinforcement learning, GNNs	Predicting stress responses
Data Integration	Multi-omics AI frameworks	Combining genomics, transcriptomics, phenomics
Data Integration	Multi-omics AI frameworks	Combining genomics, transcriptomics, phenomics
Decision Support	Expert systems	Guiding breeders on cross selection

India Millets Market Overview

According to 6Wresearch internal database and industry insights, the India Millet Market is expected to grow at a CAGR of 6.5% during 2025-2031. The key factors driving this growth are the increase in awareness about the health benefits of millets, the rising demand for plant-based protein sources, and the growing trend of millets as a gluten-free alternative to wheat and rice.

Benefits

1. Speeds up breeding cycles
2. Reduces costs of field trials and genotyping
3. Improves accuracy in selecting top-performing genotypes
4. Enhances climate resilience by simulating future conditions
5. Facilitates discovery of novel genes and traits.

Challenges

1. Data quality and standardization inconsistent datasets across environments
2. Limited labeled phenotypic data for AI training
3. Interpretability of deep learning models (black-box issue)
4. Infrastructure needs computational power, data storage
5. Integration between breeders, data scientists, and agronomists.

Future Directions

1. AI-driven autonomous breeding platforms using robotics and real-time phenotyping
2. Federated learning for sharing models without sharing sensitive data
3. Generative AI to simulate breeding outcomes or create synthetic training data
4. Integration with CRISPR gene editing to design optimal allelic combinations

Here are three real-world case studies illustrating how AI is used in plant breeding —

1. International Rice Research Institute (IRRI) / CGIAR – Hybrid Rice Breeding & Genebank Screening:

What they did

a. IRRI launched a new "Global AI-Hybrid Rice Platform" (GAI-HRP) which uses AI/ML to interrogate decades of hybrid rice trial data plus parental SNP (genetic) data, to predict optimal parental combinations for high-yielding hybrids tailored to environments.

b. In addition, IRRI's genebank used AI tools to screen huge numbers of rice accessions for flood and drought tolerance (an example: 60,000 samples screened in one year) rather than decades via traditional methods.

Achievements & significance:

a. The hybrid platform speeds up the otherwise lengthy process of selecting parents for hybrids, giving more precision in combining traits (yield, stress tolerance, etc.).

b. Using AI to screen genebank samples lets researchers uncover "hidden gems" (varieties with desirable traits) much faster and cheaply: IRRI estimates screening entire collection at ~6 % of the cost of traditional approach.

Takeaways:

a. Data + Diversity matter: Here the diversity of parental lines + rich historical trial/genomic data were key inputs.

b. Trait & environment specificity: The AI platform was designed to consider environment, market segment, etc. Good for addressing climate resilience.

c. Scalability: The genebank screening demonstrates scaling up is possible with AI tools

Conclusion

AI supports gene discovery and crop improvement strategies by identifying gene–trait associations and prioritizing candidate genes for breeding and gene-editing programs. These capabilities are particularly important for developing climate-resilient crops that can withstand drought, heat, and other environmental stresses. By accelerating decision-making and reducing costs, AI-driven plant breeding contributes to sustainable agricultural production and global food security. AI is reshaping plant breeding by enabling faster, more accurate, and data-informed selection of crop varieties. As AI technologies continue to advance and data availability increases, their integration with traditional breeding approaches will play a vital role in meeting future agricultural challenges.

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Antioxidants and their Impact on Human Health

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Abstract
Oxidative stress, resulting from an excess of free radicals, contributes to aging and the development of chronic diseases such as cardiovascular disorders, diabetes, cancer, and cognitive decline. Antioxidants are protective compounds that neutralize these harmful molecules and support cellular health. They are obtained from both endogenous sources and dietary intake, particularly fruits, vegetables, nuts, whole grains, beverages, and antioxidant-rich spices and herbs. This article explains the types and mechanisms of antioxidants, their major food sources, and their role in disease prevention. Emphasis is placed on whole-food consumption, bioavailability, gut interactions, and cautious use of supplements for maintaining overall health.

Introduction
Our body is always working, and during this process it produces some harmful molecules called free radicals. When these free radicals become too many, they start damaging our cells. This condition is known as oxidative stress, and it is linked to aging and several health problems like heart disease, diabetes, inflammation, and even cancer. To protect us from this damage, our body uses special substances called antioxidants. These antioxidants either come from the food we eat or are made naturally inside our body. Foods like fruits, vegetables, nuts, seeds, tea, and many spices contain high levels of antioxidants. Antioxidants act like the body's "defence team." They help neutralize free radicals, reduce cell damage, and support overall health. Because of this, they have become a popular topic in nutrition and health research. Many people today look for antioxidant-rich foods to stay healthy and prevent lifestyle diseases. This article explains what antioxidants are, where we get them from, how they work inside the body, and what scientific studies say about their role in maintaining good health.

What are Antioxidants?
Antioxidants are molecules found in food and made by the body that reduce or prevent damage caused by reactive oxygen species (ROS) and other free radicals. There are two broad groups: those the body makes (endogenous) and those we take in from food or supplements (exogenous). Common exogenous antioxidants include vitamin C, vitamin E, carotenoids (like beta-carotene and lycopene), and plant compounds called polyphenols (such as flavonoids and anthocyanins). These compounds differ in chemical structure, but they share the ability to slow or stop oxidation.

How Antioxidants Work?
Antioxidants protect the body in several ways:

1. **Direct neutralization**: Some antioxidants can donate an electron to a free radical, making it stable and less reactive. For example, vitamin C can neutralize certain free radicals directly.

2. **Metal binding**: Certain antioxidants can bind metal ions (like iron or copper) that would otherwise catalyze damaging chemical reactions. By binding these metals, antioxidants reduce harmful chain reactions.

3. **Enzyme support**: Some compounds boost the activity of the body's natural antioxidant enzymes (for example, glutathione peroxidase or superoxide dismutase). This helps cells clear reactive molecules more efficiently.

4. **Signalling and repair**: Some antioxidants influence cell signalling pathways that control inflammation, cell survival, and repair mechanisms. For instance, some plant compounds can turn on genes that strengthen the body's defences.

These mechanisms often work together. The antioxidant effect seen in a person usually comes from many molecules and pathways acting at once.

Major Dietary Sources of Antioxidants

Antioxidants are common in many whole foods. Eating a varied diet is the easiest way to get many types of antioxidants:

1. **Fruits**: Berries (strawberries, blueberries, raspberries), citrus fruits, grapes.
2. **Vegetables**: Leafy greens, carrots, tomatoes, bell peppers, broccoli.
3. **Nuts and seeds**: Almonds, walnuts, sunflower seeds.
4. **Whole grains and legumes**: Oats, barley, beans.
5. **Beverages**: Tea (especially green and black), coffee, and moderate amounts of red wine.
6. **Spices and herbs**: Turmeric, ginger, cinnamon, oregano.
7. **Oils and fats**: Olive oil contains antioxidant compounds; dietary fat is needed to absorb fat-soluble antioxidants like carotenoids.

Whole foods provide a mix of antioxidants and other nutrients that work together—this is usually better than taking single antioxidants in high doses.

Spices and Herbs	Important Chemical Constituents
Cloves	Eugenol, isoeugenol, acetyleugenol, sesquiterpene, pinene, vanillin, gallic acid, flavonoids, phenolic acids
Cinnamon	Eugenol, limonene, terpineol, catechins, proanthocyanidins, tannins, linalool, safrole, pinene, methyleugenol, benzaldehyde
Cardamon	Limonene, 1,8-cineole, terpinolene, myrcene, caffeic acid, quercetin, kaempferol, luteolin, pelargonidin
Coriander	Linalool, borneol, geraniol, terpineol, cumene, pinene, terpinene, quercetin, kaempferol, caffeic, ferulic, n-coumaric and vanillic acids, rutin, tocopherols, pyrogallol
Saffron	Crocins (water soluble carotenoids), safranal, flavonoids, gallic, caffeic, ferulic, *n*-catechuic, syringic, salicylic, and vanillic acids
Turmeric	Curcumins, essential oils, eugenol, carotene, ascorbic acid, caffeic, *p*-coumaric, protocatechuic, syringic, vanillic acid
Ginger	Gingerol, turmeric, paradol, geraniol, geranial, borneol, linalool, camphene, zingerol, zingiberon
Anise	Camphene, pinene, linalool, *trans*-, *cis*-anetholes, eugenol, acetanisole, rutin, luteolin-7-glucoside, apigenin-7-glucoside, isoorientin
Caraway	Monoterpenes, sesquiterpene, aromatic aldehydes, terpene esters, terpenal, terpenon, limonene, safranal, kaempferol, quercetin, tannins, caffeic, ferulic, *p*-coumaric, and chlorogenic acids
Fenugreek	Sesquiterpenes, aromatic aldehydes, terpenes
Black pepper	Piperine, pinene, camphene, limonene, terpenes, piperidine, isoquercetin, sarmentine
Oregano	Apigenin, quercetin, luteolin, myricetin, diosmetin, eriodictyol, carvacrol, thymol, rosmarinic, caffeic, *p*-coumaric, protocatechuic acid
Basil	Apigenin, catechins, quercetin, rutin, kaempferol, anthocyanins, eugenol, limonene, terpinene, carvacrol, geraniol, menthol, safrole, tannins, ursolic, *p*-coumaric, rosmarinic acids
Bay leaf	1,8-cineole, cinnamtannin
Dill	Quercetin, kaempferol, myricetin, catechins, isorhamnetin, carvone, limonene
Garlic	Allicin, diallyl sulfide, diallyl disulfide, diallyl trisulfide, allyl isothiocyanate, *S*-allyl cysteine
Horseradish	Phenyl methyl isothiocyanate, allyl isothiocyanate, sinigrin, asparagine

Allspice	Eugenol, gallic acid, quercetin
Marjoram	Limonene, pinene, terpinene, *p*-cumene, apigenin, ferulic, sinapinic, caffeic, syringic, rosmarinic, 4-hydroxybenzoic, vanillic acids
Mustard	Allyl isothiocyanate, carotene, isorhamnetin, isorhamnetin-7-O-glucoside, kaempferol glucoside
Fennelflower	Pinene, *p*-cumene, thymoquinone, thymohydroquinone, thymol, carvacrol, nigellicine, nigellidine, hederin
Onion	Quercetin, apigenin, dipyridyl disulfide, rutin, quercetin-4-glucoside
Parsley	Apigenin, luteolin, kaempferol, myricetin, quercetin, caffeic acid
Red pepper	Capsaicin, tocopherol, lutein, carotene, capsanthin, quercetin, ascorbic acid
Peppermint	Menthol, menthone, limonene, isomenthone, eriocitrin, hesperidin, apigenin, luteolin, rutin, carotenes, tocopherols, caffeic, rosmarinic, chlorogenic acid
Rosemary	Carnosol, rosmanol, geraniol, pinene, limonene, apigenin, naringin, luteolin, rosmarinic, vanillic, ursolic, caffeic acids
Sage	Geraniol, pinene, limonene, carnosol, saponin, catechins, apigenin, luteolin, rosmarinic, carnosine, vanillic, caffeic acids
Nutmeg	Catechins, lignans, myricetin, orgentin, caffeic acid
Myrtle	Anthocyanins, pinene, limonene, gallic and ellagic acids, myricetin-3-O-galactoside, myricetin-3-O-rhamnoside
Lavender	Limonene, quercetin, apigenin, kaempferol glucoside, ferulic, rosmarinic, caffeic, *p*-coumaric acid

Health Effects of Antioxidants

Cardiovascular health: Antioxidants help protect the heart and blood vessels in several ways. They reduce oxidation of LDL cholesterol, which is a key step in the development of atherosclerosis (plaque build-up in arteries). Diets rich in fruits, vegetables, nuts and tea are associated with better blood vessel function and lower risk of heart disease. The effect is usually modest but consistent when people eat antioxidant-rich foods as part of a healthy diet.

Metabolic health and diabetes: Some antioxidants improve measures related to blood sugar control and insulin sensitivity. Plant compounds in berries, cocoa, and tea have been linked to small improvements in blood glucose and cholesterol levels. These benefits are more likely when they are part of an overall healthy diet and lifestyle, including exercise and weight control.

Brain and cognitive health: Oxidative stress is thought to play a role in aging and cognitive decline. Diets high in fruits, vegetables, and other antioxidant-rich foods are associated with better cognitive performance and slower age-related decline in some studies. However, long-term clinical trials are limited, and the evidence is not yet strong enough to say antioxidants prevent diseases like Alzheimer's disease on their own.

Cancer prevention: Laboratory and animal studies show that many antioxidants can reduce DNA damage and slow the growth of cancer cells. Observational studies suggest that diets high in fruits and vegetables may lower the risk of some cancers. But results from supplement trials are mixed. In some cases, high-dose antioxidant supplements did not reduce cancer risk and in certain groups (for example, heavy smokers taking beta-carotene supplements) supplements were associated with increased risk. Whole-food sources are safer and more consistently beneficial than high-dose isolated supplements.

Immune function and inflammation: Antioxidants can reduce chronic inflammation, which is linked to many diseases. Certain dietary antioxidants help regulate immune responses and reduce inflammatory markers. This may help lower the risk of chronic conditions tied to inflammation, such as arthritis, heart disease, and metabolic disorders.

Bioavailability and the role of the gut: Not all antioxidants you eat reach the bloodstream in the same form. Many plant antioxidants are broken down in the gut and liver into smaller compounds before the body can use them. The gut microbiome (the community of bacteria in the intestines) plays a key role in transforming these compounds. This means people can respond differently to the same foods, depending on their digestion, gut bacteria, age and health. Food preparation, the food matrix (what the antioxidant is eaten with) and nutrient interactions (for example, fat helps absorb carotenoids) also affect how much gets absorbed.

Safety, Supplements and Practical Advice

1. Prefer whole foods: Fruits, vegetables, whole grains, nuts, seeds, and legumes give a balanced mix of antioxidants plus fiber, vitamins and minerals.

2. Be cautious with high-dose supplements: Large doses of single antioxidants may have no benefit or could be harmful in certain groups. Supplements are best used under medical advice, for concrete deficiencies, or specific medical reasons.

3. Balance is key: Too many antioxidants in supplement form could interfere with natural cell signalling (some oxidative signals are needed for healthy functioning).

4. Lifestyle matters: Antioxidant-rich foods work best alongside other healthy habits — regular physical activity, not smoking, maintaining a healthy weight and moderating alcohol intake.

Limitations and Gaps in Current Knowledge

1. Translating lab results to people: Many positive lab studies do not lead to clear benefits in humans because the doses used in labs are much higher and conditions differ.

2. Variability in response: People differ in how they absorb and use antioxidants. This makes one-size-fits-all recommendations less precise.

3. Short trials and surrogate outcomes: Many human studies measure short-term biomarkers (like blood antioxidant levels) rather than long-term disease outcomes. Longer, well-designed trials are needed.

Conclusion

Antioxidants are important substances that help protect the body from oxidative damage. Eating a varied diet rich in fruits, vegetables, nuts, whole grains and certain beverages like tea is a safe and effective way to obtain antioxidants and support overall health. While antioxidant supplements have their place, they are not a substitute for a healthy diet and can sometimes be harmful in high doses. Current evidence supports benefits of antioxidant-rich foods for heart health, metabolic health and possibly brain health, but more long-term human studies are needed to confirm effects on major disease outcomes. For most people, focusing on whole foods and healthy lifestyle choices provides the best balance of safety and benefit.

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Biology and Economic Importance of the Muga Silkworm

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Abstract
The muga silkworm (*Antheraea assamensis* Helfer) is a unique and endemic species of India, renowned for producing the lustrous golden muga silk. Confined largely to the northeastern region of the country, particularly Assam and adjoining states, muga silkworm rearing represents a remarkable confluence of biodiversity, traditional knowledge, rural livelihood, and cultural heritage. This article presents a comprehensive account of the biology of the muga silkworm, including its taxonomy, life cycle, host plants, and ecological requirements, along with a detailed discussion on its economic importance. Emphasis is laid on its role in employment generation, socio-cultural significance, export potential, and contribution to sustainable rural development. Challenges and future prospects of the muga silk industry are also discussed to highlight the need for scientific interventions and policy support for its long-term sustainability.

Keywords: Muga silkworm, *Antheraea assamensis*, golden silk, biology, economic importance.

Introduction
Silk has occupied a special place in human civilization since ancient times, symbolizing luxury, elegance, and cultural identity. Among the various types of silk produced in the world, muga silk holds a unique position due to its natural golden colour, durability, and rarity. Muga silk is produced exclusively by the muga silkworm, *Antheraea assamensis*, an insect species endemic to India. Unlike mulberry silk, which is produced under highly controlled indoor conditions, muga silkworm rearing is primarily an outdoor and forest-based activity, deeply integrated with the natural ecosystem. The practice of muga silkworm rearing dates back several centuries and is closely associated with the socio-cultural fabric of Assam and neighboring regions. Traditional communities have preserved and transmitted the knowledge of muga rearing across generations. In recent decades, increasing attention has been given to muga silk due to its high commercial value, eco-friendly nature, and potential for livelihood generation. Understanding the biology of the muga silkworm is essential for improving productivity and sustaining this heritage industry.

Taxonomy and Distribution
The muga silkworm belongs to the order Lepidoptera and family Saturniidae. Its taxonomic classification is as follows:

Kingdom: Animalia
Phylum: Arthropoda
Class: Insecta
Order: Lepidoptera
Family: Saturniidae
Genus: *Antheraea*
Species: *assamensis*

Antheraea assamensis is geographically restricted to the northeastern region of India, particularly Assam, parts of Meghalaya, Nagaland, Arunachal Pradesh, and Manipur. Its distribution is influenced by climatic conditions, availability of host plants, and traditional rearing practices. The silkworm thrives in humid subtropical climates with moderate rainfall and temperature.

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Host Plants of the Muga Silkworm

The muga silkworm is polyphagous in nature, feeding on several host plants. However, it shows a marked preference for certain species belonging to the family Lauraceae. The primary host plants include:

Som (*Persea bombycina*)
Soalu (*Litsea monopetala*)

Secondary and tertiary host plants such as *Litsea salicifolia*, *Litsea citrate*, *Cinnamomum glaucescens*, and *Laurus nobilis* are also utilized under specific conditions. The nutritional quality, leaf moisture, and biochemical composition of host plants significantly influence larval growth, cocoon quality, and silk yield.

Life Cycle of the Muga Silkworm

The life cycle of the muga silkworm comprises four distinct stages: egg, larva, pupa, and adult moth. Under natural conditions, the silkworm completes five to six generations per year, depending on seasonal variations.

1. Egg Stage: The eggs are oval, flattened, and pale yellow to light brown in colour. Incubation period ranges from 8 to 12 days, depending on temperature and humidity. Proper egg care is essential to ensure uniform hatching and healthy larvae.

2. Larval Stage: The larval stage is the most critical phase in the life cycle and comprises five instars. The larvae are voracious feeders and depend entirely on fresh host plant leaves for nutrition. Larval duration ranges from 23 to 45 days. Environmental factors such as temperature, rainfall, and pest incidence significantly affect larval survival. During this stage, the silkworm accumulates silk proteins that later form the cocoon.

3. Pupal Stage: Upon completion of the fifth instar, the larva spins a cocoon around itself, usually on branches or leaves. The cocoon is golden yellow to brownish in colour and is known for its strength and durability. The pupal period lasts for about 18 to 25 days in commercial crops.

4. Adult Stage: The adult moth emerges by secreting an alkaline fluid that softens one end of the cocoon. Adult moths are large, yellowish-brown, and non-feeding. Their primary function is reproduction. Mating occurs shortly after emergence, followed by egg laying, thus completing the life cycle.

Life cycle of Muga Silkworm

Ecological Requirements

Muga silkworm rearing is highly sensitive to environmental conditions. Optimal temperature ranges from 20°C to 30°C, with relative humidity between 70 and 85 percent. Excessive rainfall, drought, or sudden climatic fluctuations can adversely affect silkworm health. The outdoor nature of rearing makes the silkworm vulnerable to predators, parasitoids, and diseases, necessitating careful management practices.

Silk Characteristics and Processing

Muga silk is distinguished by its natural golden hue, which becomes brighter with each wash. The silk filament is strong, glossy, and resistant to ultraviolet radiation. Muga silk does not require dyeing, making it environmentally friendly. Cocoon reeling is traditionally done using hand-operated devices, although improved reeling technologies are being gradually introduced to enhance efficiency and quality.

Economic Importance of the Muga Silkworm

1. Employment and Livelihood Generation: Muga silkworm rearing provides employment to thousands of rural families in Northeast India. Activities such as host plant cultivation, silkworm rearing, cocoon harvesting, reeling, weaving, and marketing offer year-round income opportunities. Women play a significant role in post-cocoon activities, contributing to gender empowerment.

2. Cultural and Traditional Significance: Muga silk occupies a central place in Assamese culture. Traditional garments such as Mekhela Chador are often woven using muga silk and worn during festivals, weddings, and religious ceremonies. The silk is considered a symbol of pride and identity among the people of Assam.

3. Commercial and Export Value: Due to its rarity and superior qualities, muga silk commands a high price in domestic and international markets. The demand for eco-friendly and naturally coloured textiles has further increased its export potential. Muga silk products are often positioned as luxury items, fetching premium prices.

4. Contribution to Sustainable Development: Muga silkworm rearing is an environmentally sustainable activity that promotes biodiversity conservation and afforestation through host plant cultivation. It requires minimal chemical inputs and supports traditional agro-forestry systems, aligning well with sustainable development goals.

Challenges in Muga Silkworm Rearing

Despite its economic potential, the muga silk industry faces several challenges. These include climate change impacts, pest and disease outbreaks, low productivity, limited availability of quality seed, and inadequate infrastructure. Fragmented landholdings and lack of market access further constrain growth.

Future Prospects and Strategies

The future of the muga silk industry depends on integrating traditional knowledge with modern scientific advancements. Climate-resilient host plant varieties and races, mechanization of reeling processes, value addition, branding, and geographical indication (GI) protection can significantly boost the sector. Policy support and public-private partnerships are crucial for scaling up production and expanding markets.

Conclusion

The muga silkworm is not merely an insect producing silk; it is a living symbol of India's rich natural and cultural heritage. Its biology is intricately linked with the ecosystem, while its economic importance extends far beyond monetary value, encompassing social, cultural, and environmental dimensions. Sustained efforts in research, conservation, and capacity building are essential to preserve and promote this golden legacy for future generations.

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Calendula – The Golden Flower with Multiple Uses

Article ID: 72579

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Calendula (*Calendula officinalis*), commonly known as **Pot marigold,** is one of the most valuable medicinal and ornamental flowering plants grown across many parts of India. Due to its bright orange and yellow flowers, ease of cultivation, and wide range of uses, calendula has gained popularity among farmers, gardeners, herbal industries, and researchers.

Origin and Importance

Calendula belongs to the family Asteraceae and is native to the Mediterranean region. In India, it is grown both as a garden flower and a commercial medicinal crop. The flowers are rich in bioactive compounds, making calendula an important plant in Ayurveda, Unani, and cosmetic industries.

Why Should Farmers Grow Calendula?

1. Easy to grow crop
2. Short duration (flowers in 45–55 days)
3. Low water requirement
4. High demand in herbal and cosmetic industries
5. Suitable for small farmers and kitchen gardens

Calendula can be grown as a main crop, border crop, or intercrop.

Botanical Description

1. **Plant type:** Annual herb
2. **Height:** 30–60 cm
3. **Leaves:** Simple, oblong, light green
4. **Flowers:** Bright yellow to deep orange, daisy-like
5. **Economic part:** Flower petals and flower heads

Calendula flowers bloom continuously and attract pollinators, making them useful in ecofriendly farming systems.

Climate and Soil Requirements

Calendula grows well in:

a. Cool and mild climate
b. Temperature: 15–25°C
c. Soil: Well-drained loamy soil rich in organic matter
d. pH: 5.5–7.0
e. It is a hardy plant and can tolerate light frost and dry conditions.

Cultivation Practices

1. **Propagation:** By seeds
2. **Sowing time:** October–November (plains)
3. **Spacing:** 30 × 30 cm

Irrigation

1. Light irrigation at 7–10-day intervals
2. Avoid water stagnation

Manures: FYM and balanced nutrients improve flowering

Flowering and Harvesting

1. Flowering starts after 45–55 days
2. Flowers should be harvested at full bloom
3. Regular picking encourages more flowers

Uses of Calendula

Medicinal Uses: Calendula flowers possess:

a. Anti-inflammatory
b. Antibacterial
c. Antifungal
d. Wound-healing properties.

It is commonly used in:

a. Healing creams and ointments
b. Skin care products
c. Herbal teas.

Cosmetic Uses: Calendula extract is widely used in:

a. Soaps
b. Creams
c. Lotions
d. Shampoos

Dried petals are used as a natural yellow-orange dye in:

a. Food coloring
b. Textile industry.

Ornamental Use

Calendula is grown in:

1. Home gardens
2. Borders and beds
3. Landscaping and pots.

Economic Importance

Calendula cultivation provides:

1. Low cost of production
2. High market demand
3. Good returns for small and marginal farmers

Dried flowers and extracts are in demand in pharmaceutical and herbal industries.

Conclusion

Calendula is truly a multipurpose golden flower that combines beauty, medicinal value, and economic benefits. With increasing demand for herbal and natural products, calendula has great potential as a profitable crop as well as a valuable plant for sustainable horticulture.


Cetaphil
baby


CALENDULA
ESSENTIALS MOISTURE EYE CREAM

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Diversity Array Technology: Concepts and Applications

Article ID: 72580

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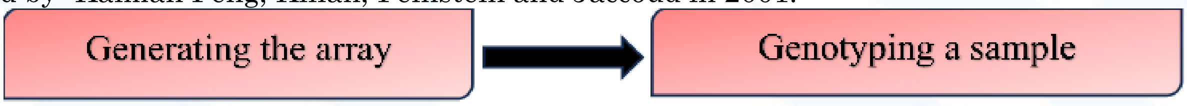
Summary
Diversity Array Technology (DArT) is a high-throughput, sequence-independent molecular marker system extensively applied in genomics-assisted plant breeding. It enables genome-wide detection of DNA polymorphism based on the presence or absence of genomic fragments through microarray-based hybridization. Recent advancements have led to the development of DArT seq, which integrates NGS with traditional DArT principles, significantly improving marker density, accuracy and SNP discovery. Although DArT markers are predominantly dominant and provide limited allelic information, their cost effectiveness, reproducibility and scalability make them highly suitable for large germplasm characterization and breeding programs.

Introduction
Diversity Array Technology (DArT) is a high-throughput genetic marker technique that can detect allelic variations at several 100 genome loci in parallel without relying on any DNA sequence information for genotyping and other genetic analysis.

It detects polymorphisms in the genome based on the presence or absence of DNA fragments.

Developed by- Kaiman Peng, Killan, Feinstein and Jaccoud in 2001.



Traits of Diversity Array Technology
1. High- throughput marker system.
2. No sequence information is needed, sequence independent.
3. DArT is based on microarray hybridizations.
4. Detect the presence v/s absence of individual fragments.
5. Efficiently and economically scan from hundreds to thousands of polymorphic markers.
6. Cost- effective
7. Versatile- Applicable to wide range of plant and animal species.

Steps in Diversity Array Technology
1. Complexity reduction of the DNA of interest
2. Library creation microarraying libraries onto glass slides
3. Microarraying fragments onto glass slides
4. Hybridisation of fluoro-labelled DNA onto slides
5. Scanning of slides for hybridization signal
6. Data Analysis and Extraction

Complexity Reduction of the DNA of Interest
DArT operates on the principle that the genomic ‘representation’ contains 2 type of fragments- Constant Fragment and Variable or polymorphic fragments.

Library Creation
1. DNA Amplification
2. Cloning
3. Library in *E. coli*

Micro Arraying

1. Selection of clones
2. Arranged into a plate format (usually 384-well plates)
3. Fragments within library amplified
4. Spotted onto glass slides
5. Genotyping array.

Hybridisation

Presence v/s absence in a genomic "representation" is assayed by hybridizing the "representation" to a DArT array consisting of a library of that species.

Scanning

1. The hybridized slides are washed and processed to remove unbound labelled DNA.
2. Then scanned using a scanner to detect fluorescent signal emitted from the hybridized fragments.
3. The result from each fluorescent channel is recorded.
4. The resulting images are stored in "tif" format.

Data Analysis

The data from scanned images is extracted and analysed using the DArT soft software and the information is managed by the DArTdb Laboratory Information Management System.

DArT Applications

1. Genome profiling and diversity analysis
2. Genetic and physical mapping
3. Simultaneous MAS for several traits
4. Identification of QTL
5. Monitoring the composition of complex DNA samples
6. Rapid introgression of genomic regions in accelerated backcrossing programs
7. Genomic selection
8. Varietal identification of crops and genetic purity testing.

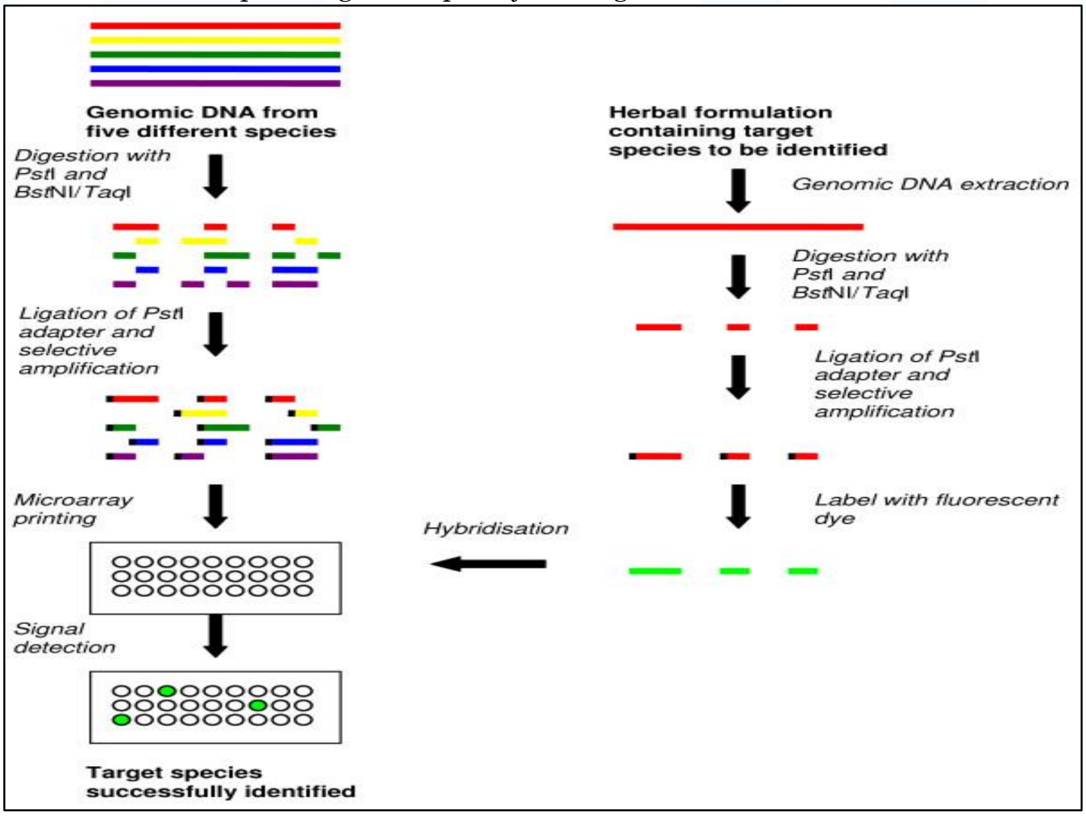


Fig1. Procedure of Diversity Array Technology

Advantages of DArT

1. Sequence information and platform independence
2. Cost- effective, reproducible and reliable
3. High marker density
4. High throughput due to a high level of multiplexing
5. DArT can combine with NGS technologies to create a GBS platform (Genotyping by sequencing used for GWAS and SNP discovery).

Disadvantages of DArT

1. Dominant marker
2. Only detects presence or absence of polymorphisms
3. Limited information content
4. Required technical expertise for optimal performance
5. Reliance on reference genome (lead to biasness if the reference genome doesn't accurately represent the diversity).

Achievements of Diversity Array Technology

1. DArT markers may prove useful for introgression of segments from alien species to the elite varieties of the legume crops.
2. In pigeonpea, by using 1,225 DArT markers in the cross between *C. platycarpus* and *C. cajan*, 2-5% *C. platycarpus* genome carrying genes for disease and insect resistance was observed.
3. Genetic mapping and diversity analysis in Barley, strawberry, chickpea, pigeonpea and groundnut.

Comparing DArT and SSR Markers

1. DArT tree reflected very clearly the organization of the accession set into isozymic groups.
2. Provide many SNP.
3. Not depend on humans too much because it depends on modern software and analyzing techniques through which we get high resolution outputs as compared to SSR.

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From Waste to Wealth: Role of Vermicomposting in Transforming Odisha's Agriculture

Article ID: 72581

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Odisha is predominantly agrarian state where agriculture not only provide livelihood to the majority of the rural population but also plays a vital role in the state's economy. More than 70 % of the working population is engaged in farming activities, mostly under the small and marginal landholdings. According to the 20th livestock census (2019), Odisha has approximately 9.90 million cattle, out of which nearly 8.30 million are indigenous breed and about 1.58 are cross breeds. The state total livestock population stand at 18.17 million, placing Odisha at the 10th position in the country for livestock population. This vast livestock based ensures abundant availability of cattle dung, which is primarily raw material of Vermicomposting. Hence Odisha enjoys a natural advantage for promoting organic farming practices through vermicomposting production.

Keywords: Vermicomposting, Odisha, soil fertility, profitable enterprise.

Agriculture in Odisha is dominated by small and marginal farmers who face multiple challenges such as declining soil fertility, increasing cost of cultivation and limited access to chemical fertilizer. To overcome these constraints and ensure sustainability, farmers are gradually shifting toward organic farming practices. Among these, Vermicomposting has emerged as a simple, eco- friendly and profitable enterprise that not only improve soil health but also provides farmer wealth.

Vermicomposting provides multiple benefits for different categories of farmers. For youth and unemployed rural scholars, it offers a low cost, skill-based enterprise that can generate self-employment. For small and marginal farmers, it reduces input cost, improve soil fertility and increase farm profitability. For women and self-help groups (SHGs), vermicomposting ensures regular income through sales of compost, earthworms and Vermiwash. Accordingly, it contributes to climate resilience by recycling farm waste, reducing dependency on chemicals and enhancing soil carbon content. In Odisha where large quantities of crop residues, livestock manure, and household organic waste remain underutilized, vermicomposting has the potential to convert "Waste to wealth".

By adopting this enterprise, rural youth and farmers can not only improve their income but also contribute to the state's journey towards sustainable and organic agriculture. With proper training, institutional support and linkage to market, vermicomposting can become a driving force in transforming Odisha's rural economy.

Opportunities and Scope of Vermicomposting in Odisha

1. Rural Youth Employment: Vermicomposting offers a low-investment, skill-oriented enterprise that can generate regular income for unemployed rural youth. Small scale units can be started with minimal infrastructure and returns are assured within 3 months.

2. Income support for small and marginal farmers: Farmers with limited resource can reduce their dependence on costly chemical fertilizers by producing their own vermicomposting from locally available cattle dung and crop residues. This not only lowers input cost but also improves soil fertility and productivity. It not only reduces the input costs but also creates a sustainable livelihood opportunity.

3. Women Empowerment and SHG Enterprise: Vermicomposting units are well suited for women farmers and SHGs group. The activity requires low physical efforts, provides quick income through sale of compost, earthworms and vermi-wash and can be easily managed at household level.

4. Market Demand and Organic Agriculture: With rising consumer preference for sale and chemical free food, organic produce has high demand in urban areas. Vermicomposting is increasingly sought after by the vegetable, fruit and other cereals. This creates a strong market linkage for producers.

5. Government Scheme and Institutional Support: Programmes such as Rastriya Krishi Vikas Yojna (RKVY), Paramparagat Krishi Vikas Yojna (PKVY), and Mission Organic Value Chain Development (MOVCD) are promoting organic inputs. Financial and technical support under these schemes provide additional opportunities for scaling up vermicomposting unit in Odisha.

6. Climate Resilient Farming System: Vermicomposting converts waste into nutrient rich manure, improves soil organic carbon and reduces greenhouse gas emissions compared to synthetic fertilizers. Hence, its strength climate resilience and ensures long term sustainability of Odisha's Agriculture.

Methods and Process of Vermicomposting

Different methods of vermicomposting are adopted depending on available resources, location and scale of operation. The most common methods are as below.

1. Upper Pit Methods: Composting tanks are constructed above ground with bricks or cement. Easy to monitor but slightly costly.

2. Deep Pit Method: Pits are dug below ground. Moisture is maintained naturally, but excess water management is difficult.

3. HDPE Method: High density polyethylene (HDPE) vermi-beds are used. Portable and durable, but initial investment is higher.

4. Windrow Method: Organic wastes are heaped in long rows (windrows) directly on the ground, earthworms are introduced, and the heap is covered with organic matter. This is the most reflective and low-cost method, suitable for farmers and SHGs in Odisha.

Process Steps of Windrow Method of Vermicomposting

Steps	Details
Site selection	Shady, well drained place, avoid direct sunlight and waterlogging
Bed Preparation	10 X 3 X 2 feet bed holds 500 kg dung, base layer of husk dry leaves / sand.
Loading waste	Add dung + Residues: Pre decompose 7-10 Days, arrange in layers
Earthworm inoculation	Eisenia foetida (As long as the pit (in feet), that many kg of earthworms is required. As an example, A 10 feet long bed requires about 10 kg of earthworms.
Moisture & Temperature	Maintain 60-70% moisture and cover with straw/ jute bags
Turning & Aeration	Light turning every 15-29 days, avoid heavy disturbance
Harvesting	Compost ready in 75-90 days. Out of the total dung initially filled in the pit, about 40 to 50 % is obtained as compost. During the process, the population of earthworm increases 2 to 3 times, which can be further utilized for the next composting cycle.

Economics

The economics of vermicomposting clearly highlights its viability as a low-cost and high-return enterprise. Even with small-scale units, farmers and rural youth can generate substantial profit through the sale of both vermicomposting and earthworms, ensuring sustainable income and employment opportunities."

First Cycle

Particulars	(Windrow method, 30 X 3 X 2 feet)		
	Quantity	Rate/unit (Rs.)	Amount
Expenditure			
Dung	1500 kg	0.50/kg	750.00
Earthworm	30 kg	300/kg	9000.00

Bricks	80 nos.	8.0/bricks	640.00
Labour charges	10 nos.	450/labour	4500.00
Total cost			**15640.00**
Income			
Compost yield	600 kg	10/kg	6000.00
Earthworm	60 kg	300/kg	18000.00
Total Return			**24000.00**
B:C Ratio			**1.53:1**

Second Cycle

Particulars	(Windrow method, 30 X 3 X 2 feet)		
	Quantity	Rate/unit (Rs.)	Amount (Rs.)
Expenditure			
Dung	1500 kg	0.50/kg	750.00
Labour charges	10 nos.	450/labour	4500.00
Total cost			**6000.00**
Income			

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Compost yield	600 kg	10/kg	6000.00
Earthworm	60 kg	300/kg	18000.00
Total Return			**24000.00**
B:C Ratio			**4:1**

Some glimpses of "Vermicompost production technology" training programmes by NHRDF officials.

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Using Drone-Based Multispectral Crop Stress Indices to Predict Nutrient Uptake

Article ID: 72582

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Abstract

In the past the society discovered how much the productivity of agriculture can be enhanced by the use of fertilizer, at that time there were concerns whether this fertilizer might somehow negative impact on soil health. Fertilizer used in a balanced way are not contributing to the soil degeneration. They are good for soil fertility. we are dependent on food chain and the minerals we are eating are basically coming from the soil and if we don't replace what we have removed, we will deplete the soil and our own diet. Drones are reshaping in every industry and agriculture is no exception, they are helping a lot of people in the agriculture industry growers, academics to bring out better faster and healthier workflow and yields not to mention costs, drones are also lowering the cost of traditionally capital-intensive operations. with the ability to survey vast fields in minutes also drones provides real time data on crop health, soil condition and pest infestation. As drone technology continue to evolve, we can look forward to AI integration, making farming not just more efficient, but sustainable.

Keywords: Unmanned aerial vehicles, remote sensing, plant nutrition, precision farming, spectral analysis, nitrogen management.

Introduction

Agriculture drones also known as agriculture UAVs, have revolutionized farming practices by incorporating technology into various agriculture processes. These drones provide a wide array of functionalities that can significantly enhance efficiency, precision and yield in farming. They come in different types, each designed used to serve specific purposes, from crop monitoring to pesticide application and beyond.

What is Multispectral Sensing, in Simple Terms?

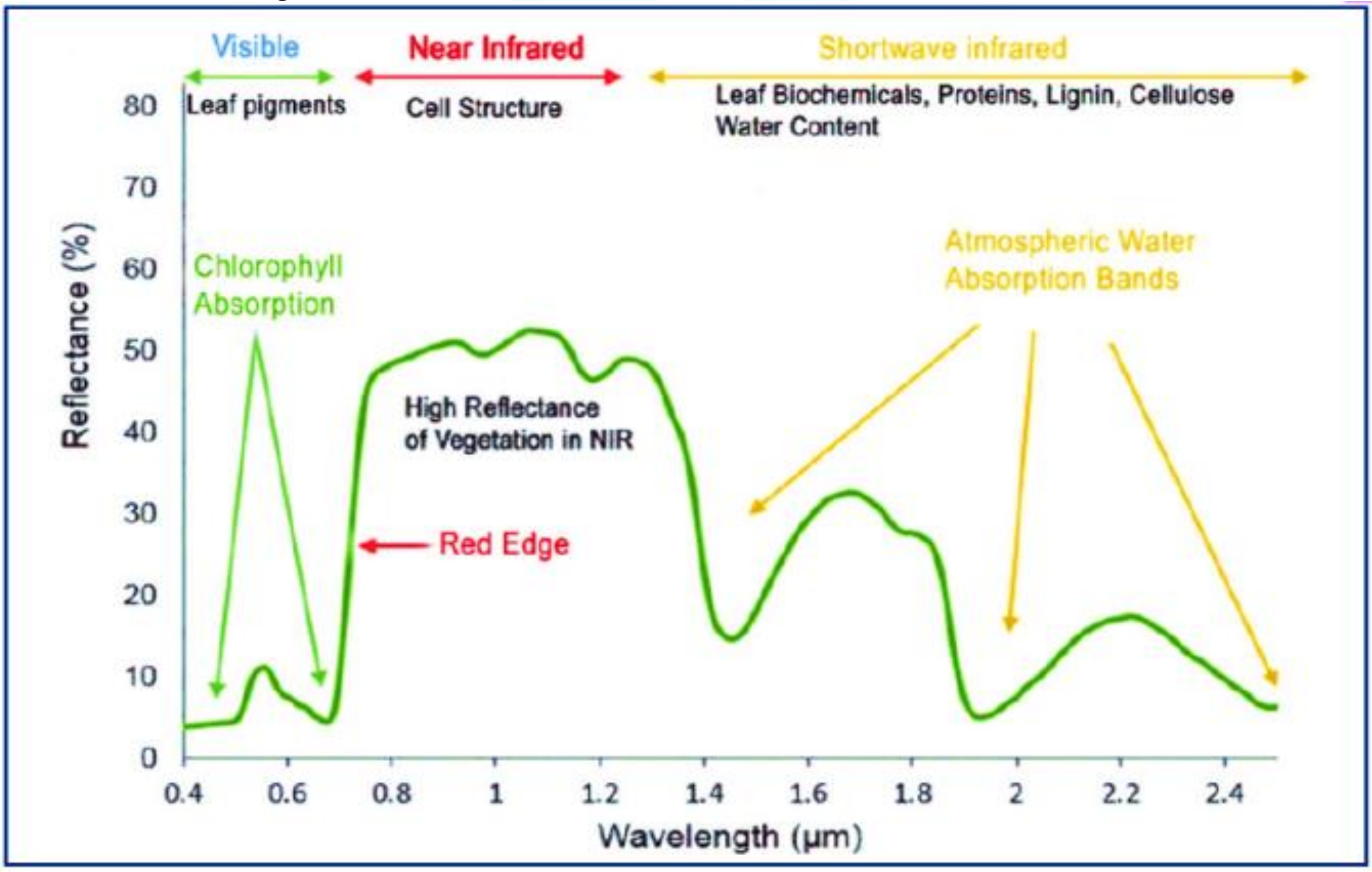
Multispectral sensing is like giving a camera super-vision. A multispectral sensor sees invisible colors of light (like infrared) on top of the regular ones, revealing hidden details. Why it's useful: It helps reveal details that aren't visible normally. For example: In farming, it can detect plant health by spotting stress in infrared light, in satellites, it's used to monitor Earth's weather, pollution, or land changes.

Visible region: vegetation reflectance is driven by pigment adsorption in the visible portion of EMR. The absorption will be high in blue wavelength and fairly high in the red wavelength and adsorption will be very low in the green wavelength. So, leaf containing lot of chlorophyll pigments will be absorbing blue and red wavelength and will be reflecting green wavelength that give the leaf a unique spectral signature that is green colour. In the progress of different cycle of its growth phase the chlorophyll content reduced hence the leaf will not seen green as previous because due to the absorption of different wavelength takes place so the colour of the leaf will get changed.

NIR region: In the given curve it is clearly seen that the reflectance will be much higher in the near infrared region than that of visible region leaves here leaf drives most of its energy requirement from the visible portion of EMR and uses that particular energy for its various function like photosynthesis that why leaf reflects very little amount in the visible portion but leaf will not be absorbed EMR with the same efficiency in the near infrared region if it absorbs the energy with the same efficiency as visible region then it over heat the leaf and at the result leaf may die so in order to prevent the leaf from the irreparable damage leaf generally has a tendency of high reflectance in the near infrared region in this region the vegetation reflectance is driven by leaf internal structure.

SWIR region: Short Wave Infrared (SWIR) the reflectance in SWIR is strongly influenced by leaf water content as leaf water content increases the reflectance decreases amount of water content within the leaf is called the turgidity so in SWIR as wavelength increases, they reflectance decreases linearly. In the above figure the dip in the wavelength at 1.4, 1.9 and 2.7 is may be due to vegetation water content or due to atmospheric water vapours.

Red Edge: the portion of EMR at which transition occurs or sudden increase in the reflectance from Red to NIR is called red edge.



What are Crop Stress Indices?

1. NDVI (Normalized Difference Vegetation Index): NDVI = (NIR − Red) / (NIR + Red)
Higher NDVI usually means more green biomass and healthier canopy. Lower NDVI can signal thin stands, bare soil, or stressed plants. NDVI has been used from satellites for decades. With drones, we get the same concept but at much finer detail.

2. NDRE (Normalized Difference Red Edge Index):

$$NDRE = \frac{(NIR - Red\ edge)}{(NIR + Red\ edge)}$$

NDRE tends to be more sensitive as compared to NDVI in dense crops. It responds to a change in chlorophyll earlier and the chlorophyll is strongly attached to nitrogen status. That is why NDRE is particularly helpful in the diagnosis of nitrogen problems in such crops as wheat, rice, and maize.

3. GNDVI (Green NDVI):

$$GNDVI = \frac{(NIR - Green)}{(NIR + Green)}$$

GNDVI tends to pick up chlorophyll variation in the upper canopy and is also widely used for nitrogen monitoring, especially at later stages when NDVI starts to "flatten out." There are many other indices that use different band combinations to focus on chlorophyll, structure, or sometimes water content. In practice, agronomists and researchers typically compare several of them to see which one best reflects what is happening in a particular crop and location.

Why Use Drones Instead of Just Walking or Satellites?

Satellites operate hundreds of miles above Earth, so their images often have lower resolution and can be distorted or blocked by clouds and the atmosphere. Drones, on the other hand, can capture very sharp imagery with centimeter-level accuracy, even down to individual plant leaves in multispectral imaging. Drones also offer more flexibility and speed. You can send one out whenever you need, instead of waiting for a satellite to pass over, which might only be once a day or even less often. It is also simpler and cheaper to mount specific sensors, such as multispectral cameras, on drones for focused tasks. In contrast, satellites cost a lot to build, launch, and operate, so they are not cost-effective for small or local applications.

On-the-Job Applications in Farm Management

Variable-Rate Application: It is an application method that conserves the fertilizer expenses, minimizes runoff of fertilizers into the environment due to overfertilization, and usually yields a higher crop output through the reasonable application of the fertilizer to the crop growth.

Early Problem Detection: An Early foliar spray or application can be used to rectify the deficiency before irreversible harm is caused.

Yield Forecasting and Planning: This type of forecasting helps in planning the logistics that organizes the space to store the harvest, the harvest crews, and the forward contract negotiation with buyers.

Conclusion

Multispectral sensors in the Unmanned aerial vehicles provide the agriculture sector with a strong new prism through which the dynamics of nutrients can be understood. Using the reflection of crops to various wavelengths of light and changing the resultant measurements into vegetation indices, we are able to make a rapid assessment of nutrient uptake on large fields in space-resolution never before available. There are no challenges to the technology. It involves an initial cost in equipment or services, must be locally calibrated to give quantitative accuracy, and requires careful interpretation to help distinguish nutrient problems among other causes of plant stress. drone-based multispectral sensing is a major advance to more sustainable and efficient agriculture. It assists farmers in doing what they have always sought to do, which is to feed their crops exactly the way they want, to minimize wastage, to conserve the environment as well as to be able to get the maximum returns on the investment that they made in the fertilizers.

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Root Exudate Signature Under Organic Systems: A Metabolic Approach

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Abstract

Root exudates are a key element between plants and soil microbiomes and, which is why, are considered as chemical messengers that condition rhizosphere ecology and nutrient cycling. Root exudate profiles cannot be ignored anymore in organic farming systems where synthetic inputs are not allowed; hence, the need to understand root exudate profiles to help maximize plant-microbe interactions and soil health. The article discusses the metabolic profiles of root exudates in organic agriculture, and the impacts of the organic management practices on exudate composition, quantity and functionality. We use metabolomic analysis to explain that the organic systems modify the release of roots, increase the recruitment of beneficial microorganisms, optimize the mobilization of nutrients, and help in the suppression of diseases. Metabolic approach demonstrates that organic farming systems have a beneficial effect on exudate profiles, which are more diverse and functional than conventional systems and have consequences on sustainable farming and soil ecosystem management.

Keywords that will be used: Root exudates, Organic farming, Metabolomics, Rhizosphere, Plant-microbe interactions, Soil health.

Introduction

Plants are talking to each other down beneath our feet, in the unknown world of soil, which we are just starting to comprehend. Each day, plant roots give up between 5-21% of all the carbon that they had previously accumulated by photosynthesis to the soil. These root exudates are made up of sugars, amino acids, organic acids, phenolic compounds and myriad other molecules which form a distinct chemical fingerprint around the roots of each plant, and which basically have an influence on the nature of the microbial community and on nutrient availability in what the scientists refer to as rhizosphere. When farmers are in an organic farming system and they do not use synthetic fertilizers or pesticides they need to work on these root exudates are even more critical.

Devoid of chemical inputs to drive nutrient supply or repress pathogens, plants are forced to more vigorously depend on their innate capacity to attract beneficial microbes, dissolve nutrients and protect themselves by root chemistry.

However, the intriguing question here is the following: does organic farming have an impact on the release of the plants through their roots? And in that case, what is the resultant impact on soil health and crop productivity of this changed chemical signature? Simple or even complex metabolic cues that differentiate plants grown organically and conventionally can be found in hundreds or even thousands of compounds in root exudates by applying advanced methods of analysis, such as mass spectrometry and nuclear magnetic resonance.

What are Root Exudates and What is the Importance?

Root Communication Chemistry Primary metabolites such as sugars (glucose, fructose, sucrose) and amino acids are food to soil microbes and essentially contracting helpful bacteria and fungi to colonize the root zone. Secondary metabolites such as flavonoids, acids and phenol, alkaloids are complex signalling molecules. An example is the attracting of the nitrogen-fixing bacteria to legume roots by flavonoids or the stimulation of the useful mycorrhizal fungi. Complex organic matter is broken down by the release of enzymes and proteins by roots and the nutrients released are made available and the chemical environment of the rhizosphere is altered to promote plant growth.

Metabolic Signatures: What is it About the Organic Root Exudates?

Enhanced Exudate Diversity and Exudate Amount: It has been found in numerous studies via metabolomic profiling that compared to conventionally grown plants, organically managed plants tend to release more and more diverse root exudates. A single extensive experiment on tomato vegetation established that organic control led to an increase in total exudate product, 30-40, and more considerably in the range of secondary metabolites compounds. Traditional systems use soluble synthetic fertilizers that contains nutrients that are immediately available to the plants. Organic matter contains a great proportion of the nutrients which are present in organic systems and require to be released by decomposing microbes. Plants in turn counter this by enhancing exudation to energize and enhance the microbial communities upon which they require nutrient mobilization.

Increased Production of Organic Acids: Production of organic acids (citric acid, malic acid, oxalic acid, etc.) is one of the least variable results in metabolomic analyses which motivates more production in organic systems. These compounds also play a key role in phosphorus nutrition because these compounds chelate (bind to) aluminium and iron in soil making available bound phosphate, which is taken up by plants. This challenge is met by an increased production of organic acids.

Enriched Phenolic and Flavonoid Profiles: A close metabolomic study of lettuce roots established that organic plants exuded much more amounts of individual flavonoid identified to provoke mycorrhizal fungi colonization. Since mycorrhizal networks may provide up to 80 percent of the phosphorus requirements of a plant, and enhance the water uptake, it is an advanced flavonoid signalling mechanism that will better metabolic management of organic plants growing in reduced-input conditions. Interestingly, the same phenolic compounds are also antimicrobial agents, which selectively inhibit harmful microorganisms and allowing or even favoring the beneficial microorganisms in their environment. The metabolic signature basically programs the rhizosphere microbiome based on plant health.

Metabolomic Methods: Our Method of Exudate Analysis

Collection In growing roots in a solution with no soil, the collection is made by planting root exudates as plants and letting the roots release their compounds into a solution that is collectable without soil contamination.

Analysis: The solutions obtained are then subjected to the metabolomic profiling analysis through the use of liquid chromatography-mass spectrometry (LC-MS), gas chromatography-mass spectrometry (GC-MS), or nuclear magnetic resonance (NMR) spectroscopy. Those are methods capable of detecting and measuring hundreds to thousands of various metabolites in a single sample.

Data Analysis: The large-scale data that are generated with the resulting datasets require computational tools including multivariate statistics, principal component analysis, and metabolopathy mapping to identify the compounds and their interaction functions that differ among treatments.

Validation: Experimental research can confirm important findings, e.g., by establishing whether specific exudate compounds actually do their intended functions (in attracting useful microbes, mobilizing food, and so on).

Challenges and Limitations

Despite the exciting nature of the research, the ways of using metabolomics to study the root exudates are questioned. The chemical complexity is staggering thousands of compounds many of which are yet to be identified which react dynamically. Laboratory experiments may not be a complete picture of what happens in the field where there is a combination of a number of environmental factors on exudation. Otherwise it is whether it is causal or correlational. The fact that organic systems have exudates differences does not in any way give that these differences are caused by such differences. Care must be taken during experimental validation in a bid to establish working relationships. Furthermore, the metabolomic analysis is very expensive and technical in nature and cannot be done to make all decisions pertaining to farm management on a daily basis. A key goal is also the development of simpler and more affordable diagnosis techniques whose development is based on the metabolomic expertise.

Conclusion

The metabolic point of view of root exudates research has brought out a dark effect of the organic evolution of the advanced chemical dialogues among vegetation and their microbial allies. The benefits of organic management systems include organic root exudates signatures of greater richness of diversity, increased amount of nutrient mobilizing compounds and defensive and signalling molecules. Such modified metabolical forms can be applied in clarification of a considerable portion of the advantages that are apparent in organic agriculture higher nutrient efficiency with reduced input level, natural disease suppression, improved soil carbon storage, and improved ecological state. The other difference is that the plants produced in an organic fashion are not lazy consumers of the compounds provided to them but they are mindful of developing their rhizospheres due to prudent expenditure of chemicals. Thorough basic knowledge and exploitation of plant-microbe interactions through root chemistry creates possibilities to the future as the challenges of supplying food to growing population, protecting and maintaining environmental health and climate change adaptation become a reality. The metabolic signatures which are identified by the aid of the analytic tools which are given are not simply scholastic waste but are functional models in order to create more robust and sustainable agriculture systems.

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Mapping Climate Risk Hotspots for Rice-Pulse Cropping Systems Using Explainable AI

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Abstract

The food security of the billions of people that are depending on rice and pulse crops is being threatened by climate change. The traditional methods of risk taking are not practically explained or their outcomes are not simply perceived and held by the stakeholders. The proposed paper presents a novel Explainable AI (X-AI) model, the model designates the regions of the climate risk hotspots to rice-pulse systems and provides the transparent demonstration of the factors that are unique to the vulnerability of the given regions. With the combination of climate data, soil properties and previous yields and machine learning models enhanced with SHAP and LIME explainability approaches, we have achieved 87 percent prediction accuracy and a general interpretability. Our hypothesis identified hotspots in South Asia, Southeast Asia, and Sub-Saharan Africa, and heat stress, variability in rainfalls and soil constraints are the major drivers of the regions. The gap between the data analysis and the actual agricultural decision-making facilitated by the methodology allows farmers and policymakers to find out not only where the dangers are located, but also why and what to take action against them.

Keywords: Climate risk, Rice-pulse systems, Explainable AI, SHAP, Agricultural vulnerability, Climate adaptation.

Introduction

Rice-pulse cropping systems sustain over three billion people worldwide, providing essential carbohydrates and proteins while improving soil health through nitrogen fixation. However, climate change threatens these systems through altered precipitation patterns, increased temperature extremes, and more frequent weather disasters. The IPCC projects potential yield declines of 10-30% by 2050 in South Asia without significant adaptation efforts. Explainable AI (X-AI) addresses this gap by combining predictive power with transparent interpretation. Techniques like SHAP (SHapley Additive exPlanations) and LIME (Local Interpretable Model-agnostic Explanations) reveal which climate variables most strongly influence risk predictions for specific locations. This transparency builds trust, validates models against domain expertise, and enables targeted adaptation strategies. This study develops an X-AI framework for mapping climate risk hotspots in rice-pulse systems with four objectives: (1) integrate multi-source climate, soil, and agricultural data; (2) develop accurate machine learning risk prediction models; (3) apply explainability techniques to identify key climate drivers; and (4) generate interpretable risk maps with actionable insights for adaptation planning.

Methodology

Location and Region under Study: The rice-pulse area that we examined covered South Asia, Southeast Asia, and Sub- Saharan Africa (approximately 15 million hectares) between 2000-2023. Climate data (temperature, precipitation, humidity, solar radiation, wind speed, extreme events) published by ERA5 reanalysis on a daily basis, soil data (texture, pH, organic carbon, water holding capacity), published by Soil Grids, historical yields, and data released by FAO databases on cropping, as well as socio-economic data (farm size, irrigation accessibility, mechanization) have been used.

Climate Risk Index (CRI): We have developed a composite index (0-100), which incorporates three dimensions: (1) Magnitude and frequency of adverse climatic conditions e.g. heat stress days, drought, flood etc; (2) Sensitivity of crops (exposure to adverse conditions at critical periods of growth); and (3) Adaptive Capability availability of irrigation systems, crop insurance, and institutional support.

Machine Learning Models: Random Forest, Gradient Boosting Machines (GBM), and Deep Neural Networks, in which 70 percent of data is used to enter training, 15 percent is used to enter validation, and 15 percent is used to enter testing. The optimization of the hyper parameters was done using Bayesian optimization and 5-fold cross-validation.

Explainability Framework: SHAP (global feature importance and local instance-level explanations), LIME (locally faithful linear approximations), Partial Dependence Plots (to visualize marginal effects) and feature interaction analysis (to discover synergistic interactions between variables) were done.

Results

The Gradient Boosting Machine achieved optimal performance (R2 = 0.89 and RMSE = 8.4 and MAE = 6.2) where 89 percent of the climate risk variation was accounted. Random Forest had the same accuracy (R2 = 0.87) with lower inferences but Deep Neural Networks (R2 = 0.86) did not have significant advantages despite their higher costs of computing.

Global Feature Importance: SHAP analysis showed that five key variables were important: Heat stress during flowering (SHAP mean |value| = 4.2): In periods of the reproductive stages, days exceeding the critical temperature limits were mostly related to the greatest risk.

Fluctuation of seasonal precipitations (3.8): The growing seasons were highly sensitive in terms of rainfall coefficient of variation that exposed the area to be highly susceptible.

Soil water carrying capacity (3.1): The stress caused by drought was aggravated by the poor water content of the soil.

Extreme rainfall events (2.9): Flooding and crop damages were correlated with frequency of rainfall, which was more than 100mm/day.

Availability of irrigation (2.6): Availability of irrigation reduced considerably the risk scores.

Heat stress is the cause of the greatest risk, 45 percent, and shrinking groundwater levels, 25 percent, in the Indo-Gangetic Plains (India/Pakistan). The SHAP analysis revealed the strongest effect of the temperature extremities in the flowering periods which suggests the development of the heat-resistant variety as the priority of the adaptation.

Critical X-AI Insights: There were four significant trends on the explainability framework:

- **a. Non-linear temperature limits:** Rice-pulse systems can be operated at temperatures up to 32degC but further above this temperature, the risk of distinguishing between different targets in breeding programs rises exponentially.
- **b. Irrigation as risk moderator:** The effect of precipitation variability is moderated on a half by irrigation, which is a measure of the value of investments.
- **c. Interactions with soil quality:** Low soil organic carbon has been found to have interactive effects of soil health on climate resilience.
- **d. Compound event effects:** Compound effects are realized on simultaneous heat-drought stress impact, which is 2.3 times higher than the amount anticipated because of additive effects and must be planned as a worst-case scenario.

Conclusion

The paper has proved that Explainable AI is a new technology that can revolutionize climate risk evaluation by offering accurate predictions with clear interpretations. Our model detected important hotspots in large areas surrounding the rice-pulse, and also demonstrated the links between heat stress and rain variability and soil constraints as causes of vulnerability in both these settings. The explainability component revealed significant non-linearities, threshold behaviors and interaction effects which shape specific adaptation strategies. Since climate change is now accelerating, interpretable artificial intelligence devices are becoming more critical to evidence-based agricultural planning. Unless farmers can act on recommendations that they do not understand, policymakers cannot defend investments they do not understand. X-AI satisfies these needs at the same time. Replacing black- box prediction with transparent and explainable risk assessment is an important development in the science of climate adaptation, which balances the level of computational sophistication with practical decision-making. Further studies are necessary to cover more crops and regions, combine real-time sensing, and build decision-support systems that convert the knowledge of X-AI to recommendations accessible to farmers. Above all, this work needs to be done by continuously involving data scientists, agricultural experts, and farming communities the best models are created with and not to the people who use them. Rice-pulse farming systems and billions of people relying on them will be able to evolve and flourish in our changing climate with a more understanding of risk, clear communication of its vulnerability, and evidence-based interventions.

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AI Enabled 'Input Omission Decision Tool' for Small Organic Growers

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Abstract

Small organic farmers strive so hard, but they find themselves in a difficult position when they have to struggle to keep the costs down and yet maintain their crops healthy and yet remain right to the organic principle. This article presents a friendly AI program, which can assist these farmers to know some of the fertilizers or amendments they can afford to miss without affecting their crop. The tool analyzes all the parameters of soil health to weather conditions and studies the previous growing seasons to produce personalized recommendations. Preliminary experiments on real farmers have proven that they have managed to reduce their input costs by 15-25 percent without a reduction in yield. They even cultivated better crops sometimes since they were not over doing it with inputs that they were not actually in need of.

Keywords: Artificial Intelligence, Organic Farming, Precision Agriculture, Input Optimization, Sustainable Agriculture, Decision Support System.

Introduction

Any farmers market today, and you will find the increasing desire towards organic foodstuff. Citizens desire food that is cultivated properly without using any artificial chemicals and that which conserves the land. However, this is all the small organic farmers do not see: it is a puzzle that can either make or break lives of these small businesses every day. The organic farmers do not have the freedom to grab a bottle of synthetic fertilizer when they need to give their farm a boost, like the conventional farmers; they have to make use of the compost, the natural rock minerals, the beneficial microbes and the plant based supplements that nature provides to them. These natural inputs are very nice to the health of soil and the quality of crops, however, they have two significant challenges they are costly and it is not easy to determine when and how much to apply.

System Architecture and Methodology

Data collection and integration will involve the gathering and integration of data.<|human|>a) Data Collection and Integration. Data collection and integration will entail data collection and data integration.

The Input Omission Decision Tool is based on a multi-layered data architecture which uses data across multiple sources to provide real-time data on soil health which is the output of soil sensors that measure pH, moisture content, organic matter, nitrogen, phosphorus, potassium and microbial activity. The factors are important in organic farming as they directly influence the health of the plants and the supply of nutrients. Crop Performance History: Records of previous crop production, quality assessments, pest and disease outbreaks and inputs utilized in previous growing seasons. This historical background allows the system of AI to acquire insights into which input tactics have been effective in specific situations.

1. Machine Learning Models: The neural networks study the time correlation of data, which establish patterns of seasons and predict the input necessary depending on current trends. Deep learning layers can be used to identify subtle patterns that have the effect of causing certain inputs to be redundant. Clustering algorithms allow the system to offer suggestions on similar database settings as a result of grouping similar agricultural scenarios and field conditions. This is advantageous to the small farmers that may have little personal historical data.

2. Decision Logic Framework: Necessity Test: Tests whether an input is presently needed or not depending on the stage of crop growth, the nutrient content of soil and the environment. Risk assessment considers the crop resilience, soil nutrient buffer capacity and climatic variables in the future to identify the risks of loss of yield or degradation of quality in case a particular input is omitted. The cost-benefit analysis will compare the potential economic loss due to the loss of yield or quality with the financial saving due to dis-inputting.

3. Implementation and User Interface: When farmers log in, they are presented with a dashboard where they can see the state of their fields, the next date of input application, and any recommendation that the AI system has made. The system generates a notification that gives a description of what will happen in case it detects an opportunity to skip an input. Moreover, the program provides educational aspect of describing concepts of soil health, functions of organic inputs, and agronomic concepts. Rather than simply blindly chasing AI instructions, this aid allows farmers to have a better idea of their farming systems.

Challenges and Limitations

Data Availability and Quality: Timely and quality data is vital to the effectiveness of the system. Lack of large sensor networks or previous data of small farms can compromise the AI ability to give the reliable recommendations. Biological Complexity: Agricultural systems have many forces beyond control that render them inherently complex. Although AI is capable of identifying trends in the data, unexpected events such as unusual insect attacks, extreme weather, or new forms of diseases may shift predictions. Access to Technology: Small farmers may lack access to cell phones, reliable internet connection, and even digital literacy to effectively use the program in high resource settings.

Conclusion

The AI Input Omission Decision Tool can help small organic farmers to reduce costs (15-25 percent) without a decrease in yields by analyzing data and identifying the particular inputs that can be safely excluded. Field testing proved that a good number of farms were applying inputs that were required unnecessarily. Besides saving money, the tool also educates the farmers regarding their land, avoids overuse of application and becomes smarter with the use of the tool by many people. The methodology shows that AI can be useful to not only massive industrial processes but also small farms that are sustainable. Organic farming in the future is aimed at achieving just what is needed, at the right time and factually as opposed to speculation.

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Nutrition Management in Bulbous Ornamental Plants

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1. In commercial floriculture bulbous ornamentals, the word 'bulb' includes underground modified stems that are used for propagation like true bulbs, corms, tubers, tuberous roots and rhizomes.

2. Most of the bulbous ornamentals are native to temperate to Mediterranean climate and produce good quality flowers during summer months in Northern and Northwestern hill regions.

3. Tropical bulbous flowers are cultivated in the plains and at low elevation in the hills.

4. They are highly valued for attractive flowers, foliage, cut flowers and potted ornamentals.

Importance & Uses

1. Bulbous ornamentals grown for flowers: *Alstroemeria, Amaryllis, Canna, Cooperia, Crinum, Dahlia, Eucharis, Gladiolus, Gloriosa, Hemerocallis, Hippeastrum, Hymenocallis, Nelumbo, Pancratium, Polyanthes, Zantedeschia.*

2. Foliage bulbous ornamentals: *Asparagus, Caladium, Calathea, Kaempferia and Sansevieria.*

3. Bulbous ornamentals used for cut flowers: *Alstroemeria, Gladiolus, Tuberose, Tulip, Lilium, Dahlia, Freesia, Narcissus, Iris, Liatris, Amaryllis* and *Zantedeschia.*

4. Bulbous potted plants: *Achimenes, Albuca, Allium, Anemone, Anthericum, Begonia, Caladium, Convallaria, Cooperanthes, Cooperia, Crinum, Crocosmia, Crocus, Cyrtanthus, Cyclamen, Eranthis, Eucharis, Eucomis, Frittilaria, Freesia, Galanthus, Gloriosa, Haemanthus, Hippeastrum, Homeria, Hyamenocalis, Iris, Ixia, Leucojum, Lilium, Muscari, Narcissun, Nerine, Ornithogalum, Oxalis, Pancratium, Ranunculus, Zephyranthes, Watsonia* and *Zantedeschia.*

Nutrient Management Planning

1. A major focus of nutrient management planning is preventing the over – application of nutrients to protect water quality and minimize impact on the environment while still providing optimum yield for economic benefit.

2. It involves accounting for and recording all the nutrients you have, determining what nutrients you will need, and planning how, how much, when and where to apply them to your crop land. This involves first determining what nutrients are in the soil (soil- testing) and what is available in growing or harvested crop and determining what has to be added to meet the needs of crops.

3. This plan will lay out how nutrient is managed according to land base characteristics, crops being grown, type of nutrient, proximity to water and application methods.

4. Records of nutrients application rates, methods, and timing help with future planning.

Challenges and Limitations

Data Availability and Quality: Timely and quality data is vital to the effectiveness of the system. Lack of large sensor networks or previous data of small farms can compromise the AI ability to give the reliable recommendations. Biological Complexity: Agricultural systems have many forces beyond control that render them inherently complex. Although AI is capable of identifying trends in the data, unexpected events such as unusual insect attacks, extreme weather, or new forms of diseases may shift predictions. Access to Technology: Small farmers may lack access to cell phones, reliable internet connection, and even digital literacy to effectively use the program in high resource settings.

Why is Nutrient Management Needed in Bulbous Crops?

INM is essential to address the following issues,
1. Declining productivity due to poor quality planting material.
2. Appearance of deficiency in secondary and micronutrients.
3. The physical condition of the soil is deteriorated as a result of long-term use of chemical fertilizers.
4. The recent energy crisis, high fertilizer cost and low purchasing power of the farming community have made it necessary to rethink alternatives.
5. Unlike chemical fertilizer, organic manure and biofertilizer are available locally at cheaper rates.
6. 20-25% plant nutrients can be met by recycling of industrial and farm waste and by use of biofertilizer.

Crop	Nutrition
Alstroemeria	The recommended dose of N(3.8-5.6%), P(0.3-0.7%), K(3.7-4.8%), Ca (0.6-1.8%) and Mg (0.2-0.4%)
Gladiolus	120kg/ha N, 150kg/ha P, 150kg/ha K_2O/ha given in 2 to 3 split doses
Tuberose	FYM 25t/ha and NPK 200:200:200 Kg/ha in 3 equal split doses
Tulip	FYM 3-5 kg/m^2 NPK 5%-10%-5%
Lilium	NPK 30:20:20g/m^2 for liquid feeding NPK 14:10:14 fertilizers should not come in contact with bulbs it leads to rotting
Dahlia	40kg N, 50kg P_2O_5, 40kg of K_2O per acre is optimum for flower yield

Future Prospects

1. Promoting soil test crop response based nutrient recommendations in bulbous crops.

2. Dynamics of nutrient uptake by the crop, nutrient removal of bulbous crops should be studied thoroughly to fill gap of nutrient demand.

3. Leaf tissue analysis in bulbous crops to decide fertigation schedules.

4. Creating awareness amongst farmers on benefits of balanced fertilization.

Conclusion

1. Widespread nutrient deficiencies and deteriorating soil health are cause of low nutrient use efficiency, productivity & profitability.

2. Balanced fertilization of bulbous crops helps in attaining targeted yield.

3. Nutrient use efficiency can be improved in bulbous crops using slow-release fertilizers, fertigation, crop residues as mulch, liquid biofertilizers and VAM.

4. Utilizing all indigenously available nutrient sources to reduce dependence on imports.

5. Effective soil and plant analysis service to back up precise fertilizer use.

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Histone Variants and their Relevance to Crop Improvement

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Summary

Histone variants constitute a fundamental source of chromatin functional diversity in plants by providing a dynamic and reversible mechanism for regulating gene expression in response to developmental and environmental cues. Encoded by distinct genes and differing in sequence, deposition, and post-translational modification profiles, variants of H1, H2A, H2B, and H3 modulate nucleosome stability, chromatin accessibility, and transcriptional outcomes. In *Arabidopsis thaliana*, extensively studied variants such as H2A.Z and H3.3 play central roles in controlling flowering time, developmental phase transitions, reproduction, and regeneration, while linker histone H1.3 and plant-specific variants like H2A.W and H2B.8 contribute to chromatin compaction, genome stability, and stress adaptability. Beyond development, histone variants fine-tune plant responses to biotic and abiotic stresses by regulating immune gene activation and stress-responsive transcriptional programs, enabling rapid yet heritable acclimation to changing environments. Collectively, these findings establish histone variants as active regulators rather than passive chromatin components and highlight their potential as an underexplored epigenetic layer for improving stress resilience, developmental plasticity, and yield stability in crop plants.

Introduction

A major source of chromatin functional diversity arises from the presence of histone variants. Histone variants are non-allelic protein isoforms of canonical histones that differ in amino acid sequence, expression patterns, and modes of deposition into chromatin. In plants, all histones except H4, namely H2A, H2B, H3, and linker histone H1, exist as multiple variant forms encoded by distinct genes. The replacement of canonical histones with specific variants can antagonize canonical histone deposition at defined chromatin loci, thereby modulating nucleosome stability, positioning, and chromatin flexibility. In addition, histone variants can harbor distinct post-translational modifications, which together define specialized chromatin states associated with particular genomic functions. From a crop improvement perspective, histone variants represent a critical yet underexplored regulatory layer controlling complex traits. Unlike DNA sequence variation, chromatin-mediated regulation via histone variants provides a rapid, reversible, and heritable mechanism for fine-tuning gene expression in response to environmental and developmental signals.

Histone Variants in Plants

In *Arabidopsis thaliana*, histone variants are grouped into four major families, H2A, H2B, H3, and H1, with H2A and H3 being the most extensively characterized. The H1 family includes H1.1, H1.2, and the stress-inducible H1.3. H1.1 and H1.2 are replicative, heterochromatin-enriched variants associated with transcriptional repression and H3K27me3 deposition, whereas H1.3 exhibits higher chromatin mobility and is induced by abiotic stresses such as drought, ABA, and low light to support adaptive gene regulation. The H2A family comprises canonical H2A, H2A.Z, H2A.X, and the plant-specific H2A.W; among these, H2A.Z plays a dual role by stabilizing transcription at transcription start sites of housekeeping genes while repressing hypervariable stress-responsive genes when deposited in gene bodies, often in coordination with Polycomb-mediated repression (Gómez-Zambrano *et al.*, 2019). H2A.X functions in the DNA damage response via ATM/ATR-dependent phosphorylation, whereas H2A.W contributes to heterochromatin compaction and genome stability (Lorković and Berger, 2017). In contrast, H2B variants are less well understood, although H2B.8 (H2B.S) is known to drive extreme chromatin compaction during seed maturation. The H3 family is the most complex, with replication-dependent H3.1 enriched in heterochromatin and replication-independent H3.3 associated with active euchromatin and rapid transcriptional responses, despite differing by only four amino acids. H3.3 contributes to stress-responsive gene regulation and flowering control via FLC, while specialized variants such as CENH3 ensure centromere identity and atypical plant-specific H3 variants (H3.6, H3.14, H3.15, H3.10) participate in stress responses, regeneration, and gametogenesis.

Roles of Histone Variants in Plant Growth and Development

Histone variants are key regulators of plant growth, development, and environmental adaptation by dynamically modulating chromatin structure and gene expression. A well-characterized example is flowering time control in *Arabidopsis thaliana*, where the histone variant H2A.Z maintains expression of the floral repressor FLOWERING LOCUS C (FLC) during vegetative growth; reduced H2A.Z deposition at the FLC transcription start site leads to premature flowering (Deal *et al*., 2007). Depending on chromatin context and post-translational modifications, particularly acetylation, H2A.Z can function in either transcriptional activation or repression (Crevillén *et al*., 2019). Flowering regulation also involves H3.3, which is deposited by the HIRA chaperone in cooperation with FRI to promote active histone marks (H3K4me3, H3K36me3), gene-loop formation at FLC, and efficient transcription; H3.3 further supports transcriptional reprogramming during seed germination (Zhao *et al*., 2022).

Roles of Histone Variants in Plant Stress Tolerance

During biotic stress, histone variants fine-tune immune gene activation and defense signaling across plant species. In wheat, the plant-specific H2A.W variant (TaH2A.1) interacts with the receptor-like kinase TaCRK10 to enhance salicylic acid-dependent resistance against stripe rust (*Puccinia striiformis*) (Wang *et al*., 2021), while in *Arabidopsis*, SWR1C-mediated H2A.Z deposition is required for resistance to fungal and bacterial pathogens such as *Sclerotinia sclerotiorum* and *Pseudomonas syringae* by regulating H2A.Z occupancy and active histone marks at defense genes (Cai *et al*., 2021). In rice, pathogen-induced repression of the BRHIS1 complex triggers monoubiquitination of histone variants, thereby activating immune responses. Histone variants also play crucial roles in abiotic stress tolerance. Reduced H2A.Z deposition at AtMYB44 enhances salt tolerance in *Arabidopsis*, whereas loss of the SWR1C subunit ARP6 impairs root development under salinity (Do *et al*., 2023); phosphate starvation in rice causes a genome-wide reduction of H2A.Z over stress-responsive gene bodies, facilitating transcriptional activation; and the drought-inducible linker histone H1.3 promotes tolerance by regulating stomatal function, redox homeostasis, and growth under water-limiting and low-light conditions. Temperature stress further underscores the context-dependent roles of histone variants, as elevated temperatures induce INO80-mediated eviction of H2A.Z from heat-responsive promoters such as HSP70, enabling rapid transcriptional activation and modulating flowering time via species-specific regulation of FT expression (Abelenda *et al*., 2023).

Conclusion

Collectively, these studies demonstrate that histone variants are not passive structural components but dynamic regulators of plant gene expression. By influencing nucleosome stability, chromatin accessibility, and interactions with histone modifications and remodeling complexes, histone variants integrate developmental cues and environmental signals. While current research has predominantly focused on H2A variants, especially H2A.Z, expanding functional analyses to other variant families will be essential for a comprehensive understanding of chromatin-mediated regulation in plants and for harnessing epigenetic mechanisms in crop improvement.

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Purpureocillium lilacinum: A Potential Biological Nematicide for Root-Knot Nematode Management

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Introduction

Root knot nematodes (RKNs), belonging to the genus *Meloidogyne*, are among the most significant groups of plant-parasitic nematodes. They are obligate, sedentary root endoparasite affect over 3,000 plant species. Given their significant economic impact, RKNs are one among the top most plant parasite threatening global food production. These nematodes invade plant roots and induce the formation of galls or "knots", which block the flow of water and nutrients. As a result, plants often show symptoms such as yellowing, stunted growth and wilting even under adequate irrigation (Abad et al., 2003). Over time, the damage hinders the plant growth and drastically reduces the productivity. In RKNs *Meloidogyne incognita, M. javanica, M. arenaria,* and *M. hapla* are regarded the most prominent species threatening agricultural and horticultural production. Due to their cosmopolitan and polyphagous nature, they frequently interact with other phytopathogens, and develop disease complexes. Nematode management primarily relies on chemical nematicides because they highly effective and quick in reaction, nevertheless there are growing concerns regarding their potential negative effects on the environment and human health and the long-term sustainability of agriculture. Therefore, it is crucial to explore alternative and safer approaches for effective nematode management. Biological Control Agents (BCAs) have emerged as effective options for managing nematode damage because of their economic viability and eco-friendly nature (Oka, 2010; Thoden et al., 2011; Rao et al., 2017). In this arena, several researchers explored specific microbial groups that play a crucial role in reducing nematode damage in agricultural and horticultural crops. These groups encompass egg-parasitic fungi, nematode-trapping fungi, various filamentous fungi, antagonistic bacteria, and diverse predatory nematodes (Kerry and Hidalgo-Diaz 2004, Kiewnick and Sikora 2005). Among these, the egg parasitic fungi, *Purpureocillium lilacinum* (earlier name *Paecilomyces lilacinus*) has been extensively exploited for the management of RKNs.

Purpureocillium lilacinum

Purpureocillium lilacinum (formerly known as *Paecilomyces lilacinus*) is a egg parasitic fungus from the Ascomycota phylum. It lives naturally in soil and in the rhizosphere of many crops. The fungus thrives in a wide temperature range (8-38 °C) and can survive a variety of pH levels. It develops a robust mycelial network that generates conidiophores, with spore germination occurring under optimal conditions, such as sufficient moisture and nutrient availability. The fungus develops colonies that exhibit colors ranging from white to light violet, which is reflected in its name, *lilacinum* (Khan and Tanaka, 2023). It thrives in various soil environments and has been found in association with plant rhizosphere and decomposing organic materials. Because of its extensive ability to thrive in various environmental conditions, this fungus is an excellent choice for applications in the field. It effectively targets the eggs, juveniles and adult females of root-knot nematodes, effectively interrupting their development and reduces their population in host plants (Holland et al., 1999). This fungus reduces nematode populations via a variety of ways, including enzymatic cuticle destruction, release of toxic metabolite and antimicrobial secretion. It also has significant colonization ability, competing for nutrients in the rhizosphere and directly parasitizing nematode eggs. Besides, it promotes plant health by fostering growth and activating the plant's defense mechanisms.

Application Methods or Delivery Mechanisms

Purpureocillium lilacinum can be applied through different delivery mechanisms for enhancing crop production by establishing itself in the rhizosphere and effectively controlling nematode incidence. One common method is seed treatment, where seeds are coated with a fungal powder or liquid formulation before planting. This approach not only safeguards young seedlings from early nematode attacks but also promotes healthy root colonization. For transplanted crops, it's often recommended to dip the seedlings' roots in a fungal suspension. This direct exposure to the biocontrol agent allows the fungus to quickly colonize the root zone, thus preventing nematode invasion during the crucial early growth stages (Holland et al., 1999; Kerry, 2000). To quickly establish the fungus soil drenching with liquid suspensions around the base of the plants is commonly used. Moreover, the effectiveness of *P. lilacinum* can be further improved when it's combined with organic amendments like neem cake, mustard cake, or farmyard manure, which not only aid in its multiplication but also enhance nematode suppression. It is also used in integrated approaches along with other biocontrol agents like *Trichoderma* spp. *Pochonia chlamydosporia*, *Pseudomonas fluorescens,* and fluorescent pseudomonads providing both nematode control and improved plant growth (Rao et al., 2015). Moreover, applying diluted liquid formulations of *P. lilacinum* through soil drenching has proven effective in nurseries, polyhouse conditions, and open fields, as it facilitates even distribution of the fungus around the plant root zone (Yang et al., 2015).

Ref: ChatGPT (Clipart)

Fig. 1 Different application methods of *Purpureocillium lilacinum* for root-knot nematode management (Images are created by using ChatGPT, Clipart)

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Knowledge and Adoption of Pesticides by the Rice Farmers

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Abstract

Rice is a major staple crop, and pesticides play an important role in protecting yields, but their over use threatens to the soil, water, biodiversity, and human health. This study analyzed rice farmers' knowledge and adoption of pesticides in India, factors affecting Integrated Pest Management (IPM) use, and constraints in adoption. Results showed that while farmers were aware of pesticide benefits and risks, their technical knowledge of safe handling and long-term impacts was limited. Larger farmers used pesticides more often and in higher doses. Training exposure, IPM experience, extension contact, and knowledge of IPM were the key factors driving adoption. High input costs, untimely supply, and lack of technical support remained major barriers. The findings highlight the need for training, extension services, and sustainable alternatives like IPM, organic farming, and biopesticides.

Keywords: Rice cultivation, Pesticide use, Integrated Pest Management (IPM), Farmer knowledge, Adoption constraints, Sustainable agriculture.

Introduction

Rice is an important & Staple food crop in the most of the world. It is cultivated in all part of the world except antarctica. It can be cultivated in an area of 150 million ha of land and produce around 573 million tons of rice with an average productivity of 3.83 tons/ha. By using the modern agricultural farming rice production is increasing to eliminate or reduce the hunger to achieve the Sustainable Development Goals (SDG) of United Nations. Hence pesticides are used to protect the crop from the harmful pest. However excess use of pesticides by the farmer can cause harm to the environment soil, Water and Air. Farmer including pesticide operators manage pests through the application of chemicals. Most of the times, they are unaware about their health which is affected by the chemicals they are used and become victims of pesticide exposure. Pesticides used in farm can caused health problem in human being like Respiratory Problem, Reproduction Problem, genetic Disorder, acute or chronic issue, mild or severe toxication Pesticide use in rice ecosystems of the Indian agriculture is worth studying because they have been multiplying day by day due to pesticide poisoning reported in different regions of India.

Knowledge of Pesticides among Rice Growers

Farmers mainly get pesticide use information from pesticide dealer or retailer. A very few farmers get collect information from government extension worker. Most of the farmer have a knowledge about rice pest and that can be reduced by the application of synthetic pesticides or chemical. They are using various pesticide which is common in rice field like herbicides (propanil, butachlor, pendimethalin), fungicides (carbendazim, propiconazole), and insecticides (organophosphates like chlorpyriphos, pyrethroids such as cypermethrin and profenofos, and neonicotinoids like imidacloprid). The maximum number of farmers understood the harmful effects of pesticides like butachlor and carbendazim cause acute hazards or toxicity if ingested orally and having low toxicity through skin contact or inhalation, but imidacloprid are highly toxic to birds. (Class U), while propanil and pendimethalin are moderately hazardous (Class III). Propiconazole and insecticides listed are moderately hazardous (Class II) by WHO classification. The farmers suggested that timely removal of weeds, appropriate timing for pesticide application, balanced doses of fertilizers, pest monitoring, correct dose of appropriate pesticides, pest tolerant varieties, increasing technical knowledge and skills by reducing the quantity of pesticides. Few farmers followed integrated pest management (IPM) practices with little understanding of the adverse effects of insecticides on the environment.

Fig. 1: Farmer Scientists Interaction for sharing knowledge on Pesticide use

Adoption of Pesticides in Rice Cultivation

In rice farming, different pesticides are used depending on pests, weeds, or diseases. Insecticides like *imidacloprid* are applied at certain crop stages for best results, while *chlorpyrifos* is used repeatedly because it breaks down quickly. Herbicides such as *penoxsulam* and *profoxydim* work under flooded field conditions, with penoxsulam lasting longer in water. *Butachlor* is more common in areas with directly seeded rice. Fungicides like *tricyclazole* and *carbendazim* are used against fungal diseases, but carbendazim residues are often found in soil and water. On average, rice farmers spray pesticides about 2.78 times per season, but large-scale farmers apply about 3.5 times, which is higher than small-scale farmers. When looking at pesticide use in the rice field, they mainly ignoring the seed treatment and sprayed during the seedling stage, tillering/heading stage, booting stage, and full heading/harvest stage. Larger farmers not only spray more pesticides but they also use larger doses per spray, meaning their total pesticide use is much higher than that of small farmers. Farmers were generally aware of both the advantage & disadvantage of pesticides like higher yields, income, easier pest control and their risks to health effects, residues and environmental damage. Some farmers understood these risks and supported integrated pest management (IPM) methods, while others believed pesticides were the only solution by increasing their use every year without considering health or environmental impacts. Experts suggest that wider adoption of IPM requires setting up more farmer field schools, giving farmers practical, hands-on training, IPM topics in school and college courses, awareness about pollution and health risks, and better supervision and support from extension workers. Teaching farmers through practical training and awareness programs is the best way to reduce excessive pesticide use and encourage safer methods like IPM and biological control.

Determinants of Knowledge and Adoption

Different farmer characteristics (like age, education, farm size, income, training, experience, etc.) to find out which factors influence the adoption of Integrated Pest Management (IPM) practices. There are Four very important factor i.e training exposure, experience with IPM, extension contact, and knowledge of IPM together these four explained about the variation in adoption. Among them, training exposure was the most important factor in which farmers who attended more training e.g., Farmer Field Schools used IPM more often because they gained knowledge, skills, and confidence. Extension media contact also played a big role, as farmers who regularly received information through extension workers or media were more motivated to try modern IPM practices. Experience in rice farming helped farmers adopt IPM as they had already seen the problems of heavy pesticide use and could compare different practices. Finally, knowledge of IPM was also significant—farmers with better understanding of IPM methods used them more. Overall, most farmers were medium to high users of IPM, but there is still need of improvement. which confirmed that knowledge, experience, and training are key drivers for wider adoption of IPM.

Constraints in Knowledge and Adoption

To understand the constraints experienced by the farmers in knowledge & adoption in rice cultivation issues were shortage of labour, inputs like fertilizer, seeds, and weedicides, not availability on time, low market price for rice, and high cost of inputs and machinery. Farmers also struggled with lack of knowledge about the right pesticide or fungicide doses, poor availability of quality seeds and compost, high cost of pesticides, and difficulty in identifying pests and diseases. Overall, the most difficult challenges were the high cost of farming and delays in getting inputs. In terms of IPM (Integrated Pest Management), the biggest barriers were lack of technical knowledge, lack of technical support, and unavailability of inputs needed for IPM. Some farmers were also unsure about which insects are harmful or beneficial and had doubts about whether IPM would really work. farmers need more practical training, better extension support, timely supply of inputs, and awareness programs. This would help them adopt IPM practices more easily and reduce the difficulties they face in rice cultivation.

Impact of Pesticide Use

In rice farming, pesticides are widely used to protect crops and ensure higher yields. While they help in productivity, their overuse has created serious problems for soil, water, human health, and the environment. Pesticides contaminate soil and water, harm useful microbes and insects, and leave toxic residues that can build up in the environment. Rice is a water-demanding crop, and pesticides are often applied directly into paddy water, which spreads contamination to nearby water sources and affects fish, insects, and other organisms. Chemicals like chlorpyrifos are commonly used but can disturb soil microbes and nematodes, reducing soil health. Many farmers also use pesticides more than the recommended limits i.e more than 10 times which increases risks to the environment and human health.

The effects also depend on the farming system: lowland rice fields lead to cause greater health and freshwater pollution which impacts compared to upland or terraced rice systems. while pesticides improve yields or productivity, their overuse in rice farming also creates major threats to soil, water, biodiversity, and human health, which showing the need for more sustainable pest management practices.

Strategies for Improvement

The Rice farming needs more sustainable practices to reduce the harmful effects of pesticides. Using Integrated Pest Management (IPM) can cut down the use of chemicals and lower the risks to health and the environment. Organic farming and separating water systems in organic fields can help reduce contamination. Rice fields can also be used for phytoremediation (cleaning pollution naturally using plants), which helps remove pesticide residues from water. Training farmers in safe pesticide use and encouraging protective gear like gloves and masks can further reduce health risks.

To solve these problems:

1. Policymakers should make stricter rules for pesticide use, promote IPM and organic farming, and develop national policies that include health and environmental checks.

2. Researchers should study the long-term harmful effects of pesticide residues on soil and water, test phytoremediation methods, and develop safer options like biopesticides.

3. Farmers should adopt IPM and organic practices, use protective clothing when spraying, and join training programs to improve skills and knowledge.

Conclusion

The study showed that while pesticides play a major role in protecting rice crops and boosting yields, their excessive use has serious negative impacts on soil, water, the environment, and human health. Farmers are aware of both the benefits and risks of pesticide use, but many still depend heavily on chemicals because of limited technical knowledge, lack of timely inputs, and insufficient training. Factors such as training exposure, farming experience, extension support, and knowledge of IPM were found to strongly influence the adoption of safer pest management practices. Major constraints faced by farmers include high costs of inputs, input shortages, lack of technical guidance, and doubts about IPM effectiveness. To address these challenges, farmers need more training, awareness programs, and better extension support, while policymakers should enforce stricter rules and promote IPM, organic farming, and biopesticides. Researchers should explore long-term environmental effects and develop safer alternatives. Overall, the findings highlight that with proper education, training, and policy support, rice production can be made more sustainable and environmentally friendly while also ensuring farmers' profitability and protecting human health.

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Assessment of Major Constraints Affecting Indofil's Performance in the Chilli Segment of Sonebhadra District

Article ID: 72590

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Introduction

Indofil industries limited is a very prominent manufacturer and supplier of agricultural chemicals in India, including pesticides, fungicides, herbicides, and plant growth regulators (Yousuf et al., 2024). Sonebhadra district of Uttar Pradesh is known for substantial chilli cultivation, but farmers often face productivity and sustainability challenges. The study aims to identify and assess the major constraints affecting indofil's performance and product adoption in the Sonebhadra chilli segment. The main objectives of the study include analysis of key constraints limiting indofil's sales and market penetration in Sonebhadra's chilli segment; evaluate farmer awareness and adoption of indofil products and practices; suggest actionable recommendations to improve indofil's performance in the region.

Indofil Company Profile (Indofil Industries Limited, 2020)

1. Indofil industries limited is a leading manufacturer and marketer of agricultural and specialty chemicals, headquartered in Mumbai.

2. It was established in the 1960s, indofil has a strong presence in over 120 countries and a wide domestic distribution network.

3. The company promotes the "crop care concept," focusing on research-based solutions for farmers to improve crop health and yield.

Vision: To be a leading, globally respected organization providing innovative and sustainable agriculture and specialty chemical solutions.

Tag line: To be committed, to innovate and to partner.

Key Indofil Products

1. Alecto
2. Ceasemite
3. Kuebiko
4. Sprint
5. Fruit Energy.

Aleacto (Anonymous, 2025)

1. Type: Insecticide (broflanilide 20% sc, meta-diamide, irac group 30).

2. Mode of action: Advanced gaba-modulating, binds to gaba receptors, causes overexcitation, paralysis, and death of pests.

3. Usage: Contact and ingestion, translaminar movement, rainfast, works at low doses.

4. Target pests: Lepidopteran caterpillars, thrips, jassids, whiteflies, fruit borers, shoot borers.

5. Benefits: Controls resistant pests, effective after rain, low residue, safe for crops.

Ceasemite (Anonymous, 2025)

1. Type: Miticide/ insecticide (propargite 42% + hexythiazox 2% EC).

2. Mode of action: Dual propargite (contact, vapor) halts mite feeding; hexythiazox (translaminar, growth regulator) kills eggs and immatures; multiple action delays resistance.

3. Usage: Foliar spray.

4. Target pests: Mites - all stages (eggs, larvae, nymphs, adults), red spider mite, yellow mite, European red mite.

5. Benefits: Fast knockdown, long residual action, resistance management.

Fruit Energy (Anonymous, 2025)

1. Type: Plant nutrition, biostimulant with metalosate technology (calcium-based), for balanced crop growth.

2. Features: Strengthens fruit cell walls, enhances nutrient absorption and translocation.

3. Usage: Foliar spray, 2 ml/liter, for fruit crops, vegetables at critical growth stages.

4. Benefits: Improves flower retention/fruit set, boosts yield and produce shelf life.

Chilli Segment in Sonebhadra

Chilli is a major cash crop in Sonebhadra district of Uttar Pradesh, critical for local farm incomes. Farmers face frequent pests, disease, and climate-related challenges, impacting yield and quality. Indofil is a key supplier of agrochemicals for chilli farmers, aiming to improve crop outcomes through its "crop care concept". Key diseases in chilli are anthracnose (fruit rot) and powdery mildew, bacterial infections such as bacterial leaf spot, and viral diseases like leaf curl.

Research Methodology

Primary data collected through farmer interviews, field visits, and observation in kushi village and other chilli producing areas. Sample included 130 randomly selected chilli growers from robertsganj block. Used a structured interview schedule focusing on demographics, cultivation practices, constraints, and product feedback.

Results and Discussion

Major constraints identified:

a. Socio-economic barriers: Many farmers have low social participation and medium economic motivation, limiting outreach effectiveness.

b. Extension and media gap: Only 42% have medium extension contact; reliance is still on traditional sources, not on company-led training programs.

c. Input availability: Occasional gaps in product supply, logistical issues with access in remote villages.

d. Limited farmer awareness: Many farmers have only a medium level of knowledge about improved production practices and indofil products.

e. Low adoption rates: Only 20% have high-level knowledge; possible reluctance to invest in new chemicals or technologies.

f. Pest and disease pressure: High incidence of pests and fungal diseases; some indofil products may be underused or misapplied.

Table 1. Motivation to use Indofil products:

Responses	No. of farmers (n=130)
Advertisement	7
Dealer Recommendations	47
Peer Influence	28
Product Quality	49

Table 2. Market presence rating:

Responses	No. of farmers (n=130)
Average	68
Excellent	11
Good	29
Poor	22

Table 3. Actionable recommendations for improving performance:

Responses	No. of farmers (n=130)
Better Pricing	32
Digital Campaigns	13
More Training Programmes	48
Stronger Dealer network	37

Table 4. Indofil's market presence rating:

Responses	No. of farmers (n=130)
Average	68
Excellent	11
Good	29
Poor	22

Table 5. Challenges faced in accessing indofil products:

Challenge Type	No. of farmers (n=130)
Poor distributer support	69
High cost	33
Lack of awareness	28

Analysis of Constraints

Constraint	Effect on Indofil performance
Low product awareness	Reduces market share, leads to low adoption
Training and extension gaps	Limits farmer capacity to properly use products
Economic motivation	Medium levels slow uptake of premium solutions
Supply chain issues	Unavailability impacts trust and loyalty
High pest and disease pressure	Increases need for frequent product usage, but improper application reduces effectiveness

Key Findings

1. Indofil has a positive brand image but faces barriers in last-mile delivery and awareness.

2. Current extension strategies need more focus on hands-on training and personal engagement.

3. Farmers appreciate efficacy of recommended products but require ongoing technical guidance on application.

Recommendations

1. Strengthen supply chain and distribution channels to ensure timely availability of products in remote areas.

2. Collaborate with local cooperatives and government schemes to support adoption of improved practices and indofil solutions.

3. Increase direct farmer training through field demonstrations, local extension workers, and regular interactive camps.

4. Develop targeted awareness campaigns using mass media, sms, and village meetings.

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Salacia chinensis: A Medicinal Climber with Curative Potential

Article ID: 72591

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Introduction

Medicinal plants form an integral part of India's healthcare system and serve as the backbone of traditional medical practices such as Ayurveda, Siddha and Unani. Owing to its rich biodiversity, India is home to more than 8,000 medicinal plant species, positioning the country as a global hub for herbal medicine. These plants not only provide affordable and accessible healthcare solutions to millions of people, particularly in rural areas, but also play a vital role in supporting rural livelihoods and local economies. Among these valuable resources, *Salacia chinensis* L., a woody climbing shrub belonging to the family Celastraceae, holds special significance. Commonly known as Saptarangi, Saptachakri or Ingali, the name "Saptarangi" is derived from Sanskrit, where *Sapta* means seven and *Rangi* means coloured, reflecting the plant's diverse appearance and wide range of traditional uses. The species has gained considerable importance as a rich repository of bioactive chemical constituents and is renowned for its medicinal properties, particularly in the management of metabolic disorders such as diabetes, owing to its ability to regulate blood glucose levels and improve insulin sensitivity. In addition to its antidiabetic potential, *Salacia chinensis* is traditionally used for treating obesity, dyslipidaemia, inflammation and digestive disorders, and is valued for its antioxidant and anti-hyperlipidaemic activities (Vyas *et al.,* 2016). Various parts of the plant, especially the roots and stems, are widely utilized in herbal formulations, underscoring its therapeutic relevance and growing demand in pharmaceutical and nutraceutical industries.

Taxonomic Classification

Kingdom: Plantae

Division: Angiosperma

Subkingdom: Tracheobionata- vascular plants

Class: Dicotyledonse

Subclass: Rosida

Order: Celastrales

Family: Celastraceae

Genus: *Salacia*

Species: *Chinensis*

Binomial name: *Salacia chinensis*

Distribution

The species is widely distributed across tropical and subtropical regions of the world. It is prevalent in India, Sri Lanka, China, Thailand, Indonesia and Brazil. In India, it mainly occurs in pockets around the Sahyadri-Konkan corridor area of Western Ghats (Keeragalaarachchi *et al.,* 2016).

Chemical Composition

Salacia chinensis contains a variety of major bioactive compounds that contribute to its medicinal properties. These include salacinol, kotalanol, neokotalanol, neosalacinol, mangiferin, salaprinol, phenolic glycosides, and triterpenes. These compounds together help in treating wide range of conditions, such as diabetes, inflammation, tumors, cardiac disorders and cancer (Majid *et al*., 2016).

Ecology

In India, flowering and fruiting occurs from February to March. This species thrives in warm and humid regions with an annual rainfall ranging from 1100 to 2500 mm and elevation of 750 meters from the sea level. It tolerates minimum temperature of 10-15°C and maximum temperature of 35-40°C. Sandy loam to clay loam, preferably acidic to neutral soils are best suitable for its cultivation.

Plant Description

It is a perennial climbing shrub characterized by slender, twining stems. The leaves are simple, opposite, and exhibit an elliptic to ovate shape, with a glossy dark green appearance and finely serrated edges. The plant produces small, clustered flowers that are typically yellowish-green or white, leading to the formation of bright reddish-orange berries containing numerous seeds covered by mucilaginous aril.

Phenotypic attributes of *Salacia chinensis:*

A) Plant B) Inflorescence C) Flower D) Fruit D) Root E) Stem

Propagation

It can be propagated through both sexual and asexual methods, although natural regeneration is generally slow. Seed propagation is the most common traditional method, in which fully mature and ripe fruits are collected, and seeds are extracted after removing the fleshy pulp and mucilaginous aril. Fresh seeds show better germination, as seed viability declines rapidly during storage. Seeds are usually sown in nursery beds or polybags filled with well-drained soil mixtures such as soil, sand and farmyard manure; however, germination is often slow and irregular, taking several weeks to months. To overcome these limitations and to ensure true-to-type planting material, vegetative propagation methods such as stem cuttings, root cuttings and air layering are increasingly preferred. Semi-hardwood stem cuttings treated with rooting hormones like indole-3-butyric acid (IBA) improve rooting and survival, while air layering during the active growing season has been found effective in producing well-established plants suitable for field planting (Bagnazari *et al.,* 2017). In addition, micropropagation and tissue culture techniques have been explored for rapid multiplication and conservation, offering scope for large-scale production of uniform, disease-free plants and reducing pressure on natural populations.

Harvesting

Harvesting involves collection of its roots, leaves, and fruits, which are used for their medicinal properties. Roots are harvested from late autumn to early spring which lasts for about 4-6 months. Leaves can be harvested throughout the growing seasons, which lasts for about 6-8 months depending on environmental conditions. They can be picked multiple times during this period as new growth occurs. The fruits ripen from spring to late summer, taking about 3-5 months from flowering to harvesting.

Medicinal Uses

Salacia chinensis is highly valued for its broad spectrum of medicinal properties and has been extensively used in traditional systems of medicine such as Ayurveda and Unani, particularly for the management of diabetes. Along with related species including *S. reticulata* and *S. oblonga*, it is recognized as an effective antidiabetic plant, with the roots and fruits constituting the most important medicinal parts. Bioactive compounds such as salacinol and kotalanol inhibit carbohydrate digestion by suppressing α-glucosidase activity, thereby regulating post-prandial blood glucose levels and improving insulin sensitivity (Ghadage *et al.,* 2017). Beyond its antidiabetic action, *Salacia chinensis* exhibits potent anti-inflammatory and antioxidant properties, which contribute to the reduction of inflammation and oxidative stress. The plant also supports cardiovascular health by improving lipid profiles and controlling dyslipidaemia, while emerging studies indicate its potential anticancer activity through inhibition of tumour growth (Nikule *et al.,* 2024). Traditionally, it has been used as a tonic and blood purifier and for the treatment of obesity, digestive disorders, amenorrhoea, dysmenorrhoea, rheumatism, skin diseases, asthma and gonorrhoea. Through its multi-targeted action mediated by compounds such as mangiferin, salacinol, kotalanol and kotalagenin derivatives, *Salacia chinensis* continues to gain significance as a promising therapeutic plant with growing applications in herbal medicine, pharmaceuticals and nutraceuticals.

Need for Conservation

Salacia chinensis is a medicinal climber of high therapeutic importance; however, its natural populations are increasingly threatened by overexploitation, habitat loss and unsustainable harvesting practices, particularly the indiscriminate removal of roots and stem bark for medicinal purposes. The species exhibits slow natural regeneration and poor seed germination, which severely restrict its capacity for recovery in the wild. In addition, agricultural expansion, deforestation in the Western Ghats and rising commercial demand from pharmaceutical and nutraceutical industries have led to a marked decline in its natural distribution. In this context, the conservation of *Salacia chinensis* has become imperative to ensure its long-term survival and sustainable utilization. The adoption of regulated and sustainable harvesting methods, promotion of systematic cultivation, development of efficient vegetative and *in vitro* propagation techniques and protection of natural habitats through *in situ* and *ex situ* conservation strategies are essential to safeguard this valuable medicinal plant for future generations.

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Insects: Not Only Harm Us but Also Benefit Us a Lot

Article ID: 72592

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Abstracts

Insects are commonly perceived as harmful organisms due to their role in crop damage and disease transmission; however, this view overlooks their immense ecological and economic value. This article highlights the dual role of insects by emphasizing their beneficial contributions alongside their harmful impacts. Insects play vital roles in ecosystem functioning through pollination, nutrient recycling, biological control, and soil improvement, thereby supporting agricultural productivity and food security. They also contribute significantly to human health and livelihoods through products such as honey, silk, and lac, and through their use in medical and pharmaceutical applications. Although certain insect species act as pests or disease vectors, sustainable management approaches such as integrated pest management promote coexistence by minimizing harm while conserving beneficial insect populations. Recognizing the positive role of insects is essential for achieving ecological balance, sustainable agriculture, and long-term human well-being.

Keywords: Beneficial insects, Natural enemies, insect pests etc.

Introduction

When we hear the word *insect*, most of us immediately think of mosquitoes, crop pests, or insects that bite, sting, or damage food. Because of this, insects are often seen only as harmful organisms. However, this view tells only half the story. In reality, insects are among the **most beneficial living organisms on Earth**, playing crucial roles in agriculture, ecosystems, human health, and even industry. Without insects, life on our planet would be severely disrupted.

Insects as Essential Ecosystem Engineers

Insects are key components of natural ecosystems. They help maintain ecological balance by acting as **pollinators, decomposers, predators, and prey**. Many flowering plants depend on insects for pollination, which is essential for seed and fruit production. Bees, butterflies, moths, flies, and beetles pollinate nearly **75% of the world's leading food crops**, directly supporting global food security (FAO, 2019). Insects also contribute to nutrient cycling. Dung beetles, ants, and termites break down organic matter, animal waste, and dead plants, returning nutrients to the soil and improving soil structure. Termites, for example, enhance soil aeration and water infiltration, which benefits plant growth, especially in tropical ecosystems (Bignell, Roisin, & Lo, 2011).

Friends of Farmers: Insects in Agriculture

While some insects are crop pests, many others are **natural enemies** that protect crops. Ladybird beetles, lacewings, spiders, parasitoid wasps, and predatory bugs feed on aphids, caterpillars, and other harmful pests. These beneficial insects form the backbone of **biological control**, reducing the need for chemical pesticides and promoting sustainable agriculture (van Lenteren et al., 2018).

Insects also help farmers indirectly by pollinating crops such as rice-adjacent vegetables, fruits, oilseeds, and pulses. Crops like mustard, sunflower, apple, mango, and many vegetables show increased yield and quality when insect pollinators are present (Klein et al., 2007).

Insects and Human Health

Insects have contributed significantly to **medical science**. Honey produced by honeybees has well-documented antibacterial and wound-healing properties. Maggots of certain fly species are used in **maggot therapy** to clean infected wounds by removing dead tissue without harming healthy cells (Sherman, 2009).

Insects have also inspired modern medicines. Compounds derived from insects show promise in treating infections, inflammation, and even cancer. For example, antimicrobial peptides isolated from insects are being studied as alternatives to antibiotics in the fight against drug-resistant bacteria (Ratcliffe, Azambuja, & Mello, 2014).

Insects as Food and Livelihood Sources

In many parts of the world, insects are an important source of nutrition. Edible insects such as crickets, grasshoppers, termites, silkworms, and beetle larvae are rich in **protein, healthy fats, vitamins, and minerals**. The Food and Agriculture Organization (FAO) recognizes edible insects as a sustainable food source that can help address future food shortages (FAO, 2013).

Insects also support rural livelihoods. Beekeeping, sericulture (silk production), lac cultivation, and biological control enterprises generate income for millions of people, particularly in developing countries like India. Silk produced by silkworms and lac secreted by lac insects are valuable natural products used in textiles, cosmetics, medicines, and industry.

The Downside: When Insects Become Harmful

Despite their benefits, some insects do cause serious problems. Crop pests reduce agricultural yields, and disease vectors such as mosquitoes transmit malaria, dengue, chikungunya, and other illnesses. However, scientists now emphasize **balanced management rather than indiscriminate elimination**. Excessive pesticide use harms beneficial insects and disrupts ecosystems, often making pest problems worse in the long run.

Living with Insects, Not Against Them

Insects are not enemies by default. They are **essential partners in sustaining life on Earth**. The challenge before humanity is to manage harmful insects wisely while conserving and promoting beneficial ones. Approaches such as **integrated pest management (IPM)**, habitat conservation, and pollinator-friendly farming help achieve this balance.

Understanding the positive roles of insects can change our perspective—from fear and destruction to appreciation and coexistence. Insects may be small, but their contribution to our survival is enormous.

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Sweet Tamarind (*Pithecellobium dulce*): Nutraceutical Potential and Ethnobotanical Importance

Article ID: 72593

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Botanical Name: *Pithecellobium dulce* (Roxb.) Benth. (*Inga dulcis* Roxb.)

Common Name: *Jilapi Fal* (Bengali), *Jungle Jalebi* (Hindi), Sweet Tamarind (English)

Family: Fabaceae

Part Used: Bark, leaves, seeds, pulp.

Abstract
Sweet tamarind (*Pithecellobium dulce* (Roxb.) Benth.) is an underutilised multipurpose tree valued for its edible fruit pulp, medicinal properties, and adaptability to diverse environmental conditions. Native to Central and South America and Mexico, the species is now widely naturalised across India and Southeast Asia. The fruit pulp is nutritionally rich, containing 75–78% moisture, 2–3.3 g protein, 18–19.6 g carbohydrates, essential minerals, and vitamins, including vitamin C and B-complex vitamins. Traditionally, various plant parts, including bark, leaves, seeds, and pulp are used in indigenous medicine to treat disorders such as dysentery, ulcers, chest congestion, and digestive problems. The tree also serves as fodder, a hedging plant, and a source of protein-rich seed residue. Owing to its nutritive value, medicinal relevance, and multipurpose utility, *P. dulce* holds significant potential for wider utilisation in food, health, and agroforestry systems.

Keywords: *Pithecellobium dulce*, *Inga dulcis,* Nutritive value, Morphology, Traditional uses.

Introduction
Sweet tamarind (*Pithecellobium dulce* (Roxb.) Benth.), locally known as *Jilapi Fal* (Bengali), is an evergreen tree belonging to the family Fabaceae. The species thrives in dry and semi-arid conditions and is commonly planted as a hedgerow, roadside tree, or multipurpose agroforestry component. Botanically, the tree is characterised by paired spines, grey bark that becomes furrowed with age, and bipinnate leaves with distinct glands. It bears round clusters of greenish-white flowers from December to May, followed by twisted pods containing pink or white edible pulp and dark glossy seeds. Fruits mature between February and August. Nutritionally, sweet tamarind pulp is a rich source of carbohydrates (18.2–19.6 g), protein (2–3.3 g), dietary fibre, and essential micronutrients such as calcium, phosphorus, iron, vitamin C, and B-complex vitamins per 100 g of edible portion. These components support its classification as a nutritionally valuable minor fruit. Beyond its edible pulp, seed-extracted cake and leaves are also used as feed for livestock. Traditional medicinal uses of *P. dulce* further emphasize its importance. The fruit pulp is taken for hemoptysis, seeds are used for ulcers and chest congestion, leaves treat sores, and root bark is used for dysentery. With its wide utility, rich nutrition, and adaptability, sweet tamarind is a promising underutilised fruit that offers strong potential for domestication and value addition.

Origin and Distribution
Pithecellobium dulce (Roxb.) is endemic to Central America, South America and Mexico. It was introduced in Indonesia and the Philippines by the Portuguese and Spaniards, respectively. It is widespread in Malaysia, India and Thailand (Verheij and Coronel, 1991; Hocking, 1993).

Morphology
This evergreen tree features spines on its branches and leaves that are bipinnate with just one pair of pinnae. Height of the plant more than 20 meter reported . The bark is grey and smooth in young trees, becoming slightly rough and furrowed in old trees. Leaves are oval or elliptic-oblong in shape measuring

2–4 cm in length with a bipenate arrangement, often with a pair of sharp spines at the base of the leaf. You can find small glands at the junction where the pinnae meet the leaflets. The tree produces greenish-white flowers arranged in rounded clusters within panicles. The calyx is about 1 millimetre long, the hairy corolla measures 3-4 millimetre in length and the stamens extend outward. Each flower is 0.3 to 0.5 cm long with hairy corolla and calyx. Flowering generally occurs between December and May. Its pod grows to be 10-13 centimetre long, twisted and swollen, typically containing 5-9 seeds, the seeds are reddish brown to black, elliptical, beanlike, and about 1 cm in length and it has pink or white pulp. Fruits are matured and obtained from February to August. (Nazar *et al.*, 2022; Lal and Nath, 2017).

Nutritive Value

Component	Composition (100 g of pulp)
Moisture	75.8-77.8 g
Protein	23.3 g
Fat	0.40.5 g
Carbohydrate	18.2-19.6 g
Fibre	1.1-1.2 g
Ca	13 mg
P	42 mg
Fe	0.5 mg
Vitamin A	25 IU
Vitamin B1	0.24 mg
Vitamin B2	0.1 mg
Vitamin B3	0.6 mg
Vitamin C	13.8mg



Traditional Uses

The edible pulp is consumed fresh and seeds are also edible and contain about 17% oil**,** while the residue left after oil extraction is rich in 30% protein, suitable for livestock feed. The leaves contain 29% crude protein and are used for livestock fodder in some areas (Lal and Nath, 2017). Fruit pulp is administered orally to halt blood flow in case of hemoptysis. The seed juice is breathed into the nostrils against chest congestion and pulverized seeds are swallowed for internal ulcers. The leaves, when used as a plaster, may ease discomfort of venereal sores and consumed with salt can heal dyspepsia, but can also trigger abortion. The root bark may be used to alleviate dysentery (Jain and De Filipps , 1991; Nordal, 1963). The wood is not commercially used as timber because of its irregular growth habit and branchiness. In South India, the plant is primarily valued for its effectiveness as a hedging species.

Conclusion

Sweet tamarind (*Pithecellobium dulce*) is a highly versatile fruit bearing tree that combines nutritional value, medicinal importance and ecological adaptability. Its seeds and foliage are important sources of protein for both humans and livestock, and its pulp is full of essential nutrients and vitamins. Its therapeutic value is further demonstrated by the fact that traditional medical systems have long used its bark, leaves, seeds, and pulp to treat a variety of illnesses.

Despite these advantages, the species remains largely underutilized, cultivated mainly in hedgerows or unmanaged areas rather than in organized orchards. Despite these advantages, the species remains underutilized, cultivated mainly in hedgerows or unmanaged areas rather than in organized orchards. Expanding scientific attention, promoting value added products, and integrating the species into agroforestry or commercial horticulture could unlock its full potential as a nutraceutical and economically important minor fruit crop.

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The Future Is Circular: Why Waste Management Matters Today

Article ID: 72594

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Waste is no longer just a cleanliness issue; it is a climate, health, and justice issue that begins at our doorstep and ends in our ecosystems. Managing it wisely is one of the simplest ways citizens, communities, and governments can work together for a healthier, fairer future.

Why Waste Management Matters?

Cities across the world generate billions of tonnes of solid waste every year, and this volume is rising with urbanization, changing lifestyles, and consumerism. When this waste is dumped in open sites or poorly managed landfills, it contaminates soil and water, attracts disease vectors, and releases methane, a potent greenhouse gas that accelerates climate change.

In many developing countries, including India, a large share of municipal budgets is spent on waste collection and disposal, yet piles of mixed garbage still line streets and drains, revealing gaps in planning, infrastructure, and public participation.

From Garbage to Resource: The 3R–5R Mindset

Modern waste management is built on a hierarchy: first refuse and reduce, then reuse and repair, and only after that recycle or recover energy from what is left. This pyramid reminds us that the most sustainable waste is the waste that never gets created in the first place.

Concepts like the “5 Rs” (refuse, reduce, reuse, repurpose, recycle) and even “7 Rs” extend this mindset, encouraging people to question every purchase, stretch the life of products, and see discarded materials as inputs to a circular economy rather than as trash to be hidden away.

India’s Waste Challenge and Opportunity

India generates tens of millions of tonnes of municipal solid waste annually, and only a part of it is scientifically processed; the rest often ends up in dumpsites that leak leachate, emit toxic smoke, and occupy valuable land on the periphery of fast-growing cities. At the same time, thousands of informal waste pickers play a crucial but under-recognized role by recovering recyclables from streets, bins, and landfills, saving municipalities money and reducing environmental burdens.

Policy reforms, such as the Solid Waste Management Rules 2016 and sector-specific rules for plastic, biomedical, e-waste and others, have expanded responsibility from municipalities alone to every waste generator, including households, institutions, and industries. Initiatives like Swachh Bharat Mission have brought waste and cleanliness into mainstream public discourse, triggering investments in segregation, collection, and processing infrastructure across urban and rural areas.

What can Households and Communities do?

The most powerful change begins at the source: simple practices like separating wet (biodegradable) waste from dry (recyclable) and hazardous waste at home determine whether materials can be recovered or are condemned to dumps. Kitchen and garden waste, which make up a large share of household garbage, can be turned into compost through home or community systems, reducing landfill load and closing the nutrient loop for urban gardens and farms.

Everyday choices—carrying a cloth bag, refusing unnecessary single-use plastics, buying in bulk instead of heavily packaged items, and switching to durable, repairable products—quietly but steadily shrink a household’s waste footprint. Parents and schools can turn waste segregation, upcycling, and composting into hands-on projects for children, building environmental responsibility as a life skill rather than a one-time campaign.

The Road Ahead: From Linear to Circular

Traditional "take–make–dispose" models treat nature as an infinite supplier and a bottomless bin, but mounting waste mountains and climate threats show this assumption is no longer tenable. A circular economic approach designs products for durability, repair, and recyclability, builds systems to recover materials at every stage, and integrates waste management with climate, health, and livelihood goals.

Technology—such as decentralized composting, biogas plants, material recovery facilities, and advanced recycling—can only succeed when it is matched by social innovation: informed citizens, responsive local governments, and inclusive policies that recognize and support informal workers in the waste value chain. Ultimately, waste management is not a service delivered to passive consumers; it is a shared civic practice that reflects how seriously society takes the rights of future generations to clean air, safe water, and a livable planet.

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Burning Crop Residues: A Hidden Crisis for Soil, Health and Climate

Article ID: 72595

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Each year, in parts of India and many other countries, farmers burn leftover stalks, straw, and stubble after harvesting crops such as rice and wheat to quickly clear fields for the next season. While this practice appears easy and cost-free in the short term, research increasingly shows that crop residue burning (CRB) causes serious and long-lasting damage to soil health, biodiversity, human health, and the climate.

Burning agricultural residue is not merely a "rural farm issue." Its impacts ripple across ecosystems, cities, public health systems, and food security. Poor air quality and smog affect millions not only in farming regions but also in distant urban centers hundreds of kilometers away (Lan *et al.*, 2022). Soil degradation threatens long-term agricultural sustainability; declining productivity can translate into higher food prices, greater dependence on chemical fertilizers, and weakened food security. Meanwhile, greenhouse gas (GHG) emissions from burning accelerate climate change; disrupting rainfall patterns, intensifying drought risk, and altering monsoon ultimately harm agriculture itself.

What is Crop Residue Burning and Why Does it Happens?

After harvesting cereal crops such as rice, wheat, maize, and millets, large quantities of straw and stubble remain on fields. In many farming systems especially where landholdings are small, farmers burn this residue to clear fields rapidly. The practice peaks during post-harvest seasons when farmers face a narrow window to prepare land for the next crop. Burning is often viewed as cheap, convenient, and labour saving compared with alternative residue management methods that require machinery, labour, or technical support. However, this "quick fix" comes at a substantial environmental, economic, and social cost.

Environmental and Soil Impacts of Crop Residue Burning

Loss of soil fertility: Burning destroys a significant share of the nutrients and organic matter returned to the soil through crop residues. Essential elements such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and organic carbon are lost during combustion. Studies show that residue burning can raise soil temperature in the top 0–1 cm layer to approximately 33.8–42.2 °C**,** killing beneficial soil microorganisms responsible for nutrient cycling and soil aggregation (www.downtoearth.org.in). The loss of organic matter and microbial life degrades soil structure, reducing its ability to retain water and nutrients and ultimately lowering soil fertility (Singh *et al.*, 2022).

Loss of biodiversity & ecosystem health: Crop residue burning affects far more than just soil chemistry. It kills insects, earthworms, decomposers, and other organisms that maintain healthy agro-ecosystems. With natural predators eliminated, populations of pests such as nematodes, rodents, and harmful insects often increase. As a result, farmers become more dependent on chemical fertilizers and pesticides, reinforcing a vicious cycle of ecological degradation. Over time, declining biodiversity and weakened soils make farms more vulnerable to droughts, floods, pest outbreaks, and climate variability (Kumar *et al.*, 2024).

Air pollution & climate change: Residue burning releases large amounts of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). It also emits particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and other toxic pollutants that severely degrade air quality.

In densely populated regions, smoke travels long distances, contributing to smog episodes in urban areas. Thus, CRB is not just a rural concern, urban air quality and public health suffer significantly as well (India Water Portal).

Public health consequences: The health impacts of crop residue burning are immediate and severe. Fine particulate matter and toxic gases aggravate respiratory diseases such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). Exposure can also cause eye and skin irritation, headaches, nausea, and cardiovascular stress (Raza *et al.*, 2022).

Vulnerable populations including children, the elderly, and individuals with pre-existing health conditions are particularly at risk, especially in densely populated regions where pollutants accumulate (India Water Portal).

Economic & agricultural impacts: Declining soil fertility leads to lower yields over time, reducing farm profitability and threatening food security (Singh *et al.*, 2022). Increased pest pressure and degraded soil health force farmers to rely more heavily on fertilizers and pesticides, raising input costs and further undermining long-term sustainability. At a broader scale, the combined costs of health care, environmental degradation and productivity loss place a significant burden on the economy.

Why do Farmers Continue to Burn Residues?

Despite its known harm, many farmers continue residue burning due to structural and economic constraints:

1. Speed and convenience: The short interval between harvesting and sowing leaves little time for alternative residue management (Bhuvaneshwari *et al.*, 2019).

2. Low awareness: Some farmers underestimate the long-term damage to soil and health or are unaware of viable alternatives.

3. Limited access to machinery: Many farmers lack affordable access to mulchers, rotavators, zero-tillage seeders, or residue-incorporation equipment (Bhuvaneshwari *et al.*, 2019).

4. Economic pressure: In intensive cropping systems such as rice–wheat rotations, rapid field turnover appears economically rational, even if it is environmentally damaging.

Sustainable Alternatives & Solutions

Several proven approaches can reduce or eliminate the need for burning:

1. In-situ residue incorporation: Ploughing residues back into the soil restores organic matter and nutrients, improving soil health (Porichha *et al.*, 2021).

2. Mechanised residue management: Mulchers, rotavators, zero-till seed drills, and other CRM tools allow residue handling without burning (Bhuvaneshwari *et al.*, 2019).

3. Value-added uses: Crop residues can be converted into biogas, compost, bio-fertilizers, or other biomass-based products, turning waste into income (Porichha *et al.*, 2021).

4. Policy and institutional support: Subsidies for machinery, farmer training programmes, and enforcement of burning regulations are essential.

5. Improved crop planning: Adjusting sowing schedules and cropping patterns can reduce time pressure and dependence on burning (Bhuvaneshwari *et al.*, 2019).

Conclusion

Crop residue burning may offer short-term convenience, but its long-term costs to soil fertility, biodiversity, air quality, human health, and climate are immense. Countries like India cannot afford to ignore these impacts if they aim for sustainable agriculture, resilient food systems, and healthy communities. Transitioning to sustainable residue-management practices such as incorporation, composting, biomass reuse, and mechanized solutions is no longer optional; it is essential. With adequate awareness, incentives, and institutional support, farmers can protect their land, their livelihoods, and the air we all breathe.

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Blooming Love: The Art and Science of Wedding Floristry

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Introduction

Wedding floristry is much more than arranging flowers—it's a sophisticated blend of science and art that creates unforgettable memories for one of life's most cherished celebrations. When viewed through the lens of floriculture, wedding floristry takes on an even deeper meaning. Rooted in the cultivation of ornamental plants and flowers, floriculture provides the essential foundation upon which wedding florists craft their masterpieces. From selecting blooms that thrive in specific climates to ensuring the longevity of arrangements on the big day, floriculture plays a pivotal role in enhancing the beauty and ambiance of weddings. This journey of flowers begins in lush fields and advanced greenhouses, where they are carefully grown and nurtured. These blossoms are then transformed by skilled florists into breathtaking floral designs, from the enchanting bridal bouquet that embodies a love story to the delicate centerpieces that set the mood for the celebration. Advancements in floriculture are shaping not only the aesthetics of wedding floristry but also its sustainability, fostering a profound connection between nature and nuptials. Together, wedding floristry and floriculture encapsulate creativity, craftsmanship, and a commitment to making weddings as beautiful and meaningful as the love they celebrate.

How are Flowers Grown and Prepared?

The journey of flowers begins in fields and greenhouses where floriculturists grow them with precision and care. Each plant is nurtured using optimal techniques, from selecting the best seeds and soil to ensuring proper watering and temperature conditions. Floriculturists monitor the growth process closely to maintain the health, beauty, and fragrance of the blooms. Once the flowers reach their peak, they are harvested carefully to preserve their freshness and quality. Post-harvest, flowers are prepared through cleaning, trimming, and hydration treatments to keep them vibrant and long-lasting.

From Greenhouses to Wedding Venues

After preparation, the flowers embark on their next journey. They are transported from greenhouses to florists, who use them to design exquisite wedding arrangements. Logistics are key at this stage- flowers are packaged securely and stored in temperature-controlled environments to avoid damage during transit. Upon arrival at wedding venues, florists arrange the blooms into stunning creations such as bridal bouquets, centrepieces, and decorative arches. This final transformation brings the vision of the couple to life, making the wedding venue truly magical.

Choosing the Right Flowers

Picking Flowers That Match the Season: Seasonality is one of the most practical and cost-effective factors in wedding flower selection. Choosing flowers that bloom naturally during the wedding season ensures not only their freshness and availability but also aligns the aesthetic with the beauty of the surrounding environment. Here's a deeper look at seasonal flower choices:

a. **Spring weddings:** Spring is synonymous with renewal and vibrant blossoms. Flowers like tulips, peonies, daffodils, and cherry blossoms are in their prime. They add soft, fresh colors and delicate fragrances, perfect for romantic and cheerful themes.

b. **Summer weddings:** Summer weddings offer a wide array of bold and bright options. Roses, hydrangeas, sunflowers, and dahlias are popular. These flowers handle the heat better and maintain their vibrant hues, complementing outdoor or beach weddings.

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c. Autumn weddings: Autumn flowers like marigolds, chrysanthemums, and dahlias bring warm, earthy tones such as orange, yellow, and deep red. These flowers beautifully reflect the rustic and cozy feel of fall weddings.

d. Winter weddings: For winter weddings, classic choices like amaryllis, poinsettias, anemones, and roses are ideal. They pair well with evergreen foliage like pine or holly, adding to the seasonal charm of a winter wonderland theme.

Decoration with Tulips

Decoration with Roses

Decoration with Marigold

Decoration with Poinsettia

Considering the Climate and Theme of the Wedding

1. Climate Compatibility: When choosing flowers, it's vital to consider both the climate of the wedding location and the theme. Here's how to approach it practically:

a. Hot or Humid Climates: Choose hardy flowers like marigold, zinnia, bird of paradise, heliconia, carnations, tropical orchids like vanda and succulents which can withstand heat without wilting.

b. Cool Climates: Roses, tulips, or lilies are better suited as they remain fresh longer in cooler weather.

2. Aligning with Wedding Themes: Every wedding theme can be enhanced with the right floral choices. Below are practical tips for flower selection based on some popular wedding styles

a. Rustic or Bohemian Weddings: Think about wildflowers, daisies, baby's breath, sunflowers, and eucalyptus. These flowers bring a natural, laid-back vibe. Pairing them with earthy elements like wooden containers or mason jars ties the theme together seamlessly.

b. Elegant or Traditional Weddings: Classic flowers like roses, lilies, peonies, and orchids are timeless for formal weddings. Opt for monochromatic or soft pastel palettes to create a sophisticated look. Arrangements in crystal or metallic vases add a touch of grandeur.

c. Tropical or Beach Weddings: Tropical flowers such as hibiscus, anthuriums, and orchids bring bold, exotic beauty to a beach setting. Pairing these with palm fronds and other greenery gives a lush and vibrant feel.

d. Whimsical or Garden-Themed Weddings: Choose playful flowers like sweet peas, ranunculus, and delphiniums in a mix of pastel hues. These create a dreamy, enchanted garden atmosphere.

e. Seasonal or Festive Weddings: For seasonal weddings like Christmas or autumn-themed events, incorporate poinsettias, holly berries, pine, or fall foliage to harmonize with the festive mood.

Creating Floral Designs

Bridal Bouquets and Wedding Decorations

1. Bridal Bouquets: When designing the bridal bouquet, florists often start by considering the bride's dress and overall style. For instance, a sleek, modern gown pairs well with minimalist bouquets featuring single-type flowers like white calla lilies. For a romantic, flowing dress, a cascading bouquet with orchids, roses, and ivy adds a dramatic touch.

a. Use sturdy stems and a well-secured base to ensure the bouquet stays intact throughout the day.

b. Select flowers with long-lasting freshness, such as carnations or roses, especially for outdoor weddings.

2. Wedding Decorations: Decorations should enhance the venue while being practical for the setting. For example:

a. Table Centrepieces: Use low arrangements for intimate dining settings or tall ones for grand venues. Choose vases or containers that prevent tipping and keep flowers hydrated throughout the event.

b. Aisle Decorations: Opt for small clusters of flowers tied to chairs or placed on stands for easy setup and removal.

c. Floral Arches: Use durable flowers like chrysanthemums or proteas for outdoor arches exposed to wind or sunlight, and secure the arrangements with floral foam or zip ties.

		
Bridal bouquet	**Table Centerpieces**	**Floral Arches**

Sustainability in Floristry

Incorporating eco-friendly flowers and sustainable practices into wedding floristry is a growing trend that blends beauty with responsibility. Choosing seasonal and locally grown flowers minimizes transportation emissions and ensures freshness, while organic blooms cultivated without synthetic pesticides offer a healthier and greener option. Innovative ideas, such as dried flowers or preserved greenery, provide long-lasting, reusable alternatives for decorations. Florists are also embracing foam-free arrangements, using biodegradable materials like chicken wire or reusable frames, to reduce environmental waste. Repurposing flowers from the ceremony for the reception and donating leftover blooms to charitable causes further enhances sustainability.

Nature and Weddings

Flowers are a beautiful bridge between nature and celebrations, especially weddings, where they bring the calming essence of the outdoors to life's most cherished moments. Their presence transforms venues into living sanctuaries, blending natural beauty with human connection. With vibrant colors, intricate textures, and soothing fragrances, flowers create an atmosphere that feels both magical and authentic.

Beyond their aesthetic appeal, flowers carry deep emotional significance, symbolizing love, unity, and new beginnings. Each bloom conveys a unique message—from roses representing eternal love to lilies signifying purity—adding meaning to every arrangement. The bride's bouquet, a personal reflection of her style and story, becomes a cherished centerpiece, while floral decorations around the venue unite guests in an ambiance of joy and warmth.

Conclusion

Wedding floristry beautifully combines the science of floriculture with creative artistry to craft unforgettable celebrations. From cultivating and preparing flowers to designing stunning arrangements, it reflects both precision and passion. Choosing the right blooms involves considering seasonality, climate, and theme, ensuring designs that are both practical and visually captivating.

Sustainable practices, such as using locally grown flowers and eco-friendly materials, enhance the beauty of weddings while minimizing environmental impact. Beyond aesthetics, flowers carry deep emotional significance, symbolizing love, unity, and hope. By connecting nature with celebrations, they transform weddings into profound and lasting memories of beauty and joy.

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Extension Strategies for Promoting Organic and Natural Horticulture Produce: Certification, Niche Markets, and Consumer Awareness

Article ID: 72597

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Introduction: The Quiet Revolution in Our Fields

Beneath the well-documented narrative of India's record-breaking horticultural output—crossing **350 million tonnes**—a transformative, soil-deep revolution is taking root. The organic and natural horticulture sector, once a niche pursued by a few, is now a dynamic frontier of Indian agriculture. According to the **World of Organic Agriculture 2023 report (FiBL)**, India holds the position of the world's **largest number of organic producers (1.6 million)** and has seen its area under organic certification grow steadily. The export of organic products reached **USD 708 million in FY 2022-23**, with horticultural produce like bananas, mangoes, and medicinal plants leading the charge (APEDA).

However, the domestic market remains a sleeping giant. The core challenge is no longer production alone, but the creation of a robust, trustworthy, and consumer-driven ecosystem. This article deconstructs the essential extension strategies needed to bridge the gap between the devoted farmer and the conscious consumer, focusing on the triad of **credible certification, niche market development, and targeted consumer awareness.**

Pillar I: Certification - The Non-Negotiable Foundation of Trust

Certification is the linchpin that converts a claim into a credible market asset. In India, a multi-layered system exists, and understanding it is the first step for any extension strategy.

1. The Institutional Framework:

a. National Programme for Organic Production (NPOP): Governed by APEDA, this is India's premier accreditation program, recognized by the European Union and Switzerland, facilitating seamless exports.

b. Participatory Guarantee System (PGS-India): Managed by the Ministry of Agriculture, this is a low-cost, peer-review certification system ideal for the domestic market and small farmers. **As**

of March 2024, over 4.5 lakh farmers are registered under PGS-India, a testament to its scalability (MoA&FW).

c. Food Safety and Standards (Organic Foods) Regulations, 2017: This mandates that any product sold as "organic" in India must carry the certification logo of either NPOP or PGS-India.

Extension Strategy Imperative:

a. Demystification Drives: Extension agents must conduct workshops using clear flowcharts and vernacular materials to explain the processes, costs, and benefits of NPOP vs. PGS.

b. Cluster Approach: Promote certification for farmer-producer organizations (FPOs) rather than individual smallholders to reduce cost and administrative burden.

c. Digital Integration: Leverage platforms like **Jaivik Kheti** portal for online management of PGS documentation, making the process transparent and accessible.

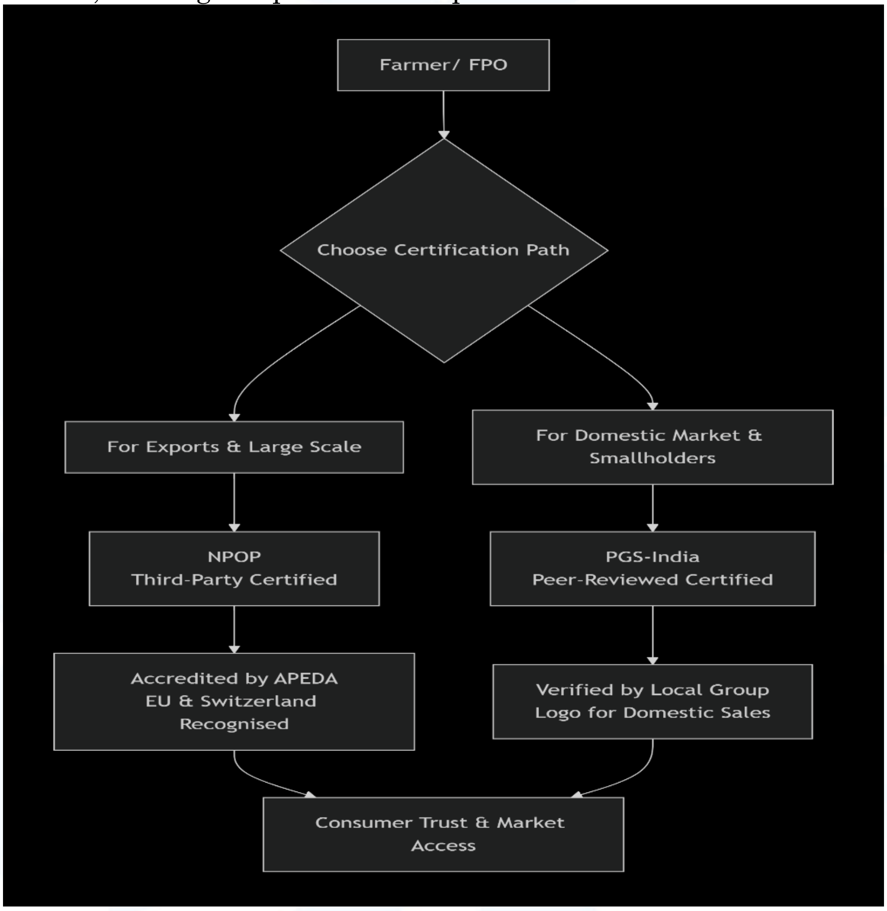

Diagram: Decision pathway for organic certification in India.

Pillar II: Identifying and Cultivating Niche Markets

The "one-size-fits-all" approach fails in organic marketing. Success lies in precise segmentation and value proposition.

1. High-Value Export Niches:

a. Climate-Smart Produce: Organic turmeric and ginger with high curcumin/gingerol content for the health supplements market in the USA and EU.

b. Superfoods: Moringa powder, amla berries, and dragon fruit targeting the global health-food segment.

c. Ethical Luxury: Heirloom varieties of mangoes (like **Langra** or **Chausa**) and pomegranates, branded with their Geographical Indication (GI) and organic status, for premium gift markets in the Gulf and Southeast Asia.

2. Burgeoning Domestic Niches:

a. Organic Baby Food: Perhaps the most sensitive and rapidly growing segment. Purees of banana, apple, and carrot require guaranteed zero-residue produce.

b. Wellness & Ayurveda Connect: Positioning organic horticulture as the authentic raw material for the booming Ayurvedic and wellness industry. A study by **IMARC Group (2023)** valued the Indian Ayurvedic market at **USD 10.6 billion**, growing at 15.5% CAGR.

c. Institutional Procurement: Targeting farm-to-table restaurants, premium hotel chains, and corporate cafeterias that are increasingly sourcing clean, traceable ingredients.

Niche Market	Target Crop Examples	Key Value Proposition	Potential Channels
Export - Superfoods	Moringa, Amla, Dragon Fruit	High nutrient density, traceability	B2B to global nutraceutical cos., online platforms (Amazon US, iHerb)
Domestic - Baby Food	Banana, Apple, Carrot, Sweet Potato	Absolute safety, zero pesticide residue	Tie-ups with brands (Slurrp Farm, Little Bowl), branded FPO products
Domestic - Wellness	Tulsi, Aloe Vera, Turmeric, Ginger	Authentic, chemical-free Ayurvedic input	Direct supply to Ayurvedic pharmacies, wellness resorts, e-commerce
Premium Gifting	GI-tagged Mangoes, Pomegranates	Exclusivity, heritage, superior taste	Curated gift boxes, online gourmet stores, airport retail

Table: Identifying and strategizing for niche markets in organic horticulture

Pillar III: Consumer Awareness: Bridging the Trust Gap

A 2022 consumer survey by **Associated Chambers of Commerce and Industry of India (ASSOCHAM)** revealed that while **65% of urban Indian consumers expressed interest in organic food, over 70% cited lack of trust and clarity in certification as a major barrier**.

Data-Driven Extension Strategies for Awareness:

a. Hyper-Local "See & Believe" Models:

i. Develop **Organic Demonstration Clusters** near urban peripheries. Facilitate "Pick-Your-Own" events and farm tours, making the organic process visible and tangible.

ii. Promote **Community Supported Agriculture (CSA)** boxes, directly linking a group of consumers to a single certified farm, fostering transparency and community.

b. Leverage Digital Storytelling:

i. Equip FPOs with tools to create simple video documentaries showcasing their certification journey, soil health practices, and farmer stories for social media (WhatsApp, Instagram).

ii. Utilize QR codes on packaging that link to the farm's PGS-India certification page or a short video of the farm, providing instant verification.

c. Strategic Partnerships for Credibility:

i. Partner with **pediatricians, nutritionists, and fitness influencers** who can credibly communicate the health benefits of residue-free produce to specific segments like new parents or fitness enthusiasts.

ii. Collaborate with retail chains to set up **in-store "Organic Literacy Corners"** with clear infographics on how to identify genuine organic labels (NPOP/PGS-India logo).

Conclusion: An Integrated Roadmap for Growth

The promotion of organic and natural horticulture is not merely an agronomic shift; it is a systemic marketing and extension challenge. The strategies must be interwoven:

1. **Certification** without accessible **markets** is futile.
2. **Niche markets** cannot be tapped without **consumer trust**.
3. **Consumer awareness** collapses without the **credibility of certification**.

The recent impetus from government schemes like **Paramparagat Krishi Vikas Yojana (PKVY)** and **Mission Organic Value Chain Development for Northeastern Region (MOVCD-NER)** provides foundational support. The next phase requires a concerted, professionalized extension effort that treats farmers as entrepreneurs and consumers as informed partners.

The goal is clear: to translate India's phenomenal producer base into a thriving, transparent, and value-added organic horticulture economy. By strategically strengthening the pillars of certification, niche marketing, and consumer awareness, we can ensure that the organic revolution benefits not just the soil and the farmer, but also the health of the nation and the resilience of our agricultural future.

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Price Risk Management and Market Intelligence for Horticultural Farmers: Forecasting, Contract Farming, and Insurance Mechanisms

Article ID: 72598

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Introduction: The Perilous Peak and the Painful Plunge

In the fertile plains of Maharashtra, a tomato farmer watches prices crash from ₹100/kg to ₹5/kg in a matter of weeks. Simultaneously, a grape grower in Nashik secures a lucrative export contract months before harvest, sleeping peacefully through the season. This dichotomy captures the core challenge of Indian horticulture: **extreme price volatility.** Unlike staple grains, perishable fruits and vegetables are subject to wild price swings driven by glut, shortage, weather shocks, and supply chain dislocations. The **National Horticulture Board (NHB)** data often reveals coefficient of variation (a measure of volatility) exceeding 40% for key vegetables like potato and onion.

The consequence is a cruel paradox: the farmer bears all the production risks yet reaps the least reward from the final consumer price. As per a **NABARD All India Rural Financial Inclusion Survey (NAFIS) report**, only about 10% of horticultural farmers benefit from any form of price assurance mechanism. The path to doubling farmers' income is paved not just with higher yields, but with smarter **Price Risk Management (PRM)** empowered by **Market Intelligence (MI)**. This article deciphers the modern toolkit—forecasting, contract farming, and insurance—that can transform farmers from passive price-takers to informed market participants.

The Imperative: Why Price Risk Management is Non-Negotiable

1. Economic Survival and Income Stability: Horticulture is capital-intensive. A price crash can wipe out a season's investment, pushing farmers into debt. Stable income expectation allows for reinvestment in quality, drip irrigation, and organic inputs, creating a virtuous cycle.

2. Reducing Post-Harvest Losses: Panic selling during a glut leads to distress sales and wasted produce. With a known price outlet, farmers can plan harvests, utilize storage, and reduce the **estimated 15-25% post-harvest losses** (ICAR data).

3. Enabling Access to Credit: Banks are more willing to lend against a secured market outlet (like a contract) or insured crop. PRM mechanisms act as collateral enhancers, improving financial inclusion.

4. Fostering Market-Oriented Production: Moving from "grow and sell" to "sell and grow" minimizes market mismatch. Intelligence-led cultivation shifts the focus from just maximum yield to optimal and profitable yield.

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Market Intelligence & Forecasting – The "Information is Power" Paradigm

Gone are the days of relying solely on the local *mandi* trader for price signals. Digital MI platforms provide predictive insights.

1. Public Initiatives:

a. NHB's Market Information System (MIS): Provides daily and weekly arrival/price data from major *mandis* across India.

b. e-NAM (National Agricultural Market): Integrates *mandis* and offers price discovery from a national buyer pool. Over **1,000 mandis** are integrated, though horticulture penetration is growing.

c. MoA&FW's Price Forecasting Model: In collaboration with IIM-Ahmedabad, the Ministry runs a **Price Forecast and Alert System for 22 horticultural crops**. This 2–4 week advance forecast is crucial for planting and marketing decisions.

2. Advanced & Private Tools:

a. Satellite & Weather Analytics: Startups use remote sensing to predict area under cultivation and yield, offering early signals of surplus or shortage.

b. Market Advisory Services (MAS): Organisations like **IMD's Gramin Krishi Mausam Seva** and private agri-tech firms send SMS/audio alerts in local languages on weather, pests, and probable market prices.

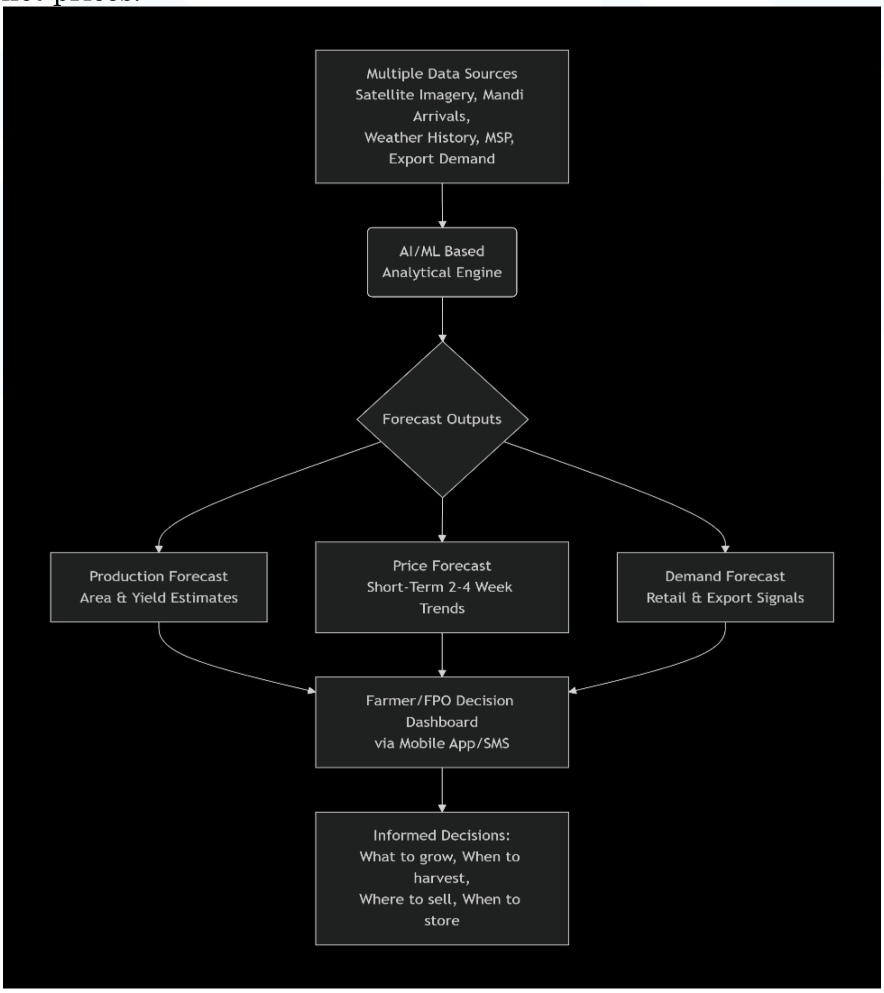

Diagram: The architecture of a modern market intelligence system for horticulture

Contract Farming & Market Linkages – Locking in Certainty

Contract farming (CF) is a formal agreement where a buyer (processor, exporter, retailer) pledges to purchase a crop at a pre-agreed price, often providing inputs and technical advice.

1. Successful Models in India:

a. **Processor-Led:** PepsiCo's partnership with potato farmers for its chips.
b. **Exporter-Led:** Mahagrapes (FPO) model for grape exports to Europe, with strict quality protocols and assured buy-back.
c. **Retailer-Led:** Big Bazaar's direct sourcing from vegetable farmer clusters.
d. **New Legal Backing:** The **Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services Act, 2020** provides a national framework, though implementation varies by state.

2. Data-Driven Benefits:

a. A **2023 study by ICRIER** found that farmers under contract farming earned **15-25% higher returns** than non-contract farmers, primarily due to price assurance, yield improvement, and cost reduction.
b. It reduces the role of intermediaries, ensuring a greater share of the consumer rupee reaches the farmer.

Model Type	Lead Agency	Key Feature	Price Risk Mitigation	Example Crops
Pre-agreed Price	Processor/Exporter	Fixed price per unit before sowing	High. Complete transfer of market risk to buyer.	Potato (chips), Gherkin, Basmati Rice
Price Band	Retail Chains	Agreed floor & ceiling price; final price based on market at harvest.	Moderate. Protects from crashes, allows upside.	Leafy vegetables, Exotic veggies
Cost-Plus	FPOs & Cooperatives	Production cost + fixed margin. Buyer provides inputs.	High. Guaranteed return on investment.	Seed production, Organic produce
Market-Linked with Bonus	Exporters	Linked to terminal market price, with quality/volume bonus.	Moderate-High. Base safety net with premium potential.	Mango, Grapes, Pomegranate

Table: Common Contract Farming Models and Their Risk Mitigation Potential

Price & Yield Insurance – The Financial Safety Net

Insurance provides a payout when parameters (yield or price) fall below a guaranteed threshold.

1. Pradhan Mantri Fasal Bima Yojana (PMFBY): While focused on food grains, it now includes select horticultural crops. It covers yield loss due to localized/perils. **Horticulture coverage under PMFBY has increased, but penetration remains below 30% for most fruit & vegetable crops** (MoA&FW).

2. Weather-Based Crop Insurance Scheme (WBCIS): More suited to horticulture. Payouts are triggered by adverse weather parameters (rainfall, temperature, humidity) correlated to yield loss. Useful for crops like grapes, citrus, and flowers.

3. The Game-Changer: Price Deficiency Payment (PDP) & Market Assurance Schemes:

> **a. Scheme for Tomato, Onion & Potato (TOP):** A pilot **Price Deficiency Payment Scheme** was tried, where farmers are paid the difference between the market price and a modal average price.
>
> **b. Market Intervention Scheme (MIS):** Activated by states during a glut, the government agencies procure at a fixed cost-to-production price. This is a critical, though often reactive, safety net for perishables.

The Future: Index-Based Livestock & Aquaculture Insurance models are being adapted for high-value horticulture, using a composite index of weather and market prices to trigger automatic payouts.

Conclusion: Towards an Integrated Risk Management Ecosystem

No single tool is a silver bullet. The future lies in **bundled solutions**. Imagine an FPO growing bell peppers:

1. Using **MI tools** to decide the planting window based on a 3-month price forecast.
2. Entering a **contract** with a supermarket chain for 60% of expected produce at a cost-plus price.
3. Insuring the remaining 40% under a **weather-based insurance** policy.
4. Using the contract document to secure a lower-interest **Kisan Credit Card (KCC)** loan.

The role of extension is pivotal. Krishi Vigyan Kendras (KVKs) and FPO promoters must become facilitators of **Market Literacy**, not just agronomic literacy. The government must accelerate the integration of **e-NAM**, promote tech-driven **FPO-led contract farming**, and design simpler, **composite insurance products** tailored for perishables.

The mantra for a resilient horticultural economy is: **Forecast with intelligence, Secure with contracts, and Insure for the residual risk.** By empowering our farmers with this triad, we can ensure that the sweat of their brow translates into stable, sustainable prosperity, making Indian horticulture truly future-proof.

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Supply Chain Management of Fruits and Vegetables in India: Constraints, Opportunities, and Reforms

Article ID: 72599

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Introduction

India's horticulture sector — especially fruits and vegetables — is among the most dynamic segments of Indian agriculture. With production increasing rapidly to feed a growing population and urbanizing consumer base, the **supply chain** has become the backbone of connecting *farmers to markets*. Effective supply chain management (SCM) ensures **quality, minimal wastage, price stability, food safety, farmer income upliftment, and consumer satisfaction**.

However, because horticultural produce is *highly perishable* and produced in fragmented smallholder systems, India's supply chain faces deep structural challenges that undermine potential socio-economic gains. Addressing these is vital for *reducing waste, stabilizing markets, and strengthening rural livelihoods*.

Why Supply Chain Management Matters?

Supply chain management refers to the coordinated *flow of fruits and vegetables* from the farm to the consumer's plate — including harvesting, storage, cooling, transport, processing, and retailing. For perishable horticultural produce, every hour counts: delays or sub-optimal handling can rapidly degrade quality and value.

According to comprehensive studies, India loses a significant portion of fruit and vegetable output at various stages of the supply chain due to **inadequate infrastructure and handling**. While estimates vary, post-harvest losses for fruits have been reported as high as **6–15%**, and for vegetables up to **4–11%** across stages like harvesting, storage, and transport. These losses cumulatively result in *substantial economic and nutrition losses* each year.

Key Constraints in India's Supply Chain

1. High Post-Harvest Losses and Cold Chain Gaps: Even though India has thousands of cold storages, *distribution and functionality are uneven*. Cold storage capacity is heavily concentrated in certain states, and much of the infrastructure serves limited commodities (e.g., potatoes), leaving fruits and vegetables with insufficient coverage.

A lack of modern cold chains — including pre-cooling at farms, refrigerated transport, and packhouses — means a large share of fresh produce spoils before reaching quality markets. One analysis suggests India loses between **30–40% of fruits and vegetables annually** due to such inadequacies.

2. Fragmentation and Inefficient Logistics: Fruit and vegetable supply chains are marked by:

a. Many smallholders producing in fragmented plots with irregular volumes.
b. Weak linkages between producers and institutional buyers.
c. A focus on local markets, with limited access to *efficient transport networks* and cold logistics.

Without aggregation mechanisms and coordination, farmers often face distress sales or sell ungraded produce at low farmgate prices.

3. Inadequate Packaging and Quality Standards: Most horticultural produce moves through the supply chain with minimal grading or protective packaging. This causes **physical damage**, quality degradation, and *price undercutting*. The absence of traceability and quality certification also limits access to high-value retail and export markets.

4. Coordination and Market Information Gaps: A fragmented system means limited visibility on demand, price information, or logistic planning. Farmers, traders, and transporters often operate in silos, leading to misaligned supply and demand, increased costs, and reduced profitability.

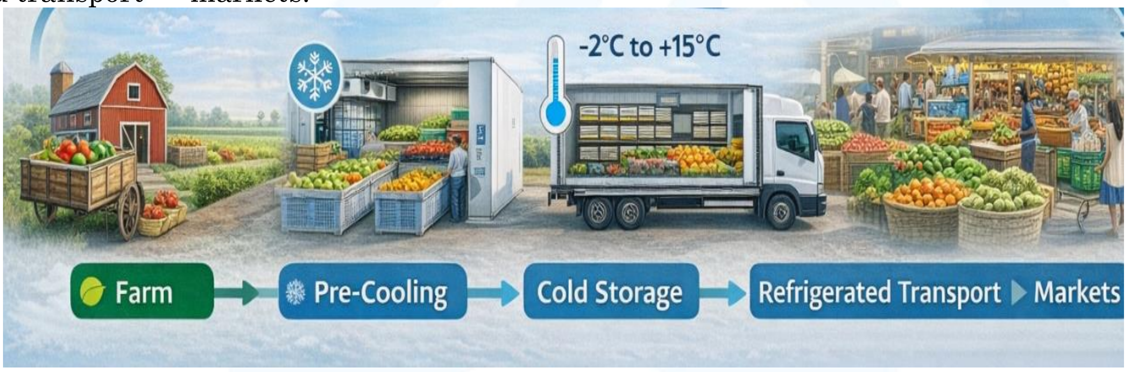
Opportunities to Strengthen the Supply Chain

Despite these constraints, several opportunities exist to improve the fruits and vegetables supply chain:

1. Expansion of Integrated Cold Chains: The Government of India's **Integrated Cold Chain and Value Addition Infrastructure Scheme** — now part of the *Pradhan Mantri Kisan Sampada Yojana (PMKSY)* — has expanded the cold chain network significantly. As of 2025, nearly **395 integrated cold chain projects** are approved, creating preservation capacity exceeding **25.52 lakh metric tonnes annually** and processing capacity of **114.66 lakh metric tonnes per year**.

The recent **increase in budgetary outlay** (₹6,520 crore through March 2026) also reflects greater emphasis on *end-to-end cold chain solutions*, including pre-cooling, transport, and distribution hubs to reduce post-harvest losses.

Diagram: A *flow chart* showing how integrated cold chains connect farms → pre-cooling → cold storage → refrigerated transport → markets.



2. Technology and Digital Integration: Emerging technologies such as:

a. IoT-enabled monitoring, to maintain ideal temperature and humidity.
b. Blockchain and traceability tools, to ensure quality transparency.
c. Demand forecasting models, helping match supply with market needs.

These modern tools can reduce spoilage, enhance efficiency, and increase trust among buyers.

3. Policy Reforms like Operation Greens: *Operation Greens* — initially launched to stabilize the production and supply of tomatoes, onions, and potatoes — has expanded its scope to include logistics, processing, and price stabilization measures for perishable crops across the supply chain.

By subsidizing agri-logistics, encouraging cold chain infrastructure, and supporting *professional supply chain management*, the scheme tackles systemic inefficiencies that previously led to volatile pricing and food losses.

4. Farmer Integration and Institutional Coordination: Promoting **Farmer Producer Organizations (FPOs)**, cooperatives, and private investors to act as aggregators can reduce fragmentation. By pooling produce and negotiating contracts with logistics providers, these institutions can help optimize supply and enhance farm incomes. Greater coordination across stakeholders also supports better **information flows and shared logistics planning**.

Benefits of Efficient Supply Chain Management

When the supply chain is well-managed, the benefits are broad:

Benefit	Impact
Reduced Losses	Less wastage, lower cost of fresh produce
Higher Farmer Income	Better access to high-value markets and prices
Consumer Price Stability	Less volatility in retail prices
Food Safety & Quality	Graded and traceable supply reduces health risks
Rural Jobs	Cold chains and logistics create new employment

All benefits are supported by observed trends and stakeholder reports across SCM studies

Conclusion

Supply chain management of fruits and vegetables in India is at a **critical juncture**. While production volumes are among the highest globally, inefficiencies in logistics, cold chains, and information flows cause significant post-harvest losses and reduced incomes for farmers. The good news is that **government initiatives, technological integration, and policy reforms** such as enhanced cold chain investments and Operation Greens are creating pathways for improvement.

Realizing the full potential of India's horticultural supply chain will require **collaborative action by government, private sector, cooperatives, and farmers**, along with continued investment in infrastructure, digital tools, and skill development. With better SCM, India can not only *feed more people but also deliver higher incomes to its farmers and better quality produce to its consumers*.

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Export Marketing of Horticultural Produce from India: Quality Standards, APEDA Role, and Global Competitiveness

Article ID: 72600

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[3]P.G. Scholar, Department of Agronomy, College of Agriculture, Dhule, (MPKV, Rahuri).
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Introduction

India's emergence as a **global horticultural powerhouse** is among the most remarkable developments in its agricultural economy. Blessed with diverse agro-climatic zones, India is the **second-largest producer** of fruits and vegetables in the world, after China, catering to both domestic and global markets. Recent estimates indicate horticulture production exceeding **350 million tonnes**, with fruits and vegetables forming a major share of this growth trajectory.

However, **production alone does not ensure global market success**. The competitiveness of horticultural exports relies critically on *quality standards, market access protocols, traceability, certification, and institutional support*. At the heart of this export ecosystem is the **Agricultural and Processed Food Products Export Development Authority (APEDA)** — mandated to develop, promote, and regulate India's agricultural exports through quality assurance and proactive market integration.

This article explores the **mechanisms of export marketing**, the **critical role of quality standards and compliance**, APEDA's strategic interventions, and how India is carving competitive spaces in the global horticultural trade.

Why Horticultural Export Marketing Matters: Relevance and Benefits

1. Strategic Economic Contribution: Horticultural exports — especially **fresh fruits and vegetables — have registered consistent growth**. During the FY 2023–24 period, India's export of fresh fruits and vegetables was valued collectively at over **USD 1.8 billion**, with processed fruits and vegetables contributing significantly as well.

Further, official government releases show that in **FY 2024–25 (April–March)**, horticultural exports reached approximately **USD 3.87 billion**, registering a **5.67% increase** over the previous year. This growth underscores horticulture's rising share within the broader agricultural export basket and its **role as a major foreign exchange earner**.

2. Livelihood and Farmer Income Enhancement: Export marketing brings **premium price realizations** for farmers, especially for high-value crops such as grapes, mangoes, bananas, citrus fruits, and exotic produce like dragon fruit. In cases like Amrapali mangoes from Odisha, targeted export initiatives helped farmers earn *multiples of domestic market prices*, empowering women and smallholder producers.

3. Market Diversification and Resilience: India's horticultural exports now reach **over 120+ countries**, with new markets being added regularly (e.g., Brazil, Georgia, Uganda, Papua New Guinea). This diversification reduces reliance on a limited set of destinations and hedges against disruptions in any single market.

Quality Standards: The Foundation of Export Marketing

1. International Quality and Safety Protocols: Export competitiveness hinges on adherence to **international quality and phytosanitary standards**. Major importing regions — including the European Union, USA, Japan, and Gulf countries — enforce stringent limits on **pesticide residues, microbial contaminants, and physical quality parameters**.

India has responded with systems that ensure global compliance:

- **a. HortiNet** — an **electronic certification and traceability platform** offered by APEDA to track quality compliance across the supply chain (from farm registration to testing and export certification).
- **b. Standard Operating Procedures (SOPs)** addressing farm registration, residue monitoring, sanitary and phytosanitary requirements, and laboratory testing protocols.

These systems help exporters generate documentation that *importing regulators require*, increasing confidence and acceptance in global markets.

2. Traceability, Testing and Certification Mechanisms: Meeting **food safety modern standards (e.g., EU MRLs, US FDA requirements)** demands rigorous residue analysis, traceability, and certification. Through financial support to set up **cold chain logistics, laboratory testing facilities, QMS systems**, and handheld traceability devices, APEDA ensures that Indian produce complies with global norms — a critical factor in reducing rejections at ports.

Without such systems, produce entering highly regulated markets can face **rejections, shipment detentions, and reputational damage** affecting market access.

APEDA's Strategic Role in Export Marketing

1. Export Promotion and Market Development: Established under the Agricultural and Processed Food Products Export Development Authority Act, APEDA's mandate extends beyond regulation — it *actively develops markets* (e.g., trade fairs, buyer-seller meets) and *supports export infrastructure*.

Key roles include:

- a. Supporting exporters in participation at **international trade fairs** to showcase Indian produce.
- b. Facilitating **buyer-seller meets** to connect Indian suppliers with international procurement agents.
- c. Identifying **target markets and key products** for focused negotiations and trade agreements.

2. Financial Assistance and Capacity Building: Financial schemes by APEDA help build **packhouses, pre-cooling units, cold stores, accredited labs, and quality management systems** — all integral to export readiness and maintaining quality during transit.

This not only strengthens compliance but also enhances *value addition*, enabling India to move from raw produce exports toward *premium and processed categories*.

3. Innovation in Export Ecosystem: APEDA's **BHARATI initiative** aims to leverage **agritech startups and innovation** to strengthen export capabilities, including integrated digital tools, value chain analytics, and scalable incubation support.

Such initiatives are designed to position India as a **competitive, tech-enabled horticultural exporter** by 2030.

Global Competitiveness: Achievements and Challenges

1. Gains and Opportunities

a. India's horticultural exports have grown impressively in recent years, with fruits and vegetables playing an increasingly significant role in total agricultural exports.

b. The diversification into — and acceptance by — new markets demonstrate rising **global competitiveness**. Export growth of more than **47%** over recent years reflects both supply capabilities and demand acceptance.

Yet India's share of **global horticultural trade remains low (around 1%)**, illustrating vast room for expansion.

2. Infrastructure and Value Chain Bottlenecks: Challenges include limited cold chain capacity, high logistics costs, inconsistent quality grading, and fragmented smallholder supply chains. This can constrain competitiveness, especially in markets where shelf-life and uniformity are critical.

3. Policy Synergies and Free Trade Agreements: Trade agreements — including ones like **India-EFTA TEPA** — can reduce tariffs and improve market access for India's horticultural exports, provided SPS compliance and mutual recognition provisions are negotiated in India's favor.

Conclusion

Export marketing of horticultural produce from India stands at the nexus of *quality compliance, institutional support, market strategies, and global competitiveness*. While India has made commendable progress — illustrated by multi-billion dollar export values, new market entries, and quality assurance systems like **HortiNet** — the journey ahead involves strengthening supply chains, expanding infrastructure, and further aligning export readiness with *high-standard global markets*.

APEDA's leadership — through facilitation, certification, financial support, and capacity building — remains pivotal to this transformation, ensuring that India's horticultural excellence translates into **sustainable economic gains for farmers, exporters, and the national economy**. Continued policy support, infrastructure investment, and digital innovation will bolster India's position as a **trusted supplier of premium horticultural produce in the global marketplace**.

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Technology Transfer Through On & Off Campus Farmers & Farm Women Training Program

Article ID: 72601

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On-Campus Farmers Training Detail

Organized an on-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"New high yielding Bio-fortified varieties of Wheat, qualities and their production technology" during 01st to 03st February, 2025 at Krishi Vigyan Kendra, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.

On-Campus Farmers Training Detail

Organized an on-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"New high yielding varieties of Fodder crops and their production technology" during 6th to 7th February, 2025 at Krishi Vigyan Kendra, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.

Off-Campus Farmers Training Detail

Organized an off-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"Varietal diversification, characteristics and seed production technology in Basmati Rice" during 16th August, 2024 at Village-Kanser Baseda, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.

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Off-Campus Farmers Training Detail

Organized an off-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"Varietal diversification, characteristics, qualities and seed production techniques of Millets" during 19th September, 2024 at Village- Yak Bagdi, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.

Off-Campus Farmers Training Detail

Organized an off-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **Varietal diversification, characteristics and seed production technology in Basmati Rice" during 20th September, 2024 at Village- Raipur Shumali, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.


Off-Campus Farmers Training Detail

Organized an off-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"New high yielding varieties of Mustard, quality attributes and production techniques" during 25th October, 2024 at Village- Kumrala, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.

Off-Campus Farmers Training Detail

Organized an off-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"New high yielding varieties of Lentil, quality attributes and production techniques" during 26th October, 2024 at Village- Fatehpur Shumali, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.

Off-Campus Farmers Training Detail

Organized an off-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"New high yielding varieties of Oats & Berseem, quality attributes and production techniques" during 04th November, 2024 at Village- Domkhera, Hasanpur, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.t

Some Important Photographs of Trainings

1. Off-campus farmers training detail: Organized an off-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"New high yielding varieties of Vegetable crops and their production techniques for Western Uttar Pradesh Region" during 10th February, 2025 at Village-Domkhera, Hasanpur, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.


2. Off-campus farmers training detail: Organized an off-campus farmers training under Plant Breeding. Total 20 farmers attended the training program. During the training program scientists were discussed about **"Varietal diversification and production techniques of new high yielding sugarcane varieties for Western Uttar Pradesh region" during 11th February, 2025 at Village-Barshabad, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology.


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Transfer of Technology Through Seed Production Program's at KVK Farm, Amroha: Case Study

Article ID: 72602

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Details of Seed Production Program

Seed production of Basmati Rice variety Pusa Basmati-1509 were conducted at Krishi Vigyan Kendra, Gajraula, Amroha during kharif, 2022. The performance of Basmati Rice variety Pusa Basmati-1509 were good in terms of plant population, spikelet development and maturity, etc. The detail of seed production crop variety are given below:

Table-1: Detail of Basmati Rice variety under seed production program:

S.No.	Name of crop	Name of variety	Season & year	Area (ha.)
1.	Basmati Rice	Pusa Basmaati-1509	Kharif, 2022	10

Seed production of Wheat variety HD-3226 & Mustard variety RH-0749 were conducted at Krishi Vigyan Kendra, Gajraula, Amroha during rabi, 2022-23. The performance of Wheat & Mustard variety were good in terms of plant population, spikelet / Siliqua development and maturity, etc. The detail of seed production crop variety are given below:

Table-2: Detail of Wheat variety under seed production program:

S.No.	Name of crop	Name of variety	Season & year	Area (ha.)
1.	Wheat	HD-3226	Rabi, 2022-23	05
2.	Mustard	RH-0749	Rabi, 2022-23	04

Seed production of Paddy variety NDR-359 were conducted at Krishi Vigyan Kendra, Gajraula, Amroha during kharif, 2023. The performance of Paddy variety NDR-359 were good in terms of plant population, spikelet development and maturity, etc. The detail of seed production crop variety are given below:

Table-1: Detail of Basmati Rice variety under seed production program:

S.No.	Name of crop	Name of variety	Season & year	Area (ha.)
1.	Paddy	NDR-359	Kharif, 2023	08

Seed production of Wheat variety DBW-187 & Mustard variety RH-0725 were conducted at Krishi Vigyan Kendra, Gajraula, Amroha during rabi, 2023-24. The performance of Wheat & Mustard variety were good in terms of plant population, spikelet / Siliqua development and maturity, etc. The detail of seed production crop variety are given below:

Table-2: Detail of Wheat variety under seed production program:

S.No.	Name of crop	Name of variety	Season & year	Area (ha.)
1.	Wheat	DBW-187	Rabi, 2023-24	05
2.	Mustard	RH-0725	Rabi, 2023-24	04

Monitoring the Top Dressing of Nano DAP in the Wheat Seed Production Crop Variety DBW-187 at Krishi Vigyan Kendra, Farm, Amroha

Seed production of Basmati Rice variety Pusa Basmati-1885 was conducted at Krishi Vigyan Kendra, Gajraula, Amroha during kharif, 2024. The performance of Basmati rice variety Pusa Basmati-1885 were good in terms of plant population, spikelet development and maturity, etc. The detail of seed production crop variety is given below:

Table-1: Detail of Basmati Rice variety under seed production program:

S.No.	Name of crop	Name of variety	Season & year	Area (ha.)
1.	Basmati rice	Pusa Basmati-1885	Kharif, 2024	05
2.	Pearl millet	Pusa Composite-701	Kharif, 2024	04

Monitoring the Roughing in the Basmati Rice Seed Production Variety Pusa Basmati-1885, During 15th August 2024 at Krishi Vigyan Kendra, Farm, Gajraula, Amroha

Monitoring the Spraying of "SAGARIKA" and NPK in the Basmati Rice Seed Production Crop Variety Pusa Basmati-1885 during 17th September 2024 at Krishi Vigyan Kendra, Farm, Gajraula, Amroha

Seed production of Wheat variety HD-3406 & Mustard variety PM-30 were conducted at Krishi Vigyan Kendra, Gajraula, Amroha during rabi, 2024-25. The performance of Wheat & Mustard variety were good in terms of plant population, spikelet / Siliqua development and maturity, etc. The detail of seed production crop variety are given below:

Table-2: Detail of Wheat variety under seed production program:

S.No.	Name of crop	Name of variety	Season & year	Area (ha.)
1.	Wheat	HD-3406	Rabi, 2024-25	05
2.	Mustard	PM-30	Rabi, 2024-25	04

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Popularization of Mustard Variety RH-0761 Among Farmers Under Cluster Frontline Demonstrations (CFLDs): Success Story

Article ID: 72603

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Background Information about Farmer Field

Shri Sompal Singh ji of Amroha district after completion his education up to M.A. degree, engaged himself in agriculture in his own land for running his family. He possesses 7.5 ha of land, out of which he cultivates Cereal Crop in 5.00 ha and 2.5 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.

Details of Technology Demonstrated

1. High yielding Oil Seed Crop Mustered RH-0761
2. Seed inoculation with Biofertilizer
3. Vermicompost 2.5 q/ha
4. 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer.

Institutional Involvement

KVK Amroha has demonstrated the high yielding Mustered variety RH-0761 along with other technology mentioned above during Rabi, 2024-25 under CFLD on Oilseed Crop.

Success Point

They wanted to grow Oil Seed Crop were remain fallow during Rabi season. Shri Sompal Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Oil Seed Crop Mustard variety RH-0761 and other necessary inputs for demonstration. The crop was sown during October, 2024 and harvested during February, 2024-25. They have harvested a very good crop (Yield: 20.01 q/ha) and earned a very good income (Net income Rs. 77,323 /ha).

Farmers' Feedback

After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Mustard variety RH-725) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Oil Seed production in Amroha district which will benefit the farmers at large.

Outcome from Technology

Demonstration	20.01	District average (Previous year)	12.05
Potential yield of variety/ technology	22.00	State average (Previous year)	10.50

Performance of technology vis-à-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	13.35	24473	75428	50955	**3.09**
Demonstration	20.01	24490	101813	77323	**4.16**
% Increase	**30.45**	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field

Demostraion Plot of Mustard variety RH-0761 at farmers field during Rabi, 2024-25

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Transfer of Technology Through Extension Functionaries and Vocational Training Program for Rural Youth

Article ID: 72604

Amit Tomar[1]
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Extension Functionaries Training Detail

Organized an Extension Functionaries training under Plant Breeding. Total 10 farmers were attended the training program. During the training program scientists were discussed about **"Varietal diversification, characteristics, seed production technology and entrepreneurship development in Basmati Rice" during 12th August, 2024 at State Seed Unit, Varshabad, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety for Basmati Rice transplanting.

Extension Functionaries Training Detail

Organized an Extension Functionaries training under Plant Breeding. Total 10 farmers were attended the training program. During the training program scientists were discussed about **"Varietal diversification, characteristics, seed production technology and entrepreneurship development in Mustard" during 13th August, 2024 at State Seed Unit, Varshabad, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety of Mustard in their cultivation practices.

Extension Functionaries Training Detail

Organized an Extension Functionaries training under Plant Breeding. Total 10 farmers were attended the training program. During the training program scientists were discussed about **"Varietal diversification, characteristics, seed production technology and entrepreneurship development in Linseed" during 14th August, 2024 at State Seed Unit, Varshabad, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety of Linseed in their cultivation practices.

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Extension Functionaries Training Detail

Organized an Extension Functionaries training under Plant Breeding. Total 10 farmers were attended the training program. During the training program scientists were discussed about **"Bio-fortified Wheat varieties, quality attributes, production techniques and awareness for Western Uttar Pradesh" during 11th November, 2024 at State Seed Godown, Varshabad, Gajraula, Amroha..** Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety of Linseed in their cultivation practices.

Extension Functionaries Training Detail

Organized an Extension Functionaries training under Plant Breeding. Total 10 farmers were attended the training program. During the training program scientists were discussed about **Organized Extension Functionaries training program on "Varietal diversification, characteristics, seed production technology and entrepreneurship development in Wheat for Western Uttar Pradesh region" during 24/01/2025 January, 2025 at State Seed Godown, Varshabad, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety of Linseed in their cultivation practices.

Extension Functionaries Training Detail

Organized an Extension Functionaries training under Plant Breeding. Total 10 farmers were attended the training program. During the training program scientists were discussed about **Organized Extension Functionaries training program on "Varietal diversification, characteristics, seed production technology and entrepreneurship development in Mustard" during 05/02/2025 February, 2025 at State Seed Godown, Varshabad, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety of Linseed in their cultivation practices.

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Vocational Training Detail

Organized an Vocational training for Rural Youth under Plant Breeding. Total 10 farmers were attended the training program. During the training program scientists were discussed about **"New high yielding varieties of Mustard, their characteristics, production technology and entrepreneurship development" during 10th to 14th September, 2024 at Krishi Vigyan Kendra, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety of Mustard in their cultivation practices.

Vocational Training for Rural Youth Training Detail

Organized a Vocational training for Rural Youth under Plant Breeding. Total 10 farmers **"New high yielding varieties of Bio-fortified Wheat, their characteristics, production technology and entrepreneurship development" during 05th to 09th November, 2024 at Krishi Vigyan Kendra, Gajraula, Amroha.** Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety of Mustard in their cultivation practices.

Vocational Training Detail

Organized an Vocational training for Rural Youth under Plant Breeding. Total 10 farmers **"New high yielding varieties of Mustard, their characteristics, production technology and entrepreneurship development" during 13th to 17th February, 2025 at Krishi Vigyan Kendra,**

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Gajraula, Amroha. Farmers were highly satisfied from the training program and also implicated the technology and seed/ variety of Mustard in their cultivation practices.

Impact Assessment of New High Yielding Variety of Groundnut GJG-32 Under Cluster Front Line Demonstrations in Western Uttar Region: Success Story

Article ID: 72605

Amit Tomar[1]
[1]ICAR-Krishi Vigyan Kendra, Gajraula, Amroha, (Directorate of Extension) Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, U.P.

Details of Cluster Front Line Demonstrations (CFLD's)

Cluster Front Line Demonstrations (CFLDs) on Groundnut was conducted during Kharif, 2024. The high yielding varieties/hybrids namely; GJG-32 was used for distribution of seed under CFLDs on Groundnut during *Kharif*-2024 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 23.50 q/ha. and mature in medium duration.

Table-01: Details of Cluster Front Line Demonstrations during Kharif, 2024:

Name of KVK	KVK, Amroha
Crop and variety name	Groundnut variety GJG-32
Name of farmer & Address	Vineet Kumar, Village- Khaikhera, Gajraula, Amroha
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Groundnut with use of IDM & IPM.
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, timely sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety GJG-32. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	23.50
- Potential yield of variety/technology	25.60

Performance of Technology Vis-A-Vis Local Check (Increase in Productivity and Returns)

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	19-50	75900	132268	65368	01.75
Demonstration	23-50	79000	159400	80400	02.20
% Increase	20.40 %				

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Good Quality Action Photographs with Caption

Performance of Groundnut variety GJG-32 under CFLD on Oilseeds during Kharif, 2024

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Popularization of Mustard Variety RH-0725 Among Farmers Under Cluster Frontline Demonstrations (CFLDs): Success Story

Article ID: 72606

Amit Tomar[1]
[1]Subject Matter Specialist (Plant Breeding), ICAR-Krishi Vigyan Kendra, Gajraula, Amroha (U.P.).

Background Information about Farmer field

Shri Jaiveer Singh ji of Amroha district after completion his education up to M.A. degree, engaged himself in agriculture in his own land for running his family. He possesses 6.5 ha of land, out of which he cultivates Cereal Crop in 5.00 ha and 1.5 ha under vegetable cultivation. But income generated from his farm was not enough for smooth running of his family. Later on he formed a farmers group along with few youths.

Details of Technology Demonstrated

1. High yielding Oil Seed Crop Mustered RH-725
2. Seed inoculation with Biofertilizer
3. Vermicompost @ 2.5 q/ha
4. 50 % recommended dose of N and full dose of P, K, Sulphur fertilizer

Institutional Involvement

KVK Amroha has demonstrated the high yielding Mustered variety RH-725 along with other technology mentioned above during Rabi, 2023-24 under CFLD on Oilseed Crop.

Success Point

They wanted to grow Oil Seed Crop were remain fallow during Rabi season. Shri Jaiveer Singh Ji along with his group came to KVK Amroha and they expressed their willingness to utilize that area for crop production. Then a team of scientists from KVK, Amroha visited the area and after discussion with the farmers and necessary survey, conducted a training program for them. Later on, they were provided with seeds of high yielding Oil Seed Crop Mustard variety RH-725 and other necessary inputs for demonstration. The crop was sown during October, 2023 and harvested during February, 2023-24. They have harvested a very good crop (Yield: 19.20 q/ha) and earned a very good income (Net income Rs. 77,323 /ha).

Farmers' Feedback

After successful implementation of the technology, farmers in the village were highly impressed and motivated by the performance of the new variety (Mustard variety RH-725) of with improved cultivation practices due to its higher net income. He is now a role model not only in his village but also for the entire farming community of the nearby villages. Farmers from other villages are motivated by the success of this farmer and showing keen interest to implement pulses production program with proven HYV seeds in their villages. These interventions have the potential to create positive impact on Oil Seed production in Amroha district which will benefit the farmers at large.

Outcome from Technology

Demonstration	19.20	District average (Previous year)	12.05
Potential yield of variety/ technology	22.00	State average (Previous year)	10.50

Performance of technology vis-à-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha	B:C ratio
Farmer practices	13.35	24473	75428	50955	**3.09**
Demonstration	19.20	24490	101813	77323	**4.16**

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% Increase	30.45	-	-	-	-

Photographs of Technology Demonstrated at Farmers Field

Demonstration Plot of Mustard variety RH-0725 at farmers field during Rabi, 2023-24

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Impact Assessment of New High Yielding Variety of Sesame GJT-05 Under Cluster Front Line Demonstrations in Western Uttar Region: Success Story

Article ID: 72607

Amit Tomar[1]
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Details of Cluster Front Line Demonstrations (CFLD's)

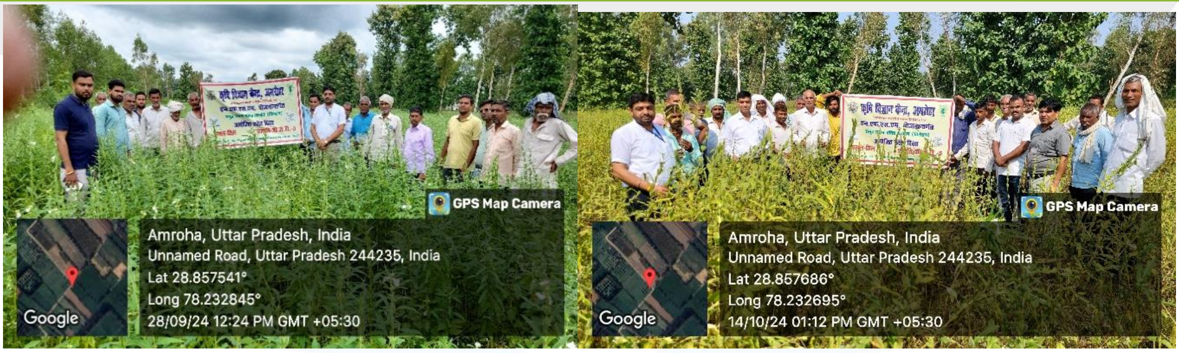
Cluster Front Line Demonstrations (CFLDs) on Sesame (*Sesamum indicum*) was conducted during Kharif, 2024. The high yielding varieties/hybrids namely; GJT-05 was used for distribution of seed under CFLDs on Sesame (*Sesamum indicum*) during *Kharif*-2024 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 12.21 q/ha. and mature in medium duration.

Table-01: Details of Cluster Front Line Demonstrations during Kharif, 2024:

Name of KVK	KVK, Amroha
Crop and variety name	Sesame variety GJT-05
Name of farmer & Address	Vineet Kumar, Village- Khaikhera, Gajraula, Amroha
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Sesame by T-78 with use of IDM & IPM.
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, timely sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety GJT-05. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	12.21
- Potential yield of variety/technology	15.00
- District average (Previous year)	6.50
- State average (Previous year)	6.18

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	9.08	24932	56659	31727	2.27
Demonstration	12.21	25105	80808	55703	3.21
% Increase	37.44 %				



Performance of Sesame variety GJT-05 under CFLD on Oilseeds during Kharif, 2024

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Impact Assessment of New High Yielding Variety of Basmati Rice Pusa Basmati-1886 Under Front Line Demonstrations in District Amroha of Western Uttar Region: Case study

Article ID: 72608

Amit Tomar[1]

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Details of Frontline Demonstrations (FLD's)

Front Line Demonstrations (FLDs) on Basmati Rice was conducted during Kharif, 2024. The high yielding varieties/hybrids namely; Pusa Basmati-1886 was used for distribution of seed under FLDs on Basmati Rice during *Kharif*-2024 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 46.25 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Kharif, 2024:

Name of KVK	KVK, Amroha
Crop and variety name	Basmati Rice variety Pusa Basmati-1886
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Basmati Rice by PB-1121 with use of IDM & IPM.
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, timely sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety PB-1886. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	46.25
- Potential yield of variety/technology	38.02

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	38.02	41375	82998	41623	2.0
Demonstration	46.25	34725	100963	66238	2.90
% Increase	21.65 %				

Good quality action photographs with caption

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Performance of Basmati Rice variety PB-1886 under FLD's during Kharif, 2024

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Impact Assessment of New High Yielding Variety of Basmati Rice Pusa Basmati-1847 Under Front Line Demonstrations in District Amroha of Western Uttar Region: Case Study

Article ID: 72609

Amit Tomar[1]

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Details of Frontline Demonstrations (FLD's)

Front Line Demonstrations (FLDs) on Basmati Rice was conducted during Kharif, 2024. The high yielding varieties/hybrids namely; Pusa Basmati-1847 was used for distribution of seed under FLDs on Basmati Rice during *Kharif*-2024 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 48.10 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Kharif, 2024:

Name of KVK	KVK, Amroha
Crop and variety name	Basmati Rice variety Pusa Basmati-1847
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Basmati Rice by PB-1121 with use of IDM & IPM.
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, timely sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety PB-1847. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	48.10
- Potential yield of variety/technology	38.25

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	38.25	42425	87975	45550	2-07
Demonstration	48.10	38850	110630	74780	3-08
% Increase	25.75 %				

Good quality action photographs with caption

Performance of Basmati Rice variety PB-1847 under FLD's during Kharif, 2024

Seed Treatment of Pusa Basmati-1847 variety for Nursery Raising

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Impact Assessment of New High Yielding Variety of Basmati Rice Pusa Basmati-1979 Under Front Line Demonstrations in District Amroha of Western Uttar Region: Case Study

Article ID: 72610

Amit Tomar[1]
[1]ICAR-Krishi Vigyan Kendra, Gajraula, Amroha, (Directorate of Extension) Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, U.P.

Details of Frontline Demonstrations (FLD's)

Front Line Demonstrations (FLDs) on Basmati Rice was conducted during Kharif, 2024. The high yielding varieties/hybrids namely; Pusa Basmati-1979 was used for distribution of seed under FLDs on Basmati Rice during *Kharif*-2024 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 46.95 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Kharif, 2024:

Name of KVK	KVK, Amroha
Crop and variety name	Basmati Rice variety Pusa Basmati-1979
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Basmati Rice by PB-1121 with use of IDM & IPM.
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, timely sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety PB-1979. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	46.95
- Potential yield of variety/technology	37.80

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	37.80	42550	86940	44390	1-95
Demonstration	46.95	35960	107985	72025	3-05
% Increase	24.20 %				

Good quality action photographs with caption

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Performance of Basmati Rice variety PB-1979 under FLD's during Kharif, 2024

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Impact Assessment of New High Yielding Variety of Basmati Rice Pusa Basmati-1985 Under Front Line Demonstrations in District Amroha of Western Uttar Region: Case Study

Article ID: 72611

Amit Tomar[1]
[1]ICAR-Krishi Vigyan Kendra, Gajraula, Amroha, (Directorate of Extension) Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, U.P.

Details of Frontline Demonstrations (FLD's)

Front Line Demonstrations (FLDs) on Basmati Rice was conducted during Kharif, 2024. The high yielding varieties/hybrids namely; Pusa Basmati-1985 was used for distribution of seed under FLDs on Basmati Rice during *Kharif*-2024 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 46.25 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Kharif, 2024:

Name of KVK	KVK, Amroha
Crop and variety name	Basmati Rice variety Pusa Basmati-1985
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Basmati Rice by PB-1121 with use of IDM & IPM.
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, timely sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety PB-1985. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	44.95
- Potential yield of variety/technology	36.95

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	36.95	42790	84985	42195	1-98
Demonstration	44.95	35995	103385	67390	2-88
% Increase	21.65 %				

Good quality action photographs with caption

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Performance of Basmati Rice variety PB-1985 under FLD's during Kharif, 2024

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Impact Assessment of New High Yielding Variety of Basmati Rice Pusa-2090 Under Front Line Demonstrations in District Amroha of Western Uttar Region: Case study

Article ID: 72612

Amit Tomar[1]
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Details of Frontline Demonstrations (FLD's)

Front Line Demonstrations (FLDs) on Basmati Rice was conducted during Kharif, 2024. The high yielding varieties/hybrids namely; Pusa-2090 was used for distribution of seed under FLDs on Basmati Rice during *Kharif*-2024 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 46.25 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Kharif, 2024:

Name of KVK	KVK, Amroha
Crop and variety name	Basmati Rice variety Pusa-2090
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Basmati Rice by PB-1121 with use of IDM & IPM.
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, timely sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety PB-1886. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	44.35
- Potential yield of variety/technology	36.00

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	36.00	40380	82800	42420	2-05
Demonstration	44.35	36290	102005	65715	2-85
% Increase	23.20 %				

Good quality action photographs with caption

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Performance of Basmati Rice variety P-2090 under FLD's during Kharif, 2024

Impact Assessment of New High Yielding Late Sown Variety of Bio-Fortified Wheat HD-3406 Under Front Line Demonstrations on Hunger Free Village Program in District Amroha of Western Uttar Region: Case Study

Article ID: 72613

Amit Tomar[1]
[1]ICAR-Krishi Vigyan Kendra, Gajraula, Amroha, (Directorate of Extension) Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, U.P.

Details of Frontline Demonstrations (FLD's)

Front Line Demonstrations (FLDs) on Bio-fortified wheat was conducted under timely sown conditions during Rabi, 2024-25. The high yielding varieties/hybrids namely; HD-3406 was used for distribution of seed under FLDs on Wheat during *Rabi,* 2024-25 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 46.25 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Rabi, 2024-25:

Name of KVK	KVK, Amroha
Crop and variety name	Wheat variety HD-3406
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Wheat
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, late sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety HD-3406. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	52.50 q/ha.
- Potential yield of variety/technology	70.40 q/ha.

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	41.50	50550	100638	57688	1.9
Demonstration	52.50	46950	127313	80363	2.7
% Increase	20.95	-	-	-	-

Good quality action photographs with caption

Performance of Bio-fortified Wheat variety HD-3406 under FLD's during Rabi, 2024-25

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Impact Assessment of New High Yielding Late Sown Variety of Bio-Fortified Wheat HD-3271 Under Front Line Demonstrations in District Amroha of Western Uttar Region: Case Study

Article ID: 72614

Amit Tomar[1]

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Details of Frontline Demonstrations (FLD's)

Front Line Demonstrations (FLDs) on Bio-fortified wheat was conducted under late sown conditions during Rabi, 2024-25. The high yielding varieties/hybrids namely; HD-3271 was used for distribution of seed under FLDs on Wheat during *Rabi,* 2024-25 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 46.25 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Rabi, 2024-25:

Name of KVK	KVK, Amroha
Crop and variety name	Wheat variety HD-3271
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Wheat
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, laate sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety HD-3271. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	44.90 q/ha.
- Potential yield of variety/technology	45.50 q/ha.

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	38.00	42075	92150	50080	1.5
Demonstration	44.90	43750	108882	65132	2.5
% Increase	15.35	-	-	-	-

Good quality action photographs with caption

Performance of Bio-fortified Wheat variety HD-3271 under FLD's during Rabi, 2024-25

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Impact Assessment of New High Yielding Late Sown Variety of Bio-Fortified Wheat HD-3298 Under on Farm Trials (OFTs) in District Amroha of Western Uttar Region: Case Study

Article ID: 72615

Amit Tomar[1]
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Details of On Farm Trials (OFT's)

On Farm Trials (OFTs) on Bio-fortified wheat was conducted under late sown conditions during Rabi, 2024-25. The high yielding varieties/hybrids namely; HD-3298 was used for distribution of seed under OFT's on Wheat during *Rabi,* 2024-25 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 46.25 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Rabi, 2024-25:

Name of KVK	KVK, Amroha
Crop and variety name	Wheat variety HD-3298
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Wheat
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, laate sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety HD-3298. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	45.35 q/ha.
- Potential yield of variety/technology	47.40 q/ha.

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	38.50	43050	93363	47550	1.9
Demonstration	45.35	44450	109973	65523	2.5
% Increase	15.10	-	-	-	-

Good quality action photographs with caption

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Performance of Bio-fortified Wheat variety HD-3298 under FLD's during Kharif, 2024

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Impact Assessment of New High Yielding Late Sown Variety of Bio-Fortified Wheat HD-3406 Under Front Line Demonstrations in District Amroha of Western Uttar Region: Case Study

Article ID: 72616

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Details of Frontline Demonstrations (FLD's)

Front Line Demonstrations (FLDs) on Bio-fortified wheat was conducted under timely sown conditions during Rabi, 2024-25. The high yielding varieties/hybrids namely; HD-3406 was used for distribution of seed under FLDs on Wheat during *Rabi,* 2024-25 in Western Uttar Pradesh region. The average yield of these varieties/hybrids are 46.25 q/ha. and mature in medium duration.

Table-01: Details of Frontline Demonstrations during Rabi, 2024-25:

Name of KVK	KVK, Amroha
Crop and variety name	Wheat variety HD-3406
Background information about farmer field	Using old variety
Details of technology demonstrated	Replacement of Local variety of Wheat
Institutional involvement	Technical guidance & Monitoring
Success point	Use of Sulphur, late sowing, timely practices & low incidence of Insect-pests & diseases.
Farmer feedback	(i) Grain yield has been increased due to selection of high yielding variety HD-3406. (ii) Uniform maturity and bold grain. (iii) Farmer are convinced to grow quality of seed & low incidence of Insect-pest & diseases.
Yield (q/ha)	
- Demonstration	54.70 q/ha.
- Potential yield of variety/technology	70.40 q/ha.

Performance of technology vis-a-vis Local check (Increase in productivity and returns):

Specific Technology	Yield (q/ha)	Gross cost (Rs/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B:C ratio
Farmer practices	45.70	43.50	110823	67773	2.4
Demonstration	54.70	44090	132647	888557	3.0
% Increase	16.45	-	-	-	-

Good quality action photographs with caption

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Performance of Bio-fortified Wheat variety HD-3406 under FLD's during Rabi, 2024-25

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Food Processing Industry in India

Article ID: 72617

Ms. Priyanka Deka[1]

[1]M.Sc. (Agri.), College of Agriculture, Department of Horticulture, Food Science and Technology, Assam Agricultural University, Jorhat.

Abstract

India's food processing industry is witnessing rapid growth, driven by a strong agricultural base, increasing consumer demand, and supportive government initiatives. India possesses abundant raw materials and a large domestic market, positioning it to become a global leader in food processing. However, challenges such as supply chain inefficiencies, inadequate infrastructure, and limited adoption of modern technology continue to hinder the sector's progress. Significant opportunities exist in improving infrastructure, adopting digital technologies, strengthening farmer-producer organisations, and enhancing value addition.By addressing these challenges and utilizing its abundant raw material base, India can enhance value addition, reduce wastage, generate employment, and strengthen food security, positioning itself as a global hub for food processing.

Introduction

The Indian economy was well developed in its own way. Traditionally, Indian villages were largely self-sufficient, with farmers producing mainly for subsistence or local village needs. The Indian farmers produced only for subsistence level, or at the maximum for the village needs. During colonial rule in India, Indian farmers were compelled to produce for the market, to feed the needs of the industrial revolution. This colonial influence led to a significant shift in agricultural patterns, moving emphasis from food grains to commercial crops like jute, cotton, indigo, tea, coffee, etc.

India transitioned from an agricultural deficit state at independence to a self-sufficient and major exporter of food grains due to emphasis on agriculture and has also emerged as a major exporter to developed as well as developing nations of the world. The per capita availability of food grains increased from 395 g per person per day in the early 1950s to the present level of 467 g per person per day, which is comparable to nutrition standards set by FAO. Indian farmers now produce more for the market rather than solely for subsistence. The trend in food grains production has also induced manifold growth in horticulture, dairy, poultry, and meat products, further enriching the supply base for food processing (IBEF,2025)..

Previously, packaging was primarily for storage using traditional methods like bins, and continued to be used for a long time. In modern times, since the world has become a global village, with a globalized market and consumer focus, packaging is market- and consumer-oriented, requiring drastic changes in packaging. This growth in agricultural output has created opportunities for the food processing industry, which adds value to produce, reduces post-harvest losses, ensures fair prices for farmers, and meets the demands of both domestic and international consumers. Furthermore, government initiatives have provided infrastructure, financial support, and policy backing, boosting investment and rural employment, while strengthening India's position as a global player in processed foods (IBEF, 2025).

Current Status of Food Processing Industry in India

India has transitioned from state of food scarcity to abundance over the past few decades, largely due to advancements in agricultural practices and policy support (MoFPI, 2024). By the mid -2010s, the production of fruits and vegetables approached nearly 80% of the total food grain production in India, highlighting the growing importance of the horticulture sector (IBEF,2025). Despite this progress, the productivity of fruits and vegetables in India remains relatively low at about 30-35% of the yield levels achieved in several developed and emerging economies, indicating substantial scope for improvement and growth(FAO,2022).

A significant disparity exists in the marketing structure of fruits and vegetables compared to cereals. Nearly 90% of fruits and vegetables are marketed directly by farmers, whereas less than 20% of cereals enter open markets due to extensive government procurement under minimum support price mechanisms (Planning Commission, 2018). Marketing has historically been a major constraint on the growth of the food sector, particularly because of inadequate storage facilities, poor logistics, and limited cold chain infrastructure. Consequently, marketing is expected to remain one of the primary challenges for the food sector in the coming decade, and future policy initiatives must prioritize strengthening marketing infrastructure and strategies (MoFPI, 2024).

Food processing plays a crucial role in absorbing agricultural surpluses, reducing post-harvest losses, ensuring remunerative prices for farmers, and making food products available to consumers at reasonable prices (IBEF, 2025). The sector also has substantial employment potential. Estimates suggest that the food processing industry generates approximately 54,000 direct jobs per billion rupees of investment, compared to about 48,000 in the textile industry and 25,000 in the paper industry, while also creating nearly four times more indirect employment opportunities (Planning Commission, 2018). Notably, around 60% of employment generated by this sector is concentrated in rural areas and small towns, thereby contributing significantly to regional and inclusive development (MoFPI, 2024).

The food processing industry in India has emerged as one of the most dynamic and rapidly expanding sectors of the economy, driven by the country's large agricultural base, changing consumption patterns, rising urbanization, and supportive government policies (IBEF,2025). India's abundant natural resources and diverse agro-climatic conditions give it a strong competitive advantage in food processing, enabling the country to be a leading global producer of agricultural products such as milk, spices, fruits, vegetables, poultry, and meat.(FAO,2022).

As of 2024, India's food processing market was valued at approximately ₹30,49,800 crore (US$ 354.5 billion) and is projected to grow to around ₹45,84,415 crore (US$ 535 billion) by the end of FY26. The sector contributes significantly to the Indian economy, accounting for about 8.8 % of Gross Value Added (GVA) in manufacturing and 8.39 % in agriculture, besides contributing roughly 13 % of India's exports and 6 % of total industrial investment. (MoFPI,2024).

Problems/Issues Affecting Food Packaging

The major problems/issues affecting the packaging of processed foods lie in the nature of the produce itself. Most of the food products have the following peculiarities:

1. Large Volumes: Raw food products require often require significant storage space, which is the major requirement for the food processing industry, especially when dealing with finished products.

2. Perennial Requirements: Many industrial food products are long lasting i.e., they are required to be purchased a few times during the entire life span of a person. The requirement for food products remains consistent throughout the year, requiring either daily purchase or home storage for consumption

3. Spoilage: Most farm products are susceptible to spoilage due to exposure to the atmosphere or by the presence of insects/pests and rodents, microbes and by natural breakdown processes. Packaging needs to address these factors to prevent spoilage.

4. Handling Losses: Farm products are often bulky in nature and vary in size, leading to substantial losses in during handling and transportation. To overcome these inherent problems, packaging has to suit the needs of individual items depending on their production time, place of production, and the volume of the produce.

Conclusion

The global food processing industry plays a vital role in ensuring food security, enhancing value addition, and supporting economic growth. However, it faces persistent challenges such as infrastructure gaps—particularly in cold chains—unorganized sectors, high production costs, and fluctuating raw material prices. In India, despite being agriculturally rich, a significant portion of produce remains under-processed due to these constraints. The sector holds enormous untapped potential, which can be realized through strategic investments in modern infrastructure, advanced technology, efficient supply chains, and market linkages. Strengthening these areas will help reduce post-harvest losses, improve product quality, meet the rising demand of urban populations, and increase farmer incomes. With continued policy support, innovation, and investment, India's food processing industry is well-positioned to emerge as a global leader in value-added agricultural products, driving economic growth and regional development.

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Food Processing Industry in India

Article ID: 72618

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[1]M.Sc. (Agri.), College of Agriculture, Department of Horticulture, Food Science and Technology, Assam Agricultural University, Jorhat.

Abstract

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References

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Rhizosphere "Information Exchange": Electrical Signalling Among Plants Under Water Stress

Article ID: 72619

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Abstract

Plants have complex signalling systems that allow them to sense and react to environmental stressors quickly. Although chemical signalling in the rhizosphere has been extensively studied, new research emphasizes electrical signalling as a quick and effective way to exchange information, especially when there is water stress. Ion fluxes in plant roots produce electrical signals that aid in coordinating physiological reactions like stress adaptation, stomatal regulation, and root growth adjustment. Signal transmission depends heavily on the rhizosphere, which is impacted by microbial activity and soil characteristics. In addition to providing fresh perspectives on plant stress tolerance, an understanding of these electrical communication pathways has important ramifications for crop and soil management in drought-prone agroecosystems.

Introduction

In order to survive harsh circumstances, plants constantly interact with their surroundings and modify their physiological processes. The rhizosphere, the small area of soil affected by root activity, is one of the most crucial zones for these interactions. This area serves as a hub for microbial activity, plant signalling and nutrient exchange. Chemical signals like root exudates, phytohormones, and microbial metabolites have historically been linked to rhizosphere communication. Recent research, however, shows that plants also use electrical signalling to quickly transmit information both inside and outside of the root system. Electrical signals are essential for plants to detect moisture deficiencies and start prompt adaptive reactions when they are under water stress.

Rhizosphere as a Communication Interface

The rhizosphere is an extremely dynamic interface made up of microbes, soil particles, and plant roots. In order to create favourable conditions for signal transmission, root activities alter the pH, ion distribution, and electrical conductivity of the soil. Ion fluxes across root cell membranes, mainly involving calcium (Ca^{2+}), potassium (K^{+}), and chloride (Cl^{-}) ions, are the source of electrical signals. Faster communication than chemical signalling is made possible by these changes in membrane potential, which travel through plant tissues as electrical impulses. This is a significant benefit during abrupt environmental stress.

Electrical Signalling Under Water Stress

Plants under water stress experience immediate physiological changes, such as altered root architecture, stomatal closure, and decreased cell turgor. Plants produce action potentials and variation potentials in addition to these reactions, which convey stress signals from roots to shoots. Electrical signals help control stomatal activity when roots detect decreasing soil moisture, which lowers water loss through transpiration. Additionally, there is evidence that stressed plants may release electrical cues into the rhizosphere, allowing nearby plants to initiate drought-response mechanisms prior to direct stress exposure.

Role of Soil Properties and Microorganisms

Electrical signal transmission is greatly influenced by soil characteristics like texture, salinity, moisture content, and organic matter. While dry or compacted soils may reduce signal strength, moist soils improve ion mobility and signal propagation. By affecting nutrient availability and root membrane stability, rhizosphere microorganisms further modify electrical signalling. By promoting effective signalling pathways and enhancing root hydraulic conductivity, beneficial microbes increase a plant's resistance to water stress.

Agricultural Significance

For soil science and sustainable agriculture, especially in water-limited settings, an understanding of electrical signalling in the rhizosphere is crucial. The creation of crop varieties resistant to drought and better soil management techniques can be aided by knowledge of plant communication mechanisms. Techniques like adding organic matter, conservation tillage, and microbial inoculation improve soil moisture retention, boost plant stress responses, and strengthen rhizosphere function.

Conclusion

Particularly in situations of water stress, the rhizosphere serves as a sophisticated information exchange system where plants exchange electrical signals. Rapid stress perception, coordinated physiological reactions, and possible interplant communication are all made possible by this signalling mode. Improved drought resilience and sustainable agricultural productivity can result from incorporating rhizosphere electrical signalling knowledge into soil and crop management techniques.

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New Facets of Maize

Article ID: 72620

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Maize (*Zea mays L.*), commonly known as corn, has long been one of the world's most important cereal crops. Originating in Mesoamerica thousands of years ago, maize has evolved from a regional staple into a truly global commodity. It feeds humans and livestock, fuels industries, and increasingly supports renewable energy systems. In recent decades, maize has entered a new phase of transformation driven by advances in genetics, agronomy, nutrition science, climate resilience, and industrial innovation. These developments reveal "new facets" of maize—roles and potentials that extend far beyond its traditional image as a food grain. This article explores these emerging facets of maize, focusing on technological innovations, nutritional improvements, climate-smart cultivation, industrial and bioenergy applications, and the socio-economic significance of maize in a rapidly changing world.

Genetic and Biotechnological Advances

One of the most significant new facets of maize lies in the field of genetics and biotechnology. Traditional breeding methods have been supplemented—and in some cases transformed—by molecular tools that allow precise improvement of maize varieties.

Hybrid Development and Molecular Breeding

Hybrid maize has been cultivated for decades, but modern molecular breeding techniques have dramatically accelerated the process. Marker-assisted selection (MAS) enables breeders to identify desirable traits such as high yield, disease resistance, or drought tolerance at early growth stages. This reduces time, cost, and uncertainty in varietal development. Genomic selection goes a step further by using whole-genome data to predict plant performance. As a result, breeders can develop maize varieties tailored to specific agro-climatic zones, soil types, and farming systems.

Genetically Modified (GM) and Gene-Edited Maize

Genetically modified maize varieties, such as Bt maize (resistant to insect pests) and herbicide-tolerant maize, have been adopted in several countries. These varieties reduce crop losses, lower pesticide use, and improve farm profitability. More recently, gene-editing technologies like CRISPR-Cas9 have opened new possibilities. Unlike traditional GM methods, gene editing can make precise changes without introducing foreign DNA. This technology is being explored to enhance nutrient content, stress tolerance, and disease resistance, representing a new frontier in maize improvement.

Nutritional Enhancement and Food Security

Maize is a staple food for hundreds of millions of people, particularly in Africa, Latin America, and parts of Asia. However, conventional maize is often deficient in essential nutrients. Addressing this challenge has revealed another important facet of maize: its potential as a vehicle for improved human nutrition.

Biofortified Maize

Biofortification involves increasing the nutrient content of crops through breeding or biotechnology. Notable examples include:

1. **Quality Protein Maize (QPM):** Enriched with lysine and tryptophan, QPM improves protein quality and helps combat malnutrition, especially among children.
2. **Provitamin A Maize:** Developed to address vitamin A deficiency, this maize variety has shown positive impacts on public health in several developing regions.
3. **Zinc- and Iron-Enriched Maize:** These varieties aim to reduce micronutrient deficiencies that affect immune function and cognitive development.

Functional Foods and Value-Added Products

Modern food science has expanded the use of maize into functional foods. Corn-based products such as cornflakes, corn oil, corn starch, and gluten-free maize flour cater to changing dietary preferences. The development of specialty maize—such as sweet corn, popcorn, and waxy maize—reflects growing consumer demand for diversity, convenience, and health-oriented foods.

Climate-Resilient and Sustainable Maize Cultivation

Climate change poses serious threats to maize production through rising temperatures, erratic rainfall, droughts, and increased pest pressure. Addressing these challenges has brought forward new facets of maize related to sustainability and resilience.

Drought- and Heat-Tolerant Varieties

Research institutions and seed companies have developed maize varieties capable of withstanding water stress and high temperatures. These climate-resilient varieties are especially important for rainfed agriculture, where farmers are most vulnerable to climate variability.

Conservation Agriculture and Smart Farming

Maize cultivation is increasingly integrated into conservation agriculture practices, including minimum tillage, crop rotation, and residue management. These practices improve soil health, reduce erosion, and enhance water-use efficiency. Digital agriculture tools—such as remote sensing, mobile-based advisory services, and precision nutrient management—are also transforming maize farming. Farmers can now make data-driven decisions on irrigation, fertilization, and pest control, improving productivity while minimizing environmental impact.

Industrial, Pharmaceutical, and Bioenergy Applications

Beyond food and feed, maize has emerged as a versatile industrial raw material. This industrial facet of maize is expanding rapidly with advances in processing and biotechnology.

Maize in Industrial Products

Maize starch is widely used in textiles, paper, adhesives, and pharmaceuticals. Corn oil serves both culinary and industrial purposes, while corn syrup and high-fructose corn syrup are key ingredients in the food and beverage industry. Bioplastics derived from maize starch represent an environmentally friendly alternative to petroleum-based plastics. These biodegradable materials are gaining importance in the context of global efforts to reduce plastic pollution.

Biofuels and Renewable Energy

Maize-based ethanol has become a major renewable energy source in several countries. Ethanol blending with gasoline reduces greenhouse gas emissions and dependence on fossil fuels. By-products such as distillers' dried grains with solubles (DDGS) are valuable animal feed, enhancing the overall efficiency of maize-based biofuel systems.

Socio-Economic and Cultural Dimensions

Maize is not just a crop; it is deeply embedded in the socio-economic and cultural fabric of many societies. This human dimension represents another important facet of maize.

Livelihoods and Rural Development

Millions of smallholder farmers depend on maize for income and food security. Improved maize varieties and better agronomic practices can significantly enhance rural livelihoods. Women, in particular, play a crucial role in maize production, processing, and marketing in many regions.

Cultural Significance

In many cultures, maize is more than food—it is identity. From tortillas and tamales in Mexico to maize porridge in Africa and corn-based dishes in Asia, maize occupies a central place in traditional cuisines and rituals. Preserving indigenous maize varieties and traditional knowledge is increasingly recognized as important for biodiversity and cultural heritage. The new facets of maize reflect its remarkable adaptability and relevance in the modern world. Advances in genetics and biotechnology are reshaping maize improvement, while nutritional enhancement positions maize as a tool against hidden hunger. Climate-resilient varieties and sustainable farming practices address environmental challenges, and expanding industrial and bioenergy applications highlight maize's economic versatility. As global populations grow and pressures on natural resources intensify, maize will continue to evolve in response to human needs and scientific innovation. Understanding and harnessing these new facets of maize is essential for achieving food security, sustainable development, and environmental resilience in the years to come.

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The Impact of Climate Change on Insect Phenology

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The study of how climate change affects insect life cycles, or phenology, has become an urgent and critical field of research. Insects, being ectothermic, are highly sensitive to even minor changes in temperature. Their developmental rates, reproductive cycles, and seasonal behaviors are directly regulated by thermal cues. This sensitivity makes them a canary in the coal mine for a warming planet. The timing of key life events, such as emergence from dormancy, mating, and migration, is meticulously synchronized with environmental conditions. When these conditions change, the timing shifts, often with cascading and unforeseen consequences for entire ecosystems. The most profound impact of shifting insect phenology is the **phenological mismatch**. This occurs when an insect's life cycle becomes desynchronized from the life cycle of a species it depends on, such as a food source or a natural predator. For instance, if a species of pollinator emerges weeks earlier than the flowers it pollinates, both the insect and the plant will suffer. The insect starves, and the plant fails to reproduce. This kind of mismatch threatens global food security by disrupting the intricate dance between pollinators and crops. Similarly, herbivores and their plant hosts may fall out of sync, leading to either a devastating increase in pest damage to crops or a decrease in the herbivore population. On the other end of the spectrum, shifts in insect phenology are allowing pests to expand their geographic ranges into previously unsuitable areas and complete more generations in a year. This leads to increased pest pressure on agriculture and greater risk of vector-borne diseases spreading to new regions. Understanding these changes is paramount. It allows us to predict potential agricultural crises, identify emerging threats to public health, and develop effective conservation strategies. Without this knowledge, we risk destabilizing entire food webs and losing invaluable ecosystem services that insects provide, such as pollination, nutrient cycling, and pest control. The data we collect today will be essential for building a resilient future. From Manual Observation to Automated Analysis. The methods used to study insect phenology have evolved significantly over time, from painstaking manual labor to sophisticated, data-driven approaches.

Past Methods: The Foundation of Knowledge

For centuries, entomological research relied on meticulous field observations and the collection of physical specimens. Early methods included.

Field Notebooks and Manual Surveys

Researchers would visit sites repeatedly to manually record the date of first appearance, peak abundance, and last sighting of a species. This required a tremendous amount of time and effort and was limited to small, localized areas.

Natural History Collections

Museums and herbaria are vast repositories of historical data. The date and location on a preserved specimen's label provide a snapshot of when and where an insect was active. By analyzing thousands of specimens collected over a century or more, researchers could piece together long-term trends.

Long-Term Monitoring Programs

Citizen science projects, like the Audubon Christmas Bird Count or butterfly monitoring schemes, have provided invaluable long-term datasets. While this is a collaborative approach, data quality can vary, and it still relies on manual, human-driven data collection.

Degree-Day Models

These theoretical models use historical temperature data to predict insect development and phenological events. They are based on the principle that a certain amount of heat accumulation (measured in "degree-days" above a specific temperature threshold) is required for an insect to complete a life stage. While a cornerstone of pest management for decades, these models are often simplified and may not account for the complexities of a changing climate.

New Technologies: The Future of Ecological Insight

The advent of new technologies has revolutionized how we study insect phenology, allowing for data collection on an unprecedented scale and with higher precision.

Remote Sensing and GIS

Satellites and drones equipped with advanced sensors can monitor vegetation phenology (the "green-up" of forests, agricultural fields) over vast areas. This data can be correlated with ground-based insect monitoring to identify large-scale phenological mismatches. Geographic Information Systems (GIS) are used to map and visualize changes in insect ranges and model how these distributions may shift under future climate scenarios.

Bioacoustics

Many insects, such as crickets, cicadas, and mosquitoes, produce species-specific sounds. Automated bioacoustic sensors placed in the field can passively record these sounds 24/7. Sophisticated algorithms and machine learning models are then used to analyze the data, identify species, and track their seasonal activity patterns, providing a continuous, non-invasive method for monitoring phenology.

Molecular Techniques

DNA barcoding, genomics, and transcriptomics provide a deeper understanding of the genetic mechanisms underlying insect responses to temperature. DNA barcoding, for example, allows for rapid and accurate species identification from environmental samples, which is crucial for large-scale biodiversity assessments.

AI and Machine Learning

This is arguably the most transformative technology. AI models can analyze the massive datasets generated by sensors, cameras, and historical records to find complex, non-linear patterns that were previously undetectable. Machine learning is used for:

1. **Automated Image Recognition:** AI models can be trained to automatically identify and count insect species from camera trap images, sticky traps, or drone footage, eliminating manual identification.

2. **Predictive Modeling:** Advanced AI models can integrate diverse data sources—temperature, rainfall, soil moisture, and historical phenology data—to create highly accurate forecasts of pest outbreaks or pollinator emergence. This is crucial for proactive management.

Citizen Science 2.0

Modern platforms like iNaturalist and eButterfly leverage smartphone technology and AI to allow citizen scientists to submit high-quality, geo-tagged observations from anywhere in the world. The sheer volume of data collected is invaluable for tracking long-term trends on a global scale The study of insect phenology is moving from a descriptive, observational science to a predictive, data-intensive discipline. While the foundational work of naturalists and long-term monitoring programs provides an essential baseline, the introduction of cutting-edge technologies has opened up new frontiers. We can now monitor insect populations in real-time, analyze data on a continental scale, and build complex models that predict future trends. Climate change has affected insect phenology substantially, causing increased or decreased phenological synchronization between species in natural and managed ecosystems. Phenological mismatches can be induced by different environments that interacting species experience or by differences in climate sensitivity among species. Insect phenology can shift due to the changes in metabolic and developmental responses to climate change. Phenological shifts may result in advanced spring emergence and delayed winter diapause, causing variation in voltinism in some species. Consequently, insect abundance may either increase due to the additional generations or decline or even go extinct due to “developmental/ecological traps.” At the community and ecosystem levels, phenological mismatches between species may modify interspecific antagonistic and mutualistic interactions, leading to changes in structure, functioning and provision of biocontrol and pollination ecosystem services. These phenological shifts may also offer promising opportunities for implementing engineering ecological methods (e.g., plant diversity manipulation) for improving these ecosystem services..The combination of old and new methods—for instance, using historical museum data to train a modern AI model—is proving to be a powerful strategy. This synergy allows us to understand not only what is happening now but also how quickly the changes are accelerating. As our climate continues to warm, the ability to accurately predict and respond to shifts in insect life cycles will be critical for maintaining biodiversity, protecting crops, and safeguarding human health. The data we are collecting and the technologies we are developing are not just academic exercises; they are essential tools for a world that must adapt to an ever-changing environment.

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The Vital Role of Soil-Dwelling Insects

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Soil-dwelling insects, also known as soil arthropods, are a diverse group of organisms that live in the ground for at least part of their life cycle. While often unseen, they are a fundamental component of the soil ecosystem, contributing to soil health, nutrient cycling, and overall ecological balance. This report will provide a running analysis of their functions, highlighting their importance as "ecosystem engineers" and the challenges they face in modern agricultural landscapes. Their activities are critical for maintaining the health and productivity of both natural and managed environments One of the primary functions of soil-dwelling insects is to break down organic matter. Organisms like termites, dung beetles, and springtails act as nature's recyclers, consuming dead plant material, animal waste, and another decaying biomass. This process, known as **bioturbation**, fragments the organic matter into smaller pieces, increasing the surface area for microbial activity. This leads to the faster mineralization of nutrients, converting complex organic compounds into simpler inorganic forms that plants can readily absorb.

Dung Beetles

These insects are highly efficient at burying and breaking down animal waste, preventing the spread of diseases and reducing greenhouse gas emissions. One study found that dung beetles can bury up to 90\% of cattle manure in grazing systems within 48 hours, significantly increasing nutrient availability in the soil.

Termites

In arid and tropical regions, termites are essential decomposers, breaking down tough woody material and recycling nutrients back into the soil. Their burrowing and feeding activities also enhance soil organic carbon and moisture content. Ecosystem Engineers: Improving Soil Structure Many soil insects are considered "ecosystem engineers" because they physically alter their environment, creating conditions that benefit other organisms. Their constant movement, digging, and tunneling create a network of channels and voids within the soil.

Soil Aeration

The burrows created by ants and termites improve soil porosity, allowing for better air and water penetration. This is crucial for the respiration of plant roots and soil microbes.

Water Infiltration

The tunnels act as conduits for water, increasing the soil's water-holding capacity and reducing surface runoff and erosion. This is particularly important in compacted agricultural soils.

Aggregate Formation

The feces of these insects, combined with organic and mineral matter, help form stable soil aggregates. These aggregates physically stabilize the soil, preventing erosion and increasing its capacity to store nutrients. Natural Pest Control A significant number of soil-dwelling insects are predators that help regulate the populations of agricultural pests. Ground beetles, for instance, are voracious predators of soil-borne pests like wireworms, slugs, and cutworms. By maintaining a healthy population of these beneficial insects, farmers can reduce their reliance on chemical pesticides.

This biological control is a more sustainable and environmentally friendly approach to pest management. Soil-dwelling insects are more than just a part of the soil; they are the architects of a healthy ecosystem. They provide crucial, free services that support agricultural productivity and ecological stability. However, their populations are increasingly under threat from modern farming practices, including intensive tillage, widespread use of broad-spectrum pesticides, and the simplification of landscapes into monocultures. The disruption of their habitat and the direct toxicity of chemicals can severely reduce their diversity and abundance.

To ensure the long-term health of our soils and food systems, it is critical to adopt conservation-minded agricultural practices. Strategies like no-till farming, the use of cover crops, and integrated pest management (IPM) can help protect and enhance these beneficial insect populations. By recognizing and valuing the work of these tiny creatures, we can foster a more resilient and productive agricultural future. Soil-dwelling beneficial insects are fundamental to the health and productivity of agricultural ecosystems. These organisms, including dung beetles, ants, termites, and springtails, act as ecosystem engineers, driving essential processes such as nutrient cycling, pest suppression, organic matter decomposition, and soil aeration.

Their activities significantly improve soil structure, fertility, and water retention, creating an environment conducive to healthy crop growth. For example, dung beetles recycle livestock manure into nutrient-rich organic matter, termites enhance soil organic carbon and moisture in arid regions, and ground beetles actively control soil-borne pests like wireworms and root maggots. Collectively, these contributions not only reduce the need for chemical fertilizers and pesticides but also promote sustainable and resilient farming systems.

Despite their invaluable roles, the populations of soil-dwelling insects face severe challenges. Intensive farming practices, habitat loss, pesticide overuse, and climate change are major threats that disrupt soil ecosystems and reduce insect diversity. Monoculture farming and frequent tillage destroy habitats and reduce biodiversity, while broad-spectrum pesticide applications harm non-target species, including beneficial insects. Climate change further exacerbates these challenges by altering temperature and moisture levels, which disrupt insect life cycles and ecological functions. To protect and enhance soil-dwelling insect populations, adopting sustainable farming practices such as reduced tillage, organic farming, and habitat diversification is essential.

Conservation efforts like cover cropping, buffer zone creation, and integrated pest management (IPM) can help preserve habitats and mitigate the impacts of agricultural intensification. Advanced tools, such as DNA-based biodiversity monitoring and precision farming technologies, offer new opportunities for understanding and managing soil insect populations effectively. Soil-dwelling insects act as ecosystem engineers. For example, termites are vital decomposers in tropical and arid regions, while dung beetles reduce parasitic pests in pastures. Ants improve soil porosity and aeration through their tunneling activities. Springtails accelerate the breakdown of organic material, contributing to the availability of essential nutrients like nitrogen and phosphorus for crops. Together, these insects improve soil health and agricultural productivity by ensuring ecosystem balance.

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Forensic Entomology: The Silent Witnesses

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Forensic entomology is the scientific study of insects and other arthropods in a legal context. While it encompasses a range of applications, its most well-known use is in criminal investigations, particularly in determining the time of death, also known as the postmortem interval (PMI). Insects are often the first organisms to arrive at a decomposing body, and their predictable life cycles and patterns of succession provide investigators with a valuable biological clock. This report will delve into the core principles of forensic entomology, its key applications, and the factors that can influence entomological evidence.The cornerstone of forensic entomology is the predictable succession of insect species on a decomposing body. This process is divided into several stages of decomposition, each attracting a specific community of insects. The first and most critical colonizers are typically blow flies (family Calliphoridae). Attracted by the scent of decomposition, adult female blow flies lay their eggs in natural orifices (e.g., mouth, nose, eyes) or wounds. The eggs hatch into larvae (maggots), which feed on the tissue. By analyzing the life stage of the maggots, an entomologist can estimate the minimum postmortem interval (PMI_{min}), which represents the time elapsed since insects first colonized the body. This is often the most accurate method for estimating time of death in the first few weeks after death.A forensic entomologist uses a variety of methods to arrive at a time-of-death estimate. One of the most common is the analysis of insect larval development. The growth rate of blow fly larvae is highly dependent on environmental factors, particularly temperature. To make an accurate estimate, the entomologist must collect meteorological data for the crime scene, including daily temperatures and precipitation, from the time of the body's discovery back to a reasonable estimated time of death. The accumulated degree hours (ADH) or accumulated degree days (ADD) model is then used to calculate the amount of heat required for a particular insect species to reach a specific developmental stage.

ADH = \sum (T_{avg} - T_{base}) \times \Delta t

Where T_{avg} is the average temperature for a given period, T_{base} is the minimum temperature required for insect development, and \Delta t is the duration of the period in hours. By matching the developmental stage of the collected maggots to the ADH data, an entomologist can determine how long the insects have been developing on the body.

Forensic entomology's applications extend beyond determining the time of death. The presence of specific insect species can provide clues about the location of the crime or whether a body has been moved. For example, some insects are native to specific geographic regions or habitats (e.g., urban vs. rural). An entomologist can also analyze the stomach contents of maggots to detect drugs or toxins that were present in the body. This is particularly useful in cases where the body is too decomposed for a standard toxicological analysis. Furthermore, insect evidence can indicate the presence of wounds that may not be visible to the naked eye, as insects are often drawn to lay eggs in these areas. However, the accuracy of forensic entomology is subject to several variables. Environmental conditions such as temperature, humidity, and sunlight exposure are the most significant factors affecting insect development. The presence of clothing, burial, or wrapping can delay or prevent insect colonization, leading to an inaccurate PMI estimate. The season of death also plays a crucial role; insect activity is generally lower in colder months. To account for these variables, forensic entomologists rely on extensive research and collaboration with other specialists to reconstruct the conditions at the crime scene Forensic entomology is the application of the biology of insects and their arthropod relatives that interact with humans, human remains, and the associated physical environment, to aid in the investigation of crimes, deaths, and other legal matters. Despite its importance, forensic entomology remains under-utilized because of its limited awareness and lack of region-specific data. This study bridges this gap by exploring entomological evidence applications

in forensic investigations within South India's unique geo-climatic conditions. This cross-sectional study analyzed 153 autopsies of decomposed dead bodies with entomological evidence conducted at a tertiary hospital mortuary in South India from January 2021 to December 2021. This study demonstrates the application of forensic entomology in estimating the time since death and highlights its potential in aiding forensic investigations. We used two distinct methods to estimate the post-mortem interval: Analyzing successional waves of insects for bodies over a month old and focusing on maggot developmental stages for corpses under a month old. A comparative analysis was conducted to assess the validity and reliability of entomological analysis in estimating post-mortem interval. The study systematically compared post-mor tem interval estimates derived from entomological evidence with those obtained from other post-mortem changes, as well as information provided in autopsy reports. Utilizing Pearson correlation heat map analysis, the results revealed a significant positive correlation between entomological estimates and those derived from other post-mortem changes and autopsy reports. The findings of this study confirm entomological analysis as a reliable, complementary method for determining post-mortem interval, highlighting its forensic utility.